Minnesota Pollution Control Agency

Office of the Commissioner

February 26, 2004

The Honorable John Marty, Chair
Environment and Natural Resources Committee
Minnesota Senate
323 Capitol

The Honorable Dallas Sams, Chair
Environment, Agriculture and Economic Development Budget Division
Minnesota Senate
328 Capitol

The Honorable Linda Scheid, Chair
Commerce Committee
Minnesota Senate
303 State Capitol

The Honorable Tom Hackbarth, Chair
Environment and Natural Resources Policy Committee
Minnesota House of Representatives
409 State Office Building

The Honorable Dennis Ozment, Chair
Environment and Natural Resources Finance Committee
Minnesota House of Representatives
479 State Office Building

The Honorable Gregory Davids, Chair
Commerce, Jobs and Economic Development Committee
Minnesota House of Representatives
379 State Office Building

Dear Committee Chairs:

I am pleased to submit to you the enclosed report entitled, "Detailed Assessment of Phosphorus Sources to Minnesota Watersheds" produced by Barr Engineering Company (Barr) under contract to the State of Minnesota. This letter and report are submitted to you to fulfill the requirements of Minn. Laws 2003, Ch. 128, Art. 1, Sections 122 and 166 which asked MPCA to report to the 2004 Legislature on the levels of non-ingested phosphorus discharged to wastewater treatment systems, the effect of lowering phosphorus on water quality, and a review of the MPCA's rules on nutrients in cleaning agents. As noted in a letter to you dated January 20, 2004, although this report was required to be submitted by February 2, it was necessary to extend the submittal date to March 1, 2004.

As nutrients in fertilizer cause crops and lawns to grow, nutrients, which get into surface water, cause excessive growth of algae and other aquatic plants. Phosphorus is the primary nutrient causing the pollution of Minnesota's surface waters. The presence of phosphorus in automatic dishwasher detergent (ADWD) was discussed by the Legislature during the 2003 Session and legislation to eliminate virtually all phosphorus in ADWD was introduced. The various perspectives of interested parties and a lack of solid data led the Legislature to charge the MPCA to research a series of questions and develop a study of the sources of phosphorus statewide. The MPCA contracted with a local consultant, Barr, to conduct the study and assist the MPCA in answering the questions posed by the Legislature. Barr has performed in an outstanding manner in this very large and complicated effort and was able to deliver a final report to the agency on February 19, 2004. Their report is enclosed with this letter.

The questions posed by the Legislature were:

1. What is a reasonable estimate for the amount of phosphorus entering municipal wastewater systems (Publicly Owned Treatment Works – (POTW's) from non-ingested sources?

   Non-ingested sources of phosphorus are commercial/industrial process water, residential and commercial ADWD, food soils (dishwashing and garbage disposals food wastes), dentifrices (oral hygiene products), noncontact cooling water, drinking water treatment agents and groundwater inflow/infiltration. Non-ingested sources of phosphorus make up 57.6 percent (2,573,000 kg/yr.) of the total amount (4,468,000 kg/yr.) of phosphorus entering POTW's. Commercial and industrial process water is 46 percent of the non-ingested phosphorus entering POTW's and food soils are about 28 percent of the non-ingested phosphorus. The phosphorus from residential and commercial use of ADWD, combined, is almost 19 percent of the non-ingested phosphorus entering POTWs. The remainder of the sources totals less than 8 percent.

2. What is a reasonable timeline for achieving a 50 percent reduction of phosphorus from non-ingested sources to municipal wastewater systems?

   Each individual POTW receives phosphorus from varying non-ingested sources. The source, or combination of sources, of non-ingested phosphorus that enters a POTW and the practicality of removing non-ingested phosphorus from specific individual sources will determine the feasibility of reaching a 50 percent removal goal in any reasonable timeframe.

   According to the Barr report, the achievement of a 50 percent reduction of non-ingested phosphorus appears to be an ambitious goal. It is theoretically possible to achieve a 50 percent reduction in non-ingested phosphorus entering a POTW, but the practicality and timeline for doing so is reliant upon a thorough examination of the data in the Barr report and ultimately, is a public policy decision. The report outlines several options that could lead to a significant reduction in non-ingested phosphorus entering POTW's. One example of the type of approach that would be necessary to achieve a significant reduction in non-ingested phosphorus entering a POTW would require a reduction to zero phosphorus in residential and commercial ADWD and a 50 percent reduction in phosphorus from commercial and industrial process water. These reductions combined would result in a reduction of 42 percent of phosphorus entering a POTW.

3. What is the effect on water quality of receiving waters as a result of lowering phosphorus in the wastewater stream?

   One method of estimating the effect of lowering the phosphorus content of the wastewater stream is to determine the relative amount of phosphorus contribution from a specific source when compared to other sources in a major basin or statewide. While this was the general approach used in this study, it is important to note that this statewide/basin method has limitations because the effect of a phosphorus reduction on water quality is related to many factors, such as type of water body (river, wetland, or lake), size of water body, geographical location, types of phosphorus sources and many others. The Barr report includes detailed estimates of the relative phosphorus contributions to surface water of the ten major basins and statewide, however an evaluation of all such individual conditions was not conducted.

There is a vast amount of information in the Barr report. Although the full content of the report has yet to be thoroughly analyzed, preliminarily we find the following information to be, in our view, significant:

a) For average flow conditions, nonpoint sources of phosphorus account for 69 percent of the phosphorus entering Minnesota surface waters and point sources account for 31 percent.
b) Of the nonpoint sources, cropland runoff (26 percent) is the single largest source followed by atmospheric deposition (13 percent) and streambank erosion (11 percent).
c) For point sources, human waste (34 percent) accounts for the single largest contribution, although the combination of the amount of phosphorus from commercial and industrial stand-alone facilities and commercial and industrial discharges treated at POTWs equals 38 percent of all point source phosphorus discharged.
d) As the water flow in rivers increases, the percentage contribution of phosphorus from point sources decreases and nonpoint source increases. Streambank erosion is the source most impacted under high flow conditions and ranges from 62,300 kg/yr. at low flow to 3,605,900 kg/yr. at high flow conditions.
e) For non-ingested phosphorus entering POTWs, commercial and industrial process water is the largest source (46 percent), residential ADWD phosphorus is 12.6 percent and commercial ADWD phosphorus is 5.9 percent.
f) The bioavailability of phosphorus was highly variable for some sources and fairly consistent for others. Bioavailability of ADWD phosphorus was 100 percent, while POTW effluent was 86 percent and cropland runoff was 58 percent.
g) Minor sources of phosphorus at the basin scale may be significant sources at the local level.

4. What is the best way to assist local units of government in removing phosphorus at public wastewater treatment plants?

The Barr report provides a review of select facilities with phosphorus removal. Treatment type, removal efficiencies and influent reduction activities are generally considered. Two Portland, Oregon facilities are noted as achieving effluent phosphorus concentrations of 0.07 mg/L. These are some of the lowest effluent concentrations in the United States. Generally, phosphorus effluent limitations are 1.0 mg/L in Minnesota, with two facilities having effluent limitations of 0.3 mg/L.

In addition, Minn. Laws Ch. 128, Art. 1, Sec. 9, Subd. 7e appropriated $296,000 to the MPCA in cooperation with the Minnesota Environmental Science and Economic Review Board (MESERB), to conduct an independent examination of selected wastewater treatment facilities by nationally recognized experts in phosphorus removal. These experts will prepare a report on influent reduction strategies and on effective phosphorus removal technologies and disseminate this information. MESERB will use the findings from data review and facility examinations to develop recommendations on low-cost, high-benefit strategies that will be most effective for facilities of various sizes and types, in various regions of the state. This information will be compiled into a report, designed to assist wastewater operators in identifying and implementing effective phosphorus removal techniques. The project is scheduled for completion June 30, 2005. At that time, MESERB and MPCA should have valuable information to report to the Legislature on this question.

5. What are the results of the Agency's review of rules on nutrients in cleaning agents under Minn. Stat. § § 116.23 and 116.24?

   The MPCA has the authority to adopt rules limiting the amount of nutrients in cleaning agents and water conditioners. Sufficient technical information and resources would be necessary to revise or promulgate rules. In Minn. Stat. § § 116.23 and 116.24, the Legislature found that nutrients contained in many cleaning agents and water conditioning agents served a valuable purpose in increasing their overall effectiveness, but the Legislature also found that they can lead to an acceleration of the natural eutrophication process of our state waters. The Legislature listed three factors that should be considered when rules imposing nutrient limitations were developed in accordance with Minn. Stat. § § 116.23 and 116.24:

   a. The availability of safe, nonpolluting and effective substitutes.
   b. The differences in the mineral content of water in various parts of the state.
   c. The differing needs of industrial, commercial and household users of cleaning agents and chemical water conditioners.

   Minn. R. 7100.015 through 7100.024 relate to the limitation of phosphorus in cleaning agents and water conditioners. No new nutrient rules or modifications of the original rules have been adopted since the mid-1970s. The MPCA has no plans to conduct rulemaking to remove phosphorus from additional cleaning agents and water conditioners without a legislative public policy decision and further legislative direction.

If you have any questions regarding this report, please contact Nelson French, of my staff at (651) 296-7352.

Sincerely,

Sheryl A. Corrigan
Commissioner

SAC:cmbg

Enclosure

Minnesota Pollution Control Agency

Detailed Assessment

of

Phosphorus Sources

to

Minnesota Watersheds

Volume 1: Executive Summary and Report

Prepared by Barr Engineering Company

February 2004

BARR

Detailed Assessment of Phosphorus Sources to Minnesota Watersheds

Under TMDL Master Contract

Prepared for

Minnesota Pollution Control Agency

Submitted by

Barr Engineering Company

February 2004

Project Funding/Costs
Funding for this project was recommended by the Legislative Commission on Minnesota Resources (LCMR) from the Environmental Trust Fund. The total cost of this report was $400,700, of which $244,000 was provided by the Environmental Trust Fund.

Acknowledgements

The Detailed Assessment of Phosphorus Sources to Minnesota Watersheds was prepared by Barr Engineering Company, with its partners Limno-Tech, Inc., Dr. David Mulla, and Dr. Prasanna Gowda, under the Total Maximum Daily Load (TMDL) Master Contract for the Minnesota Pollution Control Agency. This project was made possible by funding from the Minnesota State Legislature. Barr Engineering received valuable comments and suggestions from Minnesota Pollution Control Agency staff and the stakeholder organizations listed below.

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Detailed Assessment of Phosphorus Sources to Minnesota Watersheds

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Executive Summary

Background—The Problem with Phosphorus

Concerns about the phosphorus content of automatic dishwashing detergents, from the Minnesota State Legislature and other interested stakeholders, resulted in legislation requiring a study of all of the sources and amounts of phosphorus entering publicly-owned treatment works (POTWs) and Minnesota surface waters.

Phosphorus is the nutrient primarily responsible for the eutrophication (nutrient enrichment of waterbodies) of Minnesota's surface waters. An overabundance of phosphorus—specifically usable (bioavailable) phosphorus—results in excessive algal production in Minnesota waters. Phosphorus from point sources may be more bioavailable, impacting surface water quality more than a similar amount of nonpoint source phosphorus that enters the same surface water. Phosphorus contributions to Minnesota surface waters by point and nonpoint sources are known to vary, both geographically and over time, in response to annual variations in weather and climate. Nonpoint sources of phosphorus tend to comprise a larger fraction of the aggregate phosphorus load to Minnesota surface waters during relatively wet periods, while point sources become increasingly important during dry conditions.

Purpose of Assessment

This Detailed Assessment of Phosphorus Sources to Minnesota Watersheds was conducted to provide the Minnesota Pollution Control Agency (MPCA) with the information necessary to comply with newly enacted legislation surrounding phosphorus sources. The assessment inventories the following:

1. **Sources and amounts of phosphorus entering three different sizes and categories of publicly-owned treatment works (POTWs; i.e., wastewater treatment plants).**

   Sizes: (average daily flow rate)

   - Less than 0.2 million gallons per day (mgd)
   - 0.2 to 1.0 mgd
   - Greater than 1.0 mgd

   Categories:

   - Primarily domestic
   - Domestic with some commercial/industrial
   - Predominately commercial/industrial

   Sources: (individual and/or categorical)

   - Automatic dishwasher detergents (ADWD)
   - Other household cleaners or household non-ingested sources
   - Commercial/industrial, including:
     - Process wastewater

- Noncontact cooling water
- Other additives

- Water supply, including water treatment chemicals
- Human waste products (ingested sources)
- Groundwater intrusion to sanitary sewers

Information developed in this portion of the phosphorus inventory is intended to assist the MPCA in complying with MN Laws 2003, Chap. 128 Art. 1, Sec. 122:

The state goal for reducing phosphorus for non-ingested sources entering municipal wastewater treatment systems is at least 50 percent reduction based on the timeline for reduction developed by the commissioner under section 166, and a reasonable estimate of the amount of phosphorus from non-ingested sources entering municipal wastewater treatment system in calendar year 2003.

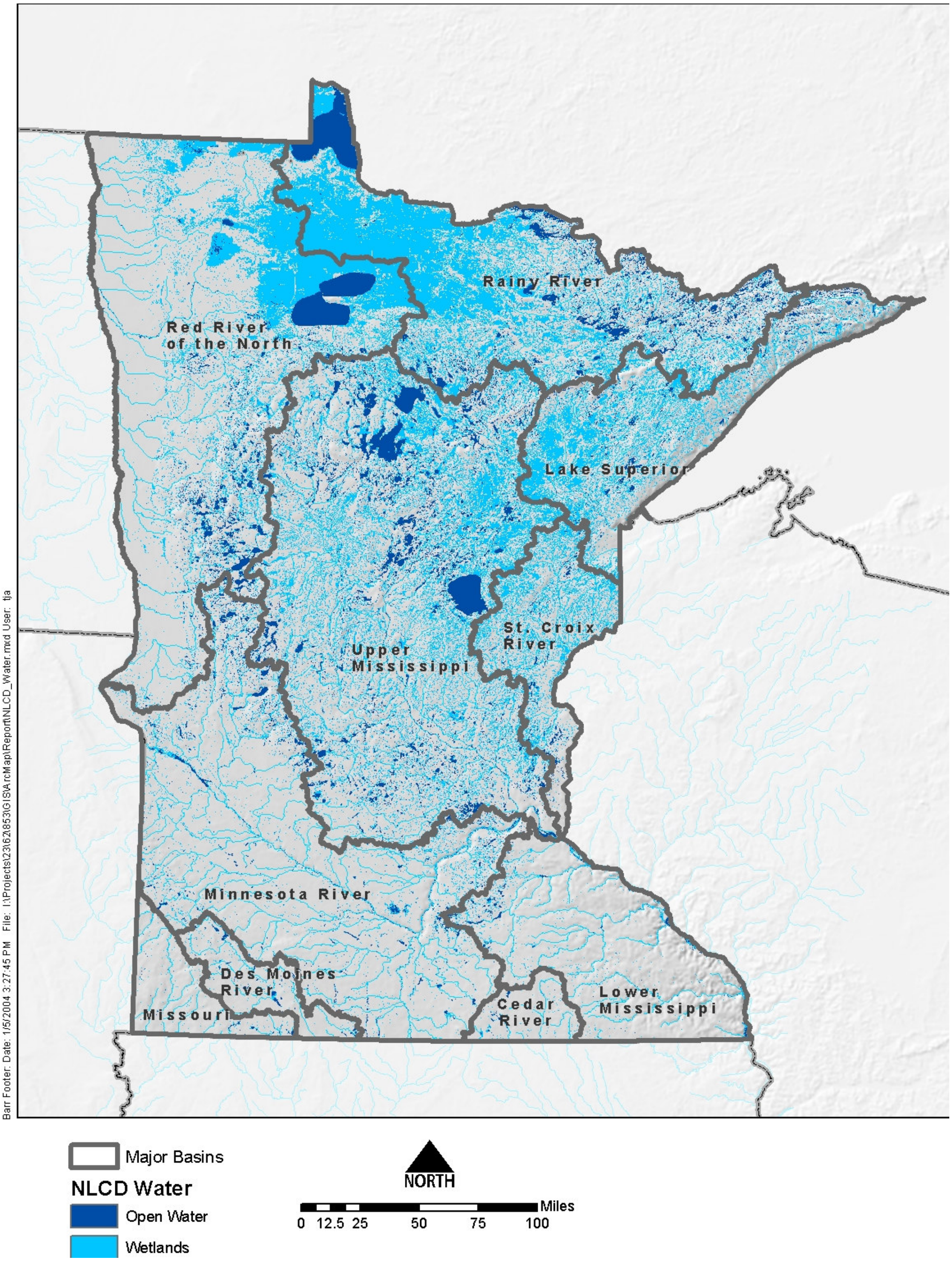
2. Sources and amounts of phosphorus entering Minnesota surface waters for each of the ten major basins (see Figure EX-1) and for the entire state of Minnesota from point- and nonpoint-sources during low (dry), average, and high (wet) flow conditions; and the effect of various phosphorus source reduction options on water quality.

Information developed in this portion of the phosphorus inventory is intended to assist the MPCA in complying with MN Laws 2003, Chap. 128, Art. 1, Sec. 166:

The commissioner of the pollution control agency must study the concept of lowering phosphorus in the wastewater stream and the effect on water quality in the receiving waters and how to best assist local units of government in removing phosphorus at public wastewater treatment plants, including the establishment of a timeline for meeting the goal in Minnesota Statutes, section 115.42.

Estimating the phosphorus source contributions to Minnesota surface waters for each of the ten major basins required a clear definition of surface waters, as well as knowledge about the amount of phosphorus produced and the mechanisms of delivery for each point and nonpoint source category, to establish a "frame of reference," or a basis for comparison by source category and by basin. For the purposes of this analysis, Minnesota surface waters were defined by mapping all of the various types of water bodies contained in the Minnesota Department of Natural Resources 24K Stream Layer (all records, including ditches and intermittent streams) and all land cover types identified as wetlands or lakes in the U.S. Geological Survey (USGS) National Land Cover Database. Figure EX-1 shows the areas of all of the Minnesota surface waters, within each of the ten major basins.

Figure EX-1 Major Basins and Surface Waters



General Project Approach

This assessment estimates the annual phosphorus loading, or amounts of phosphorus (total and bioavailable), entering all of the various types of surface waters from each of the source categories under low (dry), average and high (wet) flow conditions. The general nature and scale of this analysis allows for summarizing the estimated loadings for each major basin, and on a statewide basis. The characteristics of smaller watershed units, or subwatersheds, were not utilized to estimate the phosphorus loadings from each source category. Since each subwatershed typically drains to wetlands, lakes, ditches or streams that possess their own unique processes for transformation or phosphorus uptake, no further breakdown of phosphorus inflow or outflow loadings by subwatershed or surface water type is possible within the scope of this analysis. As a result, the phosphorus loadings discussed in this report represent the total amount of phosphorus entering all of the surface water areas that are present within each major basin for each flow condition.

…the phosphorus loadings discussed in this report represent the total amount of phosphorus entering all of the surface water areas that are present within each major basin for each flow condition.

Because of the general nature of this analysis, it can be true that sources of phosphorus which are deemed minor at the basin scale, may actually contribute the majority of phosphorus to specific surface water bodies, at a localized scale. For example, point sources typically contribute little or no phosphorus to Twin Cities Metropolitan and most outstate lakes, but can represent a significant portion of the total phosphorus load to rivers under low flow conditions. Likewise, nonpoint source amounts or categories will vary at a localized scale. Because of this, there is still a need to complete individual assessments of specific watersheds to evaluate specific loading conditions. The phosphorus loading estimates from this assessment are only intended to quantify the phosphorus source contributions originating in Minnesota for Minnesota surface waters. No attempt has been made to estimate the phosphorus loadings to the St. Croix River basin that originate from Wisconsin, to the Minnesota River basin from South Dakota, to the Rainy River basin from Canada, or to the Red River basin from North Dakota.

While the context for this analysis does not allow for direct assessments to be made about the observed water quality at the mouth of each major river basin, it does allow for a direct "apples-to-apples" comparison of the amounts of phosphorus originating from various source categories under various flow conditions. This analysis also facilitates comparison between each major basin so that the relative magnitude of each source category can be compared throughout the state. The results of this assessment should be used to make broader policy and management planning decisions and are not intended to be used in the place of Total Maximum Daily Load (TMDL) studies or detailed assessments based on site-specific water quality monitoring and modeling data. The results of this study should also be used to focus continuing monitoring efforts and prioritize additional water quality, biological and/or physical assessments.

The results of this assessment should be used to make broader policy and management planning decisions and are not intended to be used in the place of TMDL studies or detailed assessments based on site-specific water quality monitoring and modeling data.

Methods Used

In general, relatively simple methods were employed in this assessment to provide a rapid means of evaluating the relative significance of different sources and identifying critical source areas with minimal effort and data requirements. Each portion of this assessment typically involved the following stepwise approach:

1. Obtain data on source and watershed characteristics (such as per capita use/land cover/land use/soils), conduct published literature review and obtain site-specific data, where available

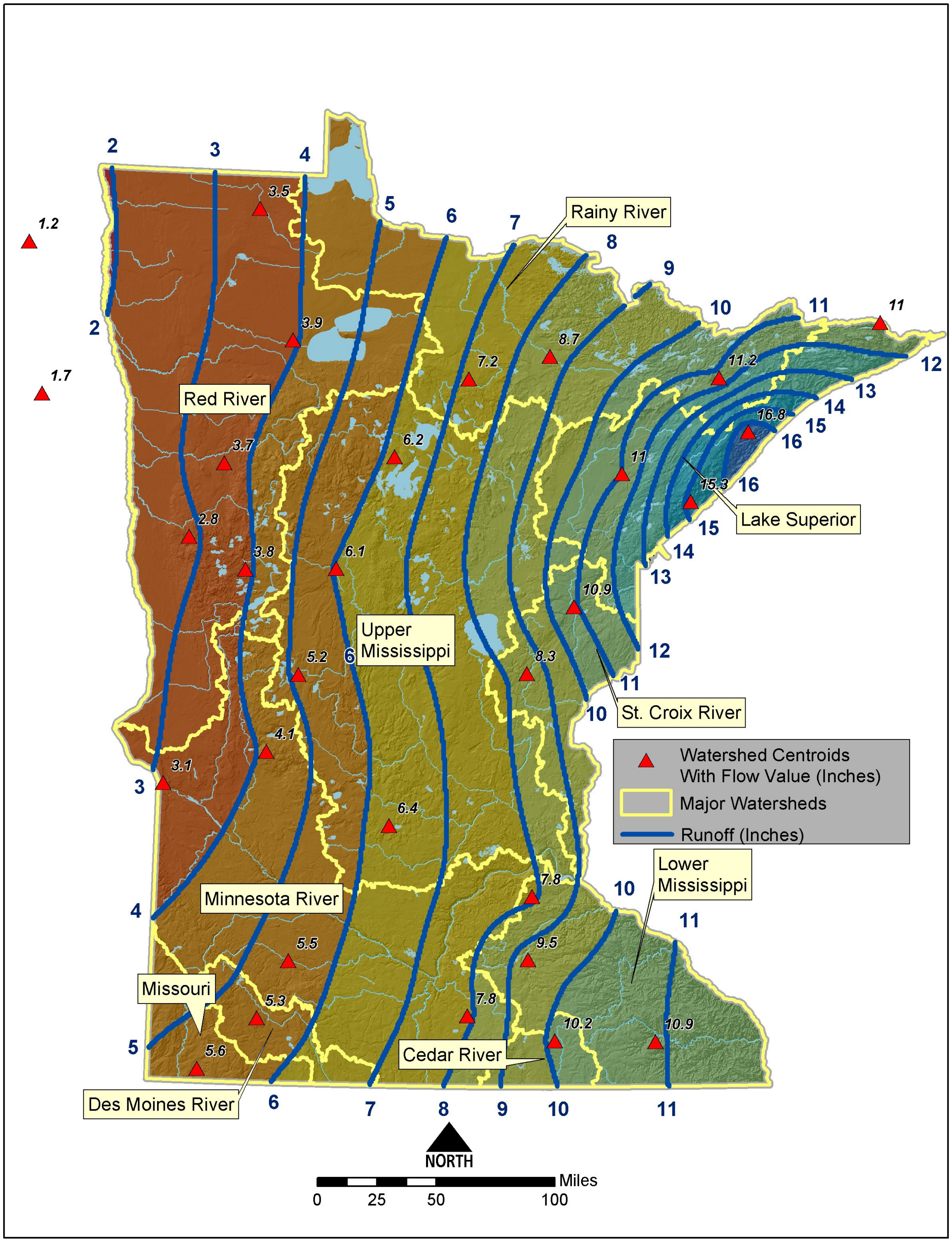
2. Use available site-specific data to develop and apply a basin-specific, regional, ecoregional or statewide phosphorus load estimation methodology that utilizes source and watershed characteristics

3. Use data from nearby study areas or other established empirical relationships applied to watershed characteristics

4. Apply best professional judgment when any data or published literature information are absent

This assessment began with an evaluation of the historical runoff and precipitation data for each basin in the state. This analysis resulted in runoff and precipitation datasets that defined what constituted low (dry), average, and high (wet) flow conditions in each of the ten major basins. The data, throughout the state, indicated that there is a general trend of decreasing runoff from east to west (see Figure EX-2). This is significant because nonpoint sources are strongly influenced by precipitation and runoff amounts.

Figure EX-2 Annual Runoff Volumes, Average Flow Conditions (Period of Record, 1979-2002)



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The Lake Superior basin has the highest runoff rate in the state, with the Baptism River watershed having the highest values within that basin (an average annual runoff of 15.3 inches). The Red River basin had the least runoff, with the Buffalo River watershed experiencing only 2.8 inches of runoff in an average year. Decreasing runoff from east to west also occurs in southern Minnesota, but the trend is less dramatic than in the north. Increases in runoff are more dramatic moving south in the state, as flows approach high flow conditions. Statewide, the gradient in runoff volumes increases significantly from low to average flow, and from average to high flow, conditions.

Categories of Findings

This assessment resulted in a number of findings, broken down into the following categories:

- Phosphorus source category loadings statewide
- Phosphorus source category loadings by major basins
- Statewide phosphorus source category loadings by flow condition
- Major basin phosphorus source category loadings by flow condition

Phosphorus Source Category Loadings Statewide

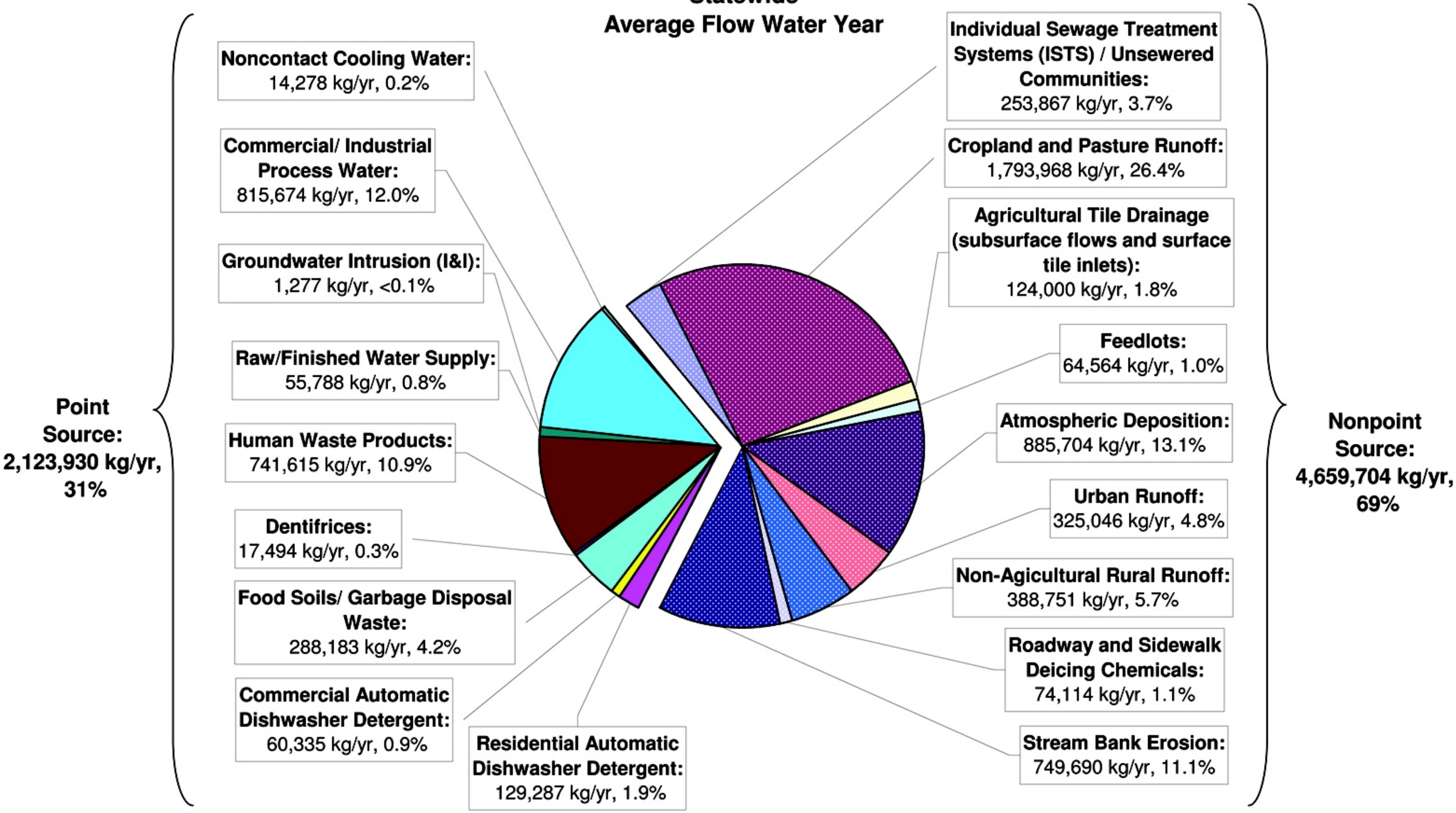
This assessment found that, under average flow conditions, the point source total phosphorus contribution represents 31 percent, while nonpoint sources of total phosphorus represent 69 percent of the loadings to surface waters, statewide (see Figure EX-3). The point source phosphorus loadings to surface waters are broken down in proportion to the influent phosphorus loadings (inflows) to wastewater treatment plants (WWTPs) in the state from each wastewater source category. This assumes that the proportion of the phosphorus load from each source category in the wastewater influent remains the same in the wastewater effluent (or treated discharge) from each treatment facility.

Figure EX-3 shows for average flow conditions the major phosphorus sources to surface waters are as follows:

- cropland and pasture runoff (26%)
- atmospheric deposition (13%)
- commercial/industrial process water (12%)

> It should be noted that the Metropolitan Council Environmental Services (MCES) Metro WWTP—which discharges to the Upper Mississippi River basin—was required to implement phosphorus removal to 1 mg/L from 2.97 mg/L (average phosphorus effluent concentration) by the end of 2005, but is already achieving the 1 mg/L limit. A reduction in the phosphorus concentration to 1 mg/L will result in a reduction of an estimated 581,000 kg of phosphorus per year, shifting the point source contribution to approximately 25 percent and raising the nonpoint source contribution to 75 percent of the total load statewide.

Figure EX-3
Estimated Total Phosphorus Contributions to Minnesota Surface Waters
Statewide
Average Flow Water Year



- streambank erosion (11%)
- human waste products (11%)

All of the remaining source category contributions are below 6 percent. The combination of residential and commercial automatic dishwasher detergent (ADWD) represents approximately 3 percent of the total phosphorus contributions to surface waters in the state, during an average year.

Phosphorus Source Category Loadings by Major Basin

This assessment found that, under average flow conditions, the relative magnitude of the total phosphorus loadings from the sum of all source categories in the Upper Mississippi River basin is significantly higher than the remaining basins, with the second highest phosphorus loadings occurring in the Minnesota River basin (see Figure EX-4a). The Lower Mississippi and Red River basin total phosphorus loadings are approximately one-third less than the Minnesota River basin loadings.

Figure EX-4a illustrates the relative magnitudes of each of the phosphorus source category loadings estimated for each basin under average flow conditions, while Figure EX-4b shows the same information normalized to the basin area, as another way to compare the phosphorus loadings from basin to basin. Figures EX-4a and EX-4b show that, relative to the other phosphorus source categories in each basin, agricultural runoff is a significant source of phosphorus in all but the Lake Superior and Rainy River basins. Human waste products are a significant source of phosphorus in the Upper Mississippi River basin, along with commercial/industrial process water and food soils.

It should be noted that the data used for this study to assess point source loadings is from the years 2001, 2002 and the first half of 2003. Since that time period, phosphorus removal was implemented at the MCES' Metro WWTP (see blue sidebar on page viii). Because this one facility accounted for approximately 74 percent of the point source phosphorus load to the Upper Mississippi River basin and an estimated 40 percent statewide, continued phosphorus removal at this one facility will have a significant impact on the future relative phosphorus loads in this basin and the state.

Figures EX-4a and EX-4b also show that atmospheric deposition comprises significant percentages of the annual phosphorus loads as follows:

- Upper Mississippi River basin (11%)
- Red River basin (29%)
- St. Croix River basin (20%)
- Rainy River basin (34%)

Figure EX-4a Total Phosphorus Loads to Minnesota Surface Waters - By Major Drainage Basin: Average Flow Conditions

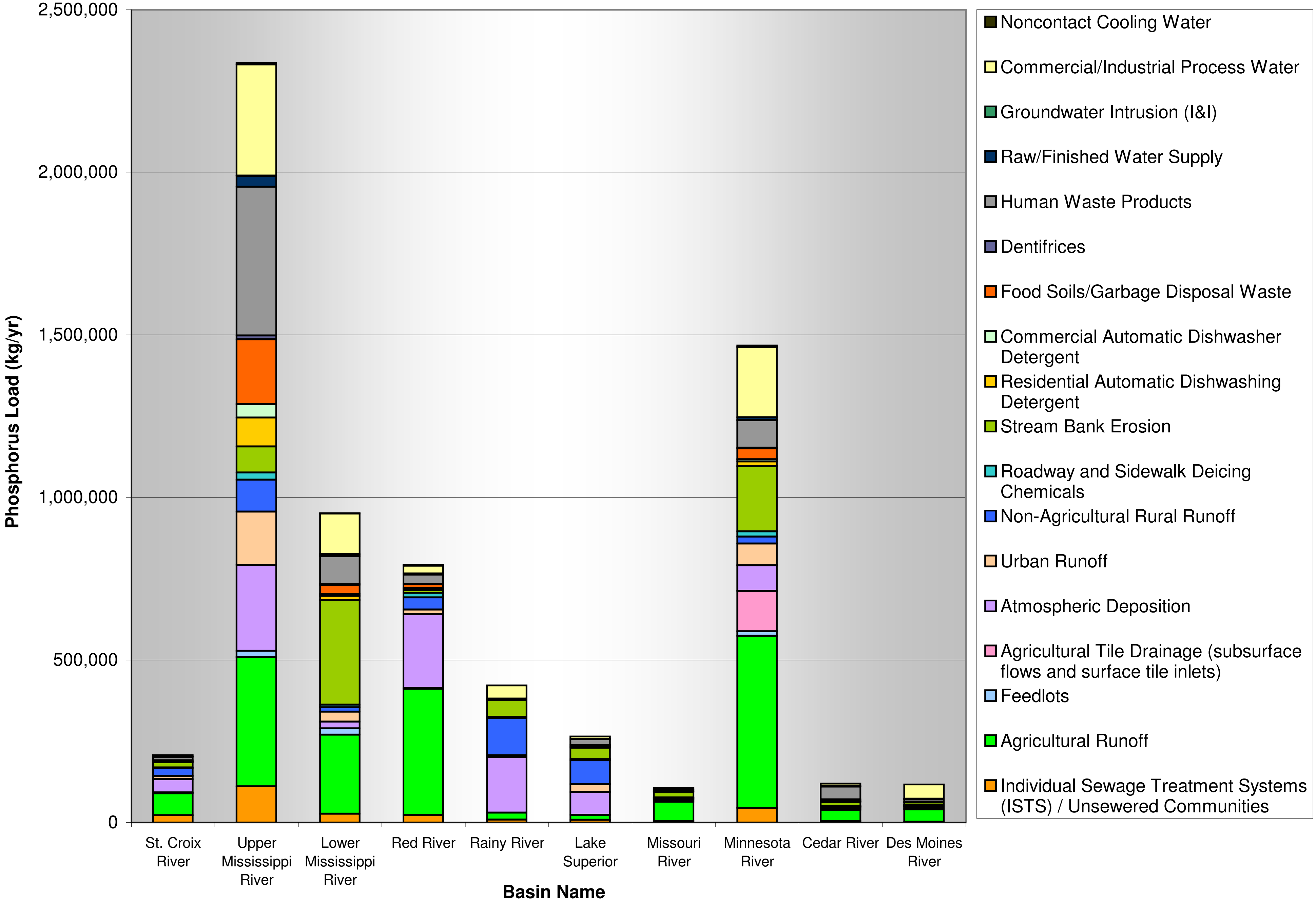


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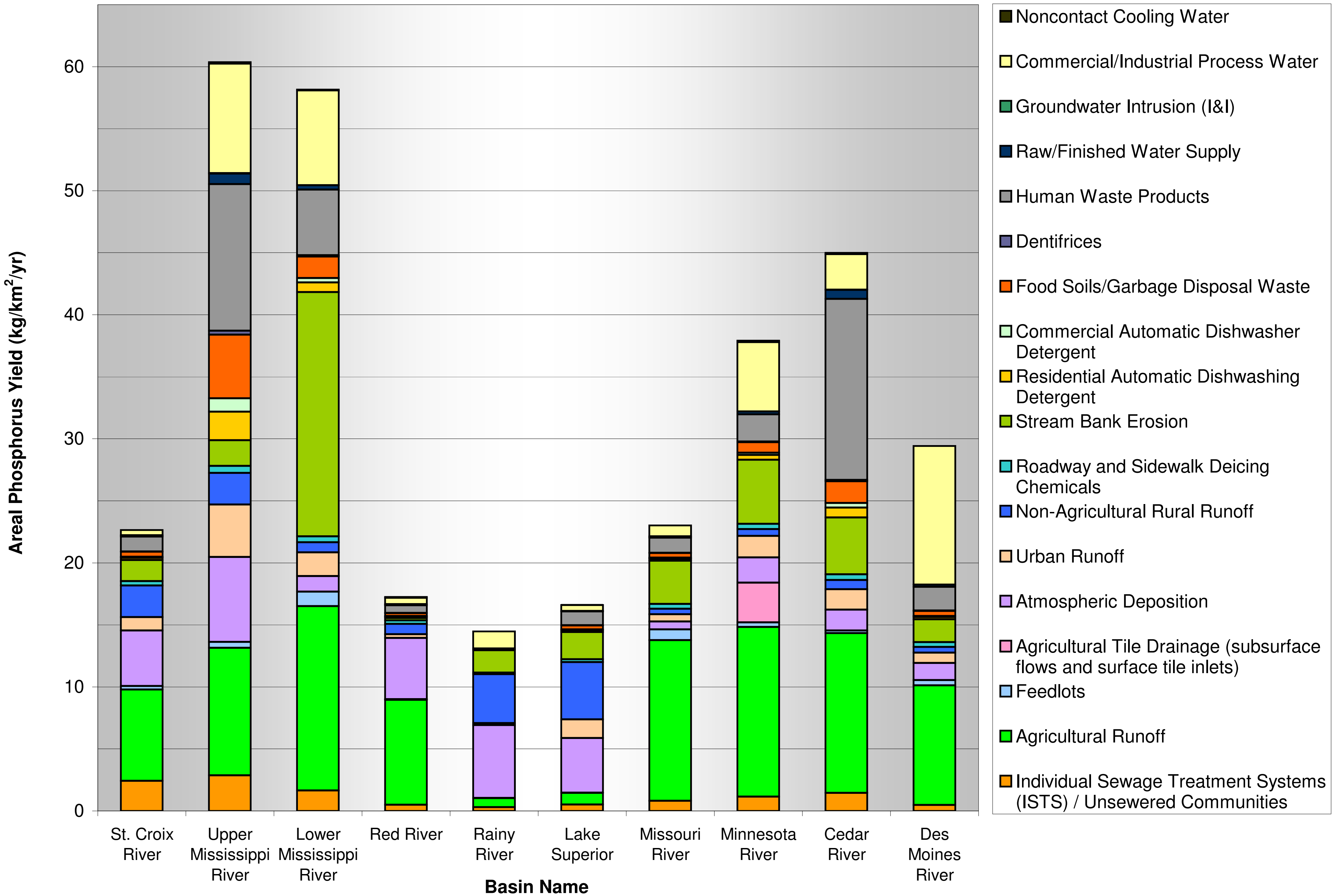
Figure EX-4b Watershed Total Phosphorus Yields to Minnesota Surface Waters - By Major Drainage Basin: Average Flow Conditions



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This reflects the large amount of surface water and the relatively low amounts of other sources in these basins.

Streambank erosion is a significant source of phosphorus in the Lower Mississippi River basin (34%) and, to a lesser degree, in the Minnesota River basin (14%). Commercial/industrial process water is an important source of phosphorus in the Lower Mississippi (13%), Minnesota (15%), Des Moines (38%), and the Rainy River (10%) basins. Non-agricultural rural runoff sources of phosphorus are important in the Rainy River (27%) and Lake Superior (28%) basins. Finally, human waste products are a significant source of phosphorus in the Upper Mississippi (20%) and Cedar River (32%) basins.

Statewide Phosphorus Source Category Loadings by Flow Condition

Both total and bioavailable phosphorus source estimates vary significantly under each flow condition. This is the result of changes in the nonpoint source loading from different flow conditions. Point source loads remain constant for the three flow conditions. Total amount and relative source contributions are summarized in Table EX-1 and Figures EX-5 through EX-9.

Low Flow Conditions

Under low flow conditions, the total point source phosphorus contribution represents 45 percent, while nonpoint sources of phosphorus represent 55 percent of the statewide loadings to surface waters. The expected load reduction of approximately 581,000 kg/yr associated with a 1 mg/L permit limit at the MCES Metro WWTP would shift the point source contribution to approximately 37 percent of the total load and the nonpoint source contribution to 63 percent. The commercial/industrial process water represents 38 percent of the point source total phosphorus contributions, while human waste products represent 35 percent. The remaining point source categories contribute less than 14 percent of the statewide point source loadings. The combination of residential and commercial automatic dishwasher detergent represents approximately 9 percent of the point source total phosphorus contributions.

Cropland and pasture runoff represent 33 percent of the nonpoint source total phosphorus loadings, while atmospheric deposition represents 30 percent, with the remaining nonpoint source contributions below 11 percent.

Under low flow conditions, the bioavailable point source phosphorus contribution represents 57 percent of the statewide loadings to surface waters (see Figure EX-6). The expected load reduction of approximately 496,800 kg/yr associated with a 1 mg/L permit limit at the MCES Metro WWTP would shift the point source contribution to approximately 50 percent of the total bioavailable phosphorus load. Commercial/industrial process water represents 40 percent of the point source bioavailable phosphorus contributions, while human waste products represent 35 percent. The remaining point source categories contribute less than 12 percent of the statewide point source loadings. The combination of residential and commercial automatic dishwasher detergent represents approximately 10 percent of the point source bioavailable phosphorus contributions.

As shown in Figure EX-6, cropland and pasture runoff represents approximately 34 percent of the nonpoint source bioavailable phosphorus loadings; atmospheric deposition represents 19 percent; and Individual Sewage Treatment Systems (ISTS)/unsewered communities represent 17 percent, with the remaining nonpoint source contributions below 12 percent. Table EX-1 generally indicates that point sources of phosphorus are more bioavailable than nonpoint sources.

Table EX-1 Statewide phosphorus contributions of point and nonpoint sources by flow condition

	Flow Condition		
	Low (Dry)	Average	High (Wet)
Total Phosphorus			
Point Source (kg/yr)	2,123,930 (45%)	2,123,930 (31%)	2,123,930 (19%)
Nonpoint Source (kg/yr)	2,638,067 (55%)	4,659,704 (69%)	8,932,735 (81%)
Total	4,761,997	6,783,634	11,056,665
Bioavailable Phosphorus			
Point Source (kg/yr)	1,975,757 (57%)	1,975,757 (44%)	1,975,757 (30%)
Nonpoint Source (kg/yr)	1,472,784 (43%)	2,559,026 (56%)	4,648,570 (70%)
Total	3,448,542	4,534,783	6,624,327

Looking more specifically at each source category in comparing Figures EX-5 and EX-6, on a proportional basis, indicates that ISTS/unsewered communities exhibits a significant increased contribution, while atmospheric deposition exhibits a significant decreased contribution, relative to the other sources for the bioavailable contribution of phosphorus. The relative shift for the remaining source categories is less than 2 percent in comparing the bioavailable and total phosphorus contributions.

Figure EX-5

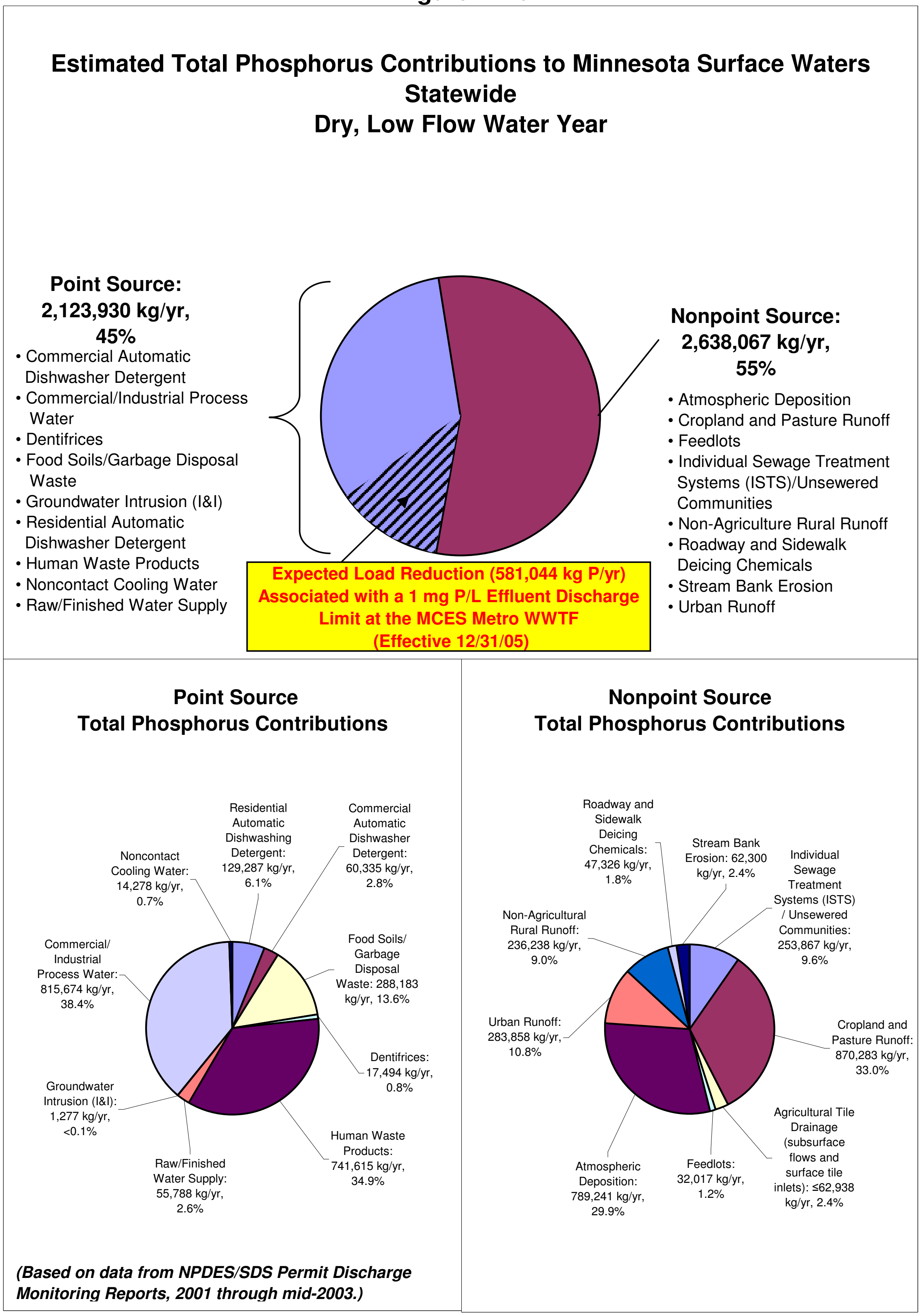
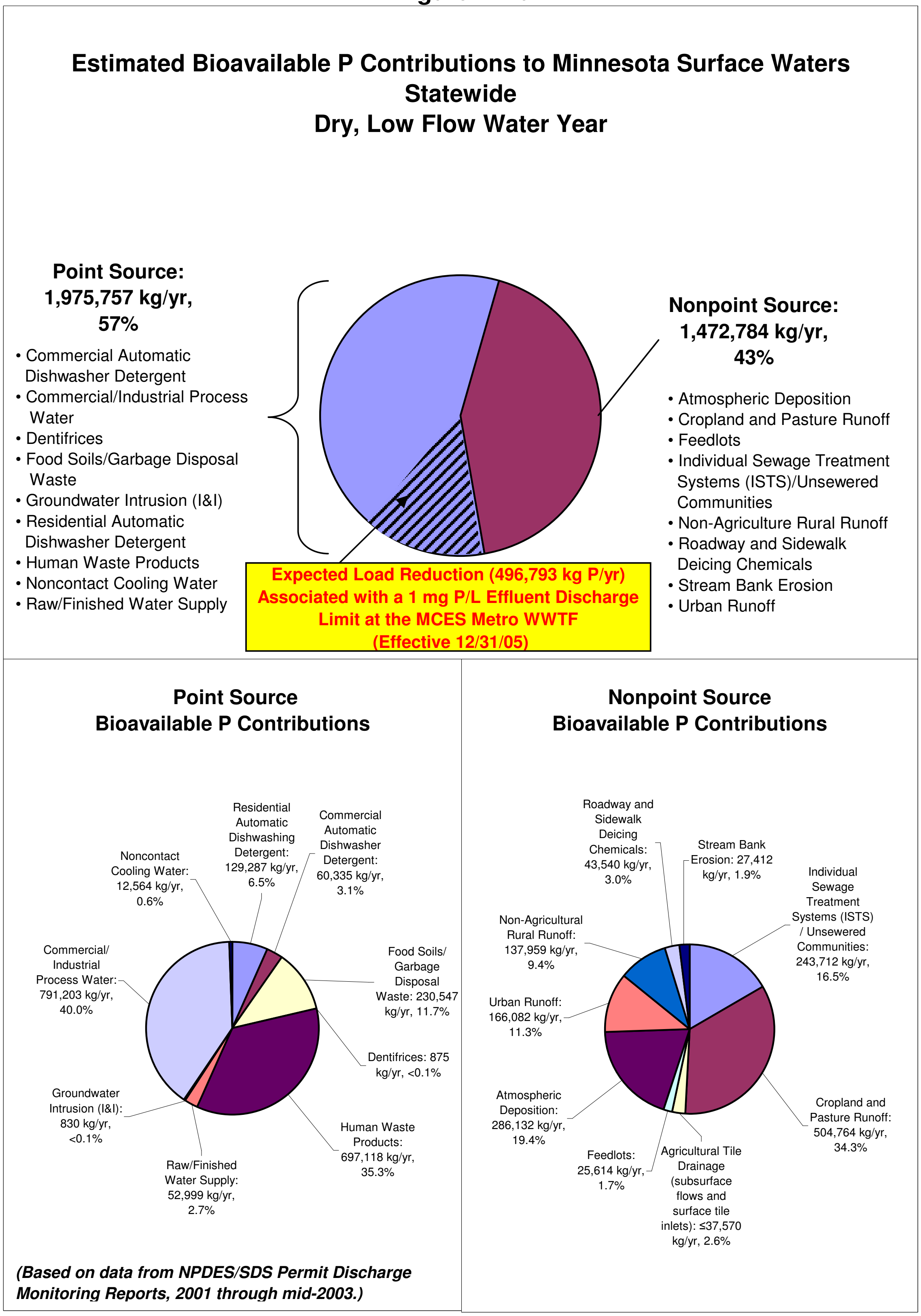

Estimated Total Phosphorus Contributions to Minnesota Surface Waters
Statewide
Dry, Low Flow Water Year
Point Source:
2,123,930 kg/yr,
45%
• Commercial Automatic Dishwasher Detergent
• Commercial/Industrial Process Water
• Dentifrices
• Food Soils/Garbage Disposal Waste
• Groundwater Intrusion (I&I)
• Residential Automatic Dishwasher Detergent
• Human Waste Products
• Noncontact Cooling Water
• Raw/Finished Water Supply
Nonpoint Source:
2,638,067 kg/yr,
55%
• Atmospheric Deposition
• Cropland and Pasture Runoff
• Feedlots
• Individual Sewage Treatment Systems (ISTS)/Unsewered Communities
• Non-Agriculture Rural Runoff
• Roadway and Sidewalk Deicing Chemicals
• Stream Bank Erosion
• Urban Runoff
Expected Load Reduction (581,044 kg P/yr)
Associated with a 1 mg P/L Effluent Discharge
Limit at the MCES Metro WWTF
(Effective 12/31/05)
Point Source
Total Phosphorus Contributions
Noncontact Cooling Water: 14,278 kg/yr, 0.7%
Residential Automatic Dishwashing Detergent: 129,287 kg/yr, 6.1%
Commercial Automatic Dishwasher Detergent: 60,335 kg/yr, 2.8%
Food Soils/ Garbage Disposal Waste: 288,183 kg/yr, 13.6%
Commercial/ Industrial Process Water: 815,674 kg/yr, 38.4%
Dentifrices: 17,494 kg/yr, 0.8%
Groundwater Intrusion (I&I): 1,277 kg/yr, <0.1%
Human Waste Products: 741,615 kg/yr, 34.9%
Raw/Finished Water Supply: 55,788 kg/yr, 2.6%
(Based on data from NPDES/SDS Permit Discharge Monitoring Reports, 2001 through mid-2003.)
Nonpoint Source
Total Phosphorus Contributions
Roadway and Sidewalk Deicing Chemicals: 47,326 kg/yr, 1.8%
Stream Bank Erosion: 62,300 kg/yr, 2.4%
Individual Sewage Treatment Systems (ISTS) / Unsewered Communities: 253,867 kg/yr, 9.6%
Non-Agricultural Rural Runoff: 236,238 kg/yr, 9.0%
Urban Runoff: 283,858 kg/yr, 10.8%
Cropland and Pasture Runoff: 870,283 kg/yr, 33.0%
Agricultural Tile Drainage (subsurface flows and surface tile inlets): ≤62,938 kg/yr, 2.4%
Atmospheric Deposition: 789,241 kg/yr, 29.9%
Feedlots: 32,017 kg/yr, 1.2%

Figure EX-6


Estimated Bioavailable P Contributions to Minnesota Surface Waters
Statewide
Dry, Low Flow Water Year
Point Source:
1,975,757 kg/yr,
57%
• Commercial Automatic Dishwasher Detergent
• Commercial/Industrial Process Water
• Dentifrices
• Food Soils/Garbage Disposal Waste
• Groundwater Intrusion (I&I)
• Residential Automatic Dishwasher Detergent
• Human Waste Products
• Noncontact Cooling Water
• Raw/Finished Water Supply
Nonpoint Source:
1,472,784 kg/yr,
43%
• Atmospheric Deposition
• Cropland and Pasture Runoff
• Feedlots
• Individual Sewage Treatment Systems (ISTS)/Unsewered Communities
• Non-Agriculture Rural Runoff
• Roadway and Sidewalk Deicing Chemicals
• Stream Bank Erosion
• Urban Runoff
Expected Load Reduction (496,793 kg P/yr) Associated with a 1 mg P/L Effluent Discharge Limit at the MCES Metro WWTF (Effective 12/31/05)
Point Source
Bioavailable P Contributions
Residential Automatic Dishwashing Detergent: 129,287 kg/yr, 6.5%
Commercial Automatic Dishwasher Detergent: 60,335 kg/yr, 3.1%
Noncontact Cooling Water: 12,564 kg/yr, 0.6%
Commercial/ Industrial Process Water: 791,203 kg/yr, 40.0%
Food Soils/ Garbage Disposal Waste: 230,547 kg/yr, 11.7%
Dentifrices: 875 kg/yr, <0.1%
Groundwater Intrusion (I&I): 830 kg/yr, <0.1%
Human Waste Products: 697,118 kg/yr, 35.3%
Raw/Finished Water Supply: 52,999 kg/yr, 2.7%
(Based on data from NPDES/SDS Permit Discharge Monitoring Reports, 2001 through mid-2003.)
Nonpoint Source
Bioavailable P Contributions
Roadway and Sidewalk Deicing Chemicals: 43,540 kg/yr, 3.0%
Stream Bank Erosion: 27,412 kg/yr, 1.9%
Individual Sewage Treatment Systems (ISTS) / Unsewered Communities: 243,712 kg/yr, 16.5%
Non-Agricultural Rural Runoff: 137,959 kg/yr, 9.4%
Urban Runoff: 166,082 kg/yr, 11.3%
Atmospheric Deposition: 286,132 kg/yr, 19.4%
Cropland and Pasture Runoff: 504,764 kg/yr, 34.3%
Feedlots: 25,614 kg/yr, 1.7%
Agricultural Tile Drainage (subsurface flows and surface tile inlets): ≤37,570 kg/yr, 2.6%

Average Flow Conditions

Under average flow conditions (see Figure EX-7), the total point source phosphorus contribution drops to 31 percent, compared to 45 percent for the statewide loadings to surface waters under low flow conditions. Cropland and pasture runoff represents 39 percent of the nonpoint source total phosphorus loadings; atmospheric deposition represents 19 percent; and streambank erosion represents 16 percent, with the remaining nonpoint source contributions below 9 percent. Compared to low flow conditions (see Figure EX-6), the relative statewide nonpoint source contributions of total phosphorus increased significantly for streambank erosion, increased slightly for cropland and pasture runoff, decreased somewhat for urban runoff, and decreased significantly for atmospheric deposition and ISTS/unsewered communities. Table EX-1 also shows that the nonpoint source phosphorus loadings nearly double from low to average flow conditions. All nonpoint source categories except ISTS/unsewered communities increase from low to average flow conditions.

High Flow Conditions

Under high flow conditions (see Figure EX-8), the total point source phosphorus contribution drops to 19 percent, compared to 31 and 45 percent for the statewide loadings to surface waters under average and low flow conditions, respectively. Streambank erosion represents 40 percent of the nonpoint source total phosphorus loadings; cropland and pasture runoff represents 31 percent; and atmospheric deposition represents 11 percent, with the remaining nonpoint source contributions below 7 percent. Compared to an average flow year (Figure EX-7), Figure EX-8 shows that the relative statewide nonpoint source contributions of total phosphorus increased significantly for streambank erosion, decreased slightly for cropland and pasture and non-agricultural rural runoff, decreased somewhat for urban runoff, and decreased significantly for atmospheric deposition and ISTS/unsewered communities. Table EX-1 shows a 3.3-fold increase in nonpoint source phosphorus loadings from low to high flow conditions and a near two-fold increase from average to high flow conditions.

Major Basin Phosphorus Source Category Loadings by Flow Condition

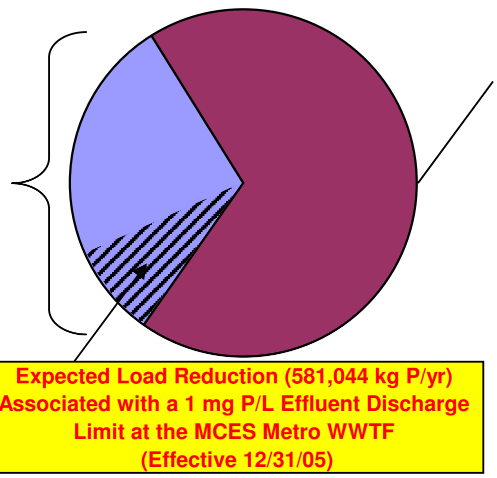
Table EX-2 presents the contributions of each source category to the total and bioavailable phosphorus loadings to surface waters in each basin and the state, by flow condition. The importance of the total and bioavailable phosphorus contributions from each source category varies significantly by basin, and somewhat by flow condition. Human waste products represent a significant portion of the total and bioavailable phosphorus loadings in the Upper Mississippi and Cedar River basins under each flow condition, and on a statewide basis, for the low and to a lesser extent average flow conditions. During low flow conditions, human waste products contribute

Figure EX-7

Estimated Total Phosphorus Contributions to Minnesota Surface Waters Statewide Average Flow Water Year

Point Source: 2,123,930 kg/yr, 31%

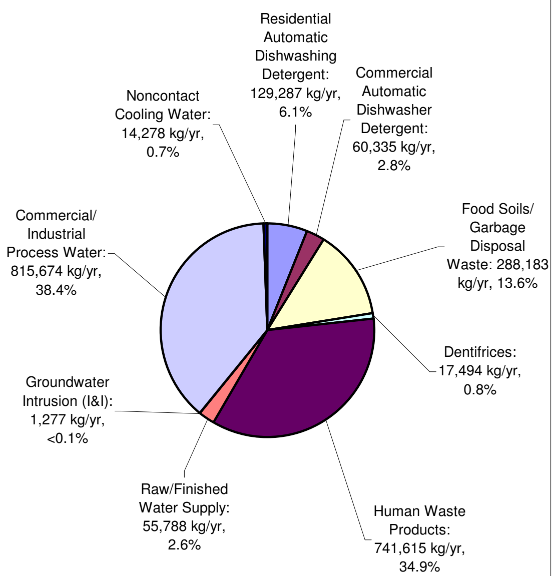
- Commercial Automatic Dishwasher Detergent
- Commercial/Industrial Process Water
- Dentifrices
- Food Soils/Garbage Disposal Waste
- Groundwater Intrusion (I&I)
- Residential Automatic Dishwasher Detergent
- Human Waste Products
- Noncontact Cooling Water
- Raw/Finished Water Supply



Nonpoint Source: 4,659,704 kg/yr, 69%

- Atmospheric Deposition
- Cropland and Pasture Runoff
- Feedlots
- Individual Sewage Treatment Systems (ISTS)/Unsewered Communities
- Non-Agriculture Rural Runoff
- Roadway and Sidewalk Deicing Chemicals
- Stream Bank Erosion
- Urban Runoff

Point Source Total Phosphorus Contributions



(Based on data from NPDES/SDS Permit Discharge Monitoring Reports, 2001 through mid-2003.)

Nonpoint Source Total Phosphorus Contributions

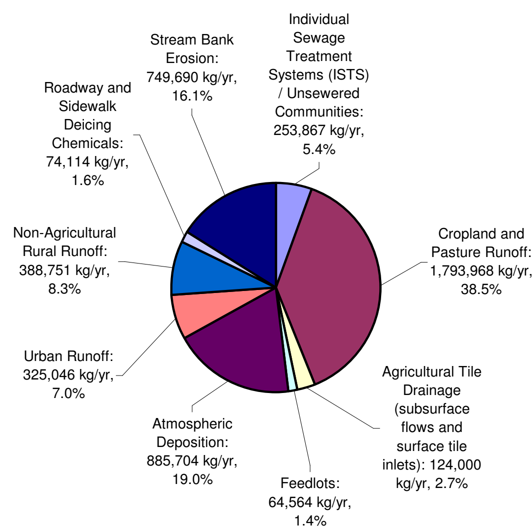
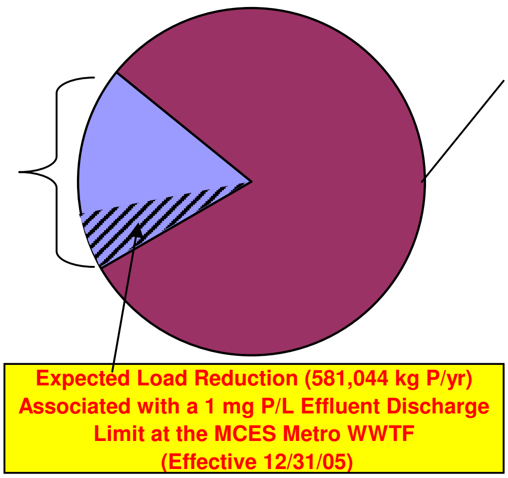


Figure EX-8

Estimated Total Phosphorus Contributions to Minnesota Surface Waters
Statewide
Wet, High Flow Water Year

Point Source:
2,123,930 kg/yr,
19%

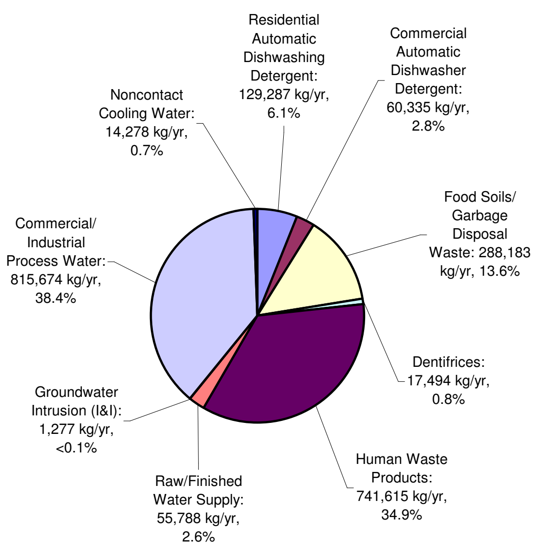
- Commercial Automatic Dishwasher Detergent
- Commercial/Industrial Process Water
- Dentifrices
- Food Soils/Garbage Disposal Waste
- Groundwater Intrusion (I&I)
- Residential Automatic Dishwasher Detergent
- Human Waste Products
- Noncontact Cooling Water
- Raw/Finished Water Supply



Nonpoint Source:
8,932,735 kg/yr,
81%

- Atmospheric Deposition
- Cropland and Pasture Runoff
- Feedlots
- Individual Sewage Treatment Systems (ISTS)/Unsewered Communities
- Non-Agriculture Rural Runoff
- Roadway and Sidewalk Deicing Chemicals
- Stream Bank Erosion
- Urban Runoff

Point Source
Total Phosphorus Contributions



(Based on data from NPDES/SDS Permit Discharge Monitoring Reports, 2001 through mid-2003.)

Nonpoint Source
Total Phosphorus Contributions

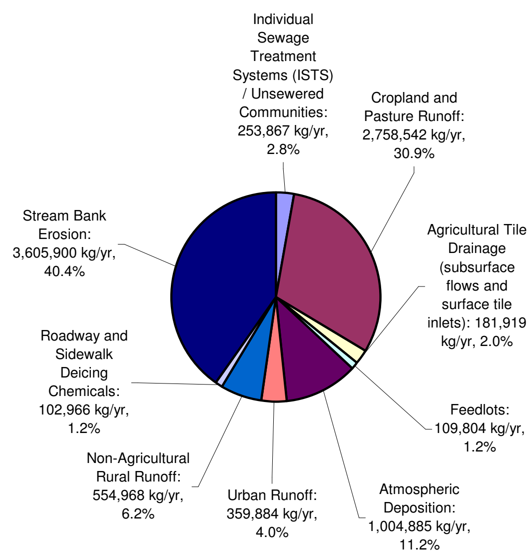


Table EX-2 Major Source Category Contributions of Total and Bioavailable Phosphorus to Each Basin and the State, by Flow Condition

Basin	St. Croix River						Upper Mississippi River						Lower Mississippi River					
Flow Condition	Low		Average		High		Low		Average		High		Low		Average		High	
Source Category	TP	BP	TP	BP	TP	BP	TP	BP	TP	BP	TP	BP	TP	BP	TP	BP	TP	BP
Point Sources																		
Residential ADWD																		
Commercial ADWD																		
Food Soils/ Garbage Disposal Waste							◆	◆										
Dentifrices																		
Human Waste Products		◆					■	■	◆	■	◆	◆	◆	◆		◆		
Raw/Finished Water Supply																		
Groundwater Intrusion (I&I)																		
Commercial/Industrial Process Water							◆	■	◆	◆	◆	◆	■	■	◆	◆		◆
Noncontact Cooling Water																		
NonPoint Sources																		
ISTS/Unsewered Communities	◆	■	◆	◆		◆												
Cropland and Pasture Runoff	■	■	■	■	■	■	◆		◆	◆	■	◆	■	◆	■	■	◆	◆
Agricultural Tile Drainage																		
Feedlots																		
Atmospheric Deposition	■	◆	◆	◆	◆	◆	◆		◆									
Urban Runoff																		
Non-Agicultural Rural Runoff	◆		◆	◆														
Roadway and Sidewalk Deicers																		
Stream Bank Erosion					■	■					◆				■	■	■	■

Basin	Red River						Rainy River						Lake Superior					
Flow Condition	Low		Average		High		Low		Average		High		Low		Average		High	
Source Category	TP	BP	TP	BP	TP	BP	TP	BP	TP	BP	TP	BP	TP	BP	TP	BP	TP	BP
Point Sources																		
Residential ADWD																		
Commercial ADWD																		
Food Soils/ Garbage Disposal Waste																		
Dentifrices																		
Human Waste Products		◆												◆		◆		
Raw/Finished Water Supply																		
Groundwater Intrusion (I&I)																		
Commercial/Industrial Process Water							◆	■		◆								
Noncontact Cooling Water																		
NonPoint Sources																		
ISTS/Unsewered Communities																		
Cropland and Pasture Runoff	■	■	■	■	■	■												
Agricultural Tile Drainage																		
Feedlots																		
Atmospheric Deposition	■	■	■	◆	■	◆	■	■	■	■	■	◆	■	■	■	◆	◆	◆
Urban Runoff													◆	◆				
Non-Agicultural Rural Runoff							■	■	■	■	■	■	■	■	■	■	■	■
Roadway and Sidewalk Deicers																		
Stream Bank Erosion					◆	◆			◆	◆	■	■			◆	◆	■	■

Basin	Missouri River						Minnesota River						Cedar River					
Flow Condition	Low		Average		High		Low		Average		High		Low		Average		High	
Source Category	TP	BP	TP	BP	TP	BP	TP	BP	TP	BP	TP	BP	TP	BP	TP	BP	TP	BP
Point Sources																		
Residential ADWD																		
Commercial ADWD																		
Food Soils/ Garbage Disposal Waste																		
Dentifrices																		
Human Waste Products		◆						◆					■	■	■	■	■	■
Raw/Finished Water Supply																		
Groundwater Intrusion (I&I)																		
Commercial/Industrial Process Water							■	■	◆	■		◆		◆				
Noncontact Cooling Water																		
NonPoint Sources																		
ISTS/Unsewered Communities																		
Cropland and Pasture Runoff	■	■	■	■	■	■	■	■	■	■	■	■	◆	◆	■	■	■	■
Agricultural Tile Drainage																		
Feedlots																		
Atmospheric Deposition																		
Urban Runoff																		
Non-Agicultural Rural Runoff																		
Roadway and Sidewalk Deicers																		
Stream Bank Erosion			◆	◆	■	■			◆		■	■			◆		■	■

Basin	Des Moines River						Statewide					
Flow Condition	Low		Average		High		Low		Average		High	
Source Category	TP	BP	TP	BP	TP	BP	TP	BP	TP	BP	TP	BP
Point Sources												
Residential ADWD												
Commercial ADWD												
Food Soils/ Garbage Disposal Waste												
Dentifrices												
Human Waste Products							◆	■	◆	◆		◆
Raw/Finished Water Supply												
Groundwater Intrusion (I&I)												
Commercial/Industrial Process Water	■	■	■	■	■	■	◆	■	◆	◆		◆
Noncontact Cooling Water												
NonPoint Sources												
ISTS/Unsewered Communities												
Cropland and Pasture Runoff	■	◆	■	■	■	■	◆	◆	■	■	■	■
Agricultural Tile Drainage												
Feedlots												
Atmospheric Deposition							◆		◆			
Urban Runoff												
Non-Agicultural Rural Runoff												
Roadway and Sidewalk Deicers												
Stream Bank Erosion					■	◆			◆		■	■

KEY: TP -- Total Phosphorus
BP -- Bioavailable Phosphorus
ADWD -- Automatic Dishwashing Detergent

■ -- Source category represents more than 20% of the total basin phosphorus loading.
◆ -- Source category represents between 10% and 20% of the total basin phosphorus loading.
□ -- Source category represents less than 10% of the total basin phosphorus loading.

between 10 and 20 percent of the bioavailable phosphorus loadings in the Lake Superior and St. Croix, Lower Mississippi, Red, Missouri, and Minnesota River basins. Commercial/industrial process water represents a significant portion of the total and bioavailable phosphorus loadings in the Upper Mississippi, Lower Mississippi, Minnesota, and Des Moines River basins under each flow condition, and on a statewide basis, for the low and to a lesser extent average flow conditions. Phosphorus contributions from ISTS/unsewered communities are of relative importance in the St. Croix River basin.

Cropland and pasture runoff represents significant total and bioavailable phosphorus loadings in the St. Croix, Lower Mississippi, Red, Missouri, Minnesota, Cedar and Des Moines River basins, and on a statewide basis, under all flow conditions. The phosphorus contribution from cropland and pasture runoff is also significant in the Upper Mississippi River basin for the average and high flow conditions. Atmospheric deposition represents a significant portion of the phosphorus loadings in the Lake Superior, St. Croix, Red, and Rainy River basins for each flow condition. Non-agricultural rural runoff contributes a significant portion of the phosphorus loadings in the Lake Superior and Rainy River basins for each flow condition. It should be noted, based on the analyses used in this study, that the typical rate of total phosphorus export from each acre of non-agricultural land is approximately four times lower than the corresponding load from each acre of contributing agricultural land (cropland and pasture). Finally, Table EX-2 shows that streambank erosion is an important source of phosphorus under high flow conditions for all of the basins, and is fairly significant in the Lake Superior, Lower Mississippi, Rainy and Missouri River basins under average flow conditions. Streambank erosion can also contribute somewhat significant amounts of total phosphorus statewide and to the Minnesota and Cedar River basins under average flow conditions.

Concepts for Lowering Phosphorus Export from Point Sources

The concepts for lowering the phosphorus export from point sources are presented in two parts:

1) Lowering phosphorus loading discharged to POTWs
2) Lowering point source phosphorus loading to surface waters

Lowering Phosphorus Loading Discharged to POTWs

The assessment of phosphorus sources entering POTWs are intended to assist the MPCA in complying with MN Laws 2003, Chap. 128 Art. 1, Sec. 122., as follows:

The state goal for reducing phosphorus from non-ingested sources entering municipal wastewater treatment systems is at least a 50 percent reduction developed by the commissioner under section

166, and a reasonable estimate of the amount of phosphorus from non-ingested sources entering municipal wastewater treatment systems in calendar year 2003.

For purposes of complying with this legislation, this study has estimated that the current non-ingested phosphorus load entering POTWs is 2,573,000 kg/yr. A 50 percent reduction would require decreasing the phosphorus discharged to POTWs by at least 1,286,000 kg/yr. (Note: in this study, human wastes are the only ingested source; all other sources are defined as non-ingested.) The following reduction tactics for non-ingested sources are listed in descending order of applicability:

- Next to human wastes, a variety of industrial and commercial dischargers contribute the most phosphorus to POTWs. The contribution of phosphorus from these commercial and industrial sources accounts for approximately 46 percent (1,183,600 kg/yr) of the non-ingested phosphorus load discharged into POTWs. Total removal of phosphorus from commercial and industrial wastewater is not a feasible option. In most cases, reduction would have to come from resource/product substitution, improvements in technology, through recycling and reuse, and through pretreatment of wastewater prior to discharge to the POTW. Reducing commercial and industrial phosphorus contribution to POTWs by one half would reduce the total non-ingested phosphorus discharged to POTWs by almost 23 percent. Excise taxes and/or effluent strength charges may provide an incentive to reduce this source of phosphorus discharged to POTWs.

- Food soils and garbage disposal wastes account for approximately 28 percent (725,000 kg/yr) of the non-ingested phosphorus discharged to POTWs. This is a substantial amount, but it would be difficult to implement product modification or prohibit the discharge of food wastes into the sewer systems. Approximately 25 percent of the phosphorus from this source is discharged into the sewer system as garbage disposal waste. Garbage disposal waste could be sent elsewhere (trash, compost, etc.), whereas it would be more difficult to manage the food associated phosphorus from dish rinsing and dish washing. Short of inducing the food product industries to reduce their use of phosphates or eliminating garbage disposals and prohibiting the discharge of food wastes down the drain, there appears to be few choices for reducing this phosphorus load to POTWs. Public education about this issue might help reduce the discharge of food wastes down the drain.

- Residential ADWD contributes almost 13 percent (334,500 kg/yr) of the non-ingested phosphorus load to POTWs. Although there has been a slight decline in the consumption of phosphorus for residential ADWD, SRI publication Chemical Economics Handbook - Industrial Phosphates (SRI, 2002) states that "it is unlikely that detergents with much lower phosphorus contents will be available in the near future." Currently, at least one brand of ADWD does not contain phosphorus; the phosphorus content of other brands varies significantly. Advertising and prominent content labeling would help reduce this source by aiding consumers in choosing low phosphorus products.

- Commercial and institutional ADWD contributes a statewide average of approximately 6 percent (152,000 kg/yr) of the influent non-ingested phosphorus load discharged into POTWs.

- Water supply chemicals account for an estimated 5.5 percent (141,500 kg/yr) of the non-ingested phosphorus load to POTWs statewide. Phosphorus is used for the sequestration (withdrawal) of metals, such as iron and manganese, and for the corrosion control of lead and copper, which in some cases is a human health issue and is required by law for those communities that do not pass the state corrosion tests. Reduction options include iron and manganese removal or substituting alternative water treatment chemicals in place of those containing phosphorus.

- Dentifrices (toothpaste, mouth wash, denture cleaners) account for less than 2 percent of the total non-ingested phosphorus load to POTWs. Because the phosphorus load from this source is so minimal, it does not warrant major reduction steps.

- Stormwater inflow and infiltration (I & I) contribute a negligible amount of phosphorus to POTW influent. Although there are many good reasons to limit inflow and infiltration into sewer systems—such as preventing hydraulic overloading of treatment facilities—the reduction of influent phosphorus is not one of them.

Overall Recommendation for Lowering Phosphorus Loads to POTWs

Given that food soils would be very difficult to reduce, and that dentifrices, noncontact cooling water, and I & I contribute so little to the influent phosphorus load discharged to POTWs, it is recommended that reduction efforts focus on the following:

- residential ADWD
- commercial and industrial process wastewater
- commercial and institutional ADWD
- water treatment chemicals

A summary of the phosphorus load discharged to POTWs and the reduction potential is presented in Table EX-3.

Table EX-3 Reduction Potential for Phosphorus Loads to POTW

Summary	Phosphorus Load to POTWs (kg/yr)	Portion of Total Load to POTW
Total Phosphorus Load Discharged to POTWs	4,468,000	
Human Waste Load	1,900,000	43
Non-Ingested Waste Load	2,573,000	57
Phosphorus Source	**% Reduction to Non-Ingested Phosphorus Load (%)**	**Cumulative Reduction to Non-Ingested Phosphorus Load (%)**
Residential ADWD reduced to 0	13	13
Commercial ADWD reduced to 0	6	19
Commercial and Industrial Process Water reduced by one half	23	42
Total Reduction		**42**

To reach the state goal of a 50 percent reduction in the total non-ingested phosphorus contribution to POTWs, residential and commercial/institutional ADWD and water treatment chemicals would need to be eliminated completely and commercial and industrial process wastewater would need to be reduced more than 64 percent. Given that it will be difficult to completely eliminate commercial/institutional ADWD and water treatment chemicals, while reducing the commercial and industrial process wastewater loading by such a substantial amount, a 50 percent reduction in the total non-ingested phosphorus contribution to POTWs appears to be an ambitious goal.

Lowering Phosphorus Loads to Surface Waters

Recommendations for lowering the point source phosphorus load discharged to surface waters in each major basin vary, based on the type of treatment facility and treatment processes employed. Phosphorus that comes from POTW outflows (effluent) represents, on average, more than 80 percent of the total point source loads to waters of the state. The largest source of phosphorus from POTWs is from large (> 1.0 mgd) facilities (88%). Phosphorus reduction efforts should begin at these facilities. As discussed previously, many POTWs have implemented phosphorus removal and others will begin to implement it in the near future. The largest impact, as noted previously, is phosphorus removal at the MCES' Metro WWTP (see blue sidebar on page viii). The reduction of the effluent phosphorus concentration to 1 mg/L at this one facility will result in the effluent phosphorus from POTWs being reduced from 80 percent to 74 percent of the point source load to waters of the state.

Privately owned wastewater treatment systems account for less than 0.5 percent of the total point source phosphorus discharged statewide. Increased phosphorus removal at these facilities will have only a negligible impact on the statewide point source phosphorus load.

Direct commercial and industrial sources statewide constitute approximately 18 percent of the point source phosphorus load. Combining direct commercial/industrial discharges with commercial/industrial discharges following treatment at POTWs represents 38 percent, statewide. It was not within the scope of this study to categorize the phosphorus loading data by commercial and industry type or to determine which industries are the largest contributors. However, it is recommended that industrial dischargers that make major contributions to the phosphorus loadings be evaluated in further detail.

Current Effluent Phosphorus Reduction Efforts by Wastewater Treatment Plants

As part of this study, several WWTPs were surveyed regarding phosphorus treatment methods and a review of the efforts of each of the cities to reduce phosphorus in their effluent was completed. The WWTPs ranged in size (0.7 to 24 million gallons per day), treatment methods (chemical and/or biological), and phosphorus discharge requirements (0.07 mg/L to 2.41 mg/L). Four of the eight WWTPs surveyed used chemical treatment only for phosphorus removal. Four of the eight WWTPs used enhanced biological phosphorus removal (EBPR). In addition to EBPR, three of the four plants surveyed also use chemical treatment to meet total phosphorus discharge requirements below 1 mg/L. The Rock Creek and Durham WWTPs in Portland, Oregon use EBPR and two-point alum addition to meet a stringent 0.07 mg/L total phosphorus discharge requirement set for the Tualatin Watershed west of Portland. Pilot testing and full-scale system modifications were required to reach the high level of phosphorus removal achieved by these plants. Alum is added to the primary clarifier prior to EBPR, as well as the secondary clarifier. The effluent from the secondary clarifier is then filtered for an average total phosphorus effluent concentration of 0.05 mg/L. Significant cost savings were observed once enhanced biological phosphorus removal was implemented at the Durham facility (i.e., the chemical costs for alum were cut by one third).

The City of St. Cloud has a Phosphorus Management Plan (PMP), with a primary goal of limiting the amount of phosphorus coming into the facility by means of a phosphorus reduction program and public outreach. The goal of the phosphorus reduction program is to assist non-domestic nutrient contributors (NDNC) in developing phosphorus reduction strategies that will reduce the amount of phosphorus that enters the wastewater collection system and eliminate phosphorus slug loads. The city works with industrial users to keep phosphorus discharges to the WWTP below 6 mg/L. This method is effective at reducing spike loads and the average influent phosphorus concentrations.

The following summarizes the conclusions of the survey evaluating phosphorus reduction efforts by wastewater treatment plants:

- The cities implementing source reduction programs all achieved significant reduction in phosphorus loading on their WWTPs using a variety of methods: public outreach, phosphorus bans, surcharges for phosphorus treatment, and maximum limits on significant industrial users (SIU) phosphorus discharges.

- The St. Cloud WWTP showed that a reduction in influent phosphorus loading and phosphorus slug loads lead to a reduction in effluent phosphorus concentration.

- Chemical treatment is capable of reaching the lowest phosphorus effluent concentrations.

- The cost per unit of total phosphorus removed varied from $0.96 to $20.00 per pound of total phosphorus removed. The cost of treating phosphorus chemically appeared to show an economy of scale.

- The cost for chemical treatment was lower for those WWTPs that used a combination of EBPR and chemical treatment.

- EBPR alone is generally effective at achieving 0.5 mg/L to 1 mg/L effluent phosphorus concentrations. Chemical addition is necessary to achieve effluent phosphorus concentrations less than 0.5 mg/L. One of the best available bio/chemical treatment facilities (Durham WWTP, OR) was able to achieve an average effluent phosphorus concentration of 0.05 mg/L. To reach this low effluent concentration, significant pilot testing was required and phosphorus removal efficiency was dependent upon wastewater characteristics.

- Once the initial capital improvements are made there are no additional costs associated with phosphorus removal using EBPR.

- In some cases, EBPR can be implemented with simple process modifications (e.g., St Cloud aeration modifications) that achieve reductions in effluent phosphorus concentrations. St

Cloud was able to achieve an effluent phosphorus concentration of approximately 1 mg/L with this approach.

The Minnesota Environmental Science and Economic Review Board (MESERB) received funding from the legislature to complete a Wastewater Phosphorus Control and Reduction Initiative. The Initiative consists of an independent examination of selected wastewater treatment facilities by nationally recognized experts in biological phosphorus removal. A final report will evaluate actual and potential methods of phosphorus reduction, and develop a list of recommended cost-effective reduction strategies. Two seminars will also provide wastewater operators with the tools to implement immediate measures to reduce phosphorus in the final effluent. Project completion is scheduled for April 2005.

Concepts for Lowering Phosphorus Export from Nonpoint Sources

Agricultural Runoff

Comparing past agricultural runoff loadings with the current phosphorus loading estimates—when it is assumed that moldboard plowing (which lifts, fractures and inverts the soil, producing furrows) is used on all row cropland—allows for an evaluation of the extent of progress in controlling phosphorus losses over the last twenty years, due to improvements in tillage management. Modeling indicates that in the Minnesota River basin, compared to an era when moldboard plowing was widely practiced, current day phosphorus losses from agricultural cropland have been reduced by about 146,000 kg/yr (from about 664,000 to 518,000 kg/yr), for a 28% reduction. In the Upper Mississippi River basin, current phosphorus losses from agricultural land have been reduced by about 87,000 kg/yr, for a 24% reduction. Similar comparisons show a 7% reduction for the Red River basin and no significant reduction for the Lower Mississippi River basin.

Although modeling indicates improvements in phosphorus reduction over the past 20 years, increased reduction could come from improved phosphorus fertilizer and manure management. If University of Minnesota recommendations were followed more consistently, phosphorus fertilizer usage could be reduced. For instance, the University has set a threshold above which crops do not respond to additional phosphorus. But phosphorus fertilizer is spread on significant areas of land in the Minnesota River basin, and elsewhere, even if soil test phosphorus levels exceed that threshold. Excess applications in the past were considered cheap forms of insurance for crop yield needs and, since even high soil phosphorus levels were wrongly perceived not to be released from soils, the environmental impact was considered minimal. Modeling indicates that in the Minnesota River basin, reductions in the rate of phosphorus fertilizer application could reduce phosphorus losses to surface waters by about 81,000 kg/yr, as compared to existing conditions, for a 16% reduction. Comparable levels of reduction could occur with improved phosphorus fertilizer management in the Red River, and the Upper and Lower Mississippi River basins.

The potential impact of improved manure application methods is significant in the Red River basin. Phosphorus loads to surface waters could be reduced by about 75,000 kg/yr, for a 20% reduction. Improved manure application methods could potentially reduce phosphorus loads to surface waters in the Upper Mississippi (12%), Lower Mississippi (7%), and Minnesota River (7%) basins. Decreasing the area of cropland within 100 m of surface waters, which corresponds to land retirement programs such as those promoted in the Conservation Reserve and Conservation Reserve Enhancement Programs, are estimated to decrease the phosphorus loadings to levels that are comparable to non-agricultural rural runoff.

Atmospheric Deposition

Soil dust is estimated to be the largest source of atmospheric phosphorus. Therefore, reducing soil dust, particularly from wind erosion from agricultural fields, through the application of wind erosion best management practices (shelterbelts, no till planting, use of cover crops, etc.) should be a high priority.

Deicers

Efforts are currently underway, as part of MnDOT's road weather information system (RWIS), to use timely and accurate weather and road data in deicing application decisions to optimize the use of deicing materials. More accurate weather information could lead to reduced usage of deicing agents. These types of efforts should be used by other winter road maintenance agencies throughout the state. The use of brines should be considered to improve the effectiveness of deicing agents and thereby reduce the use of other deicers. The high phosphorus content of many of the agriculturally derived alternatives to road salt is of concern, as many of these products have phosphorus concentrations 100 to 10,000 times greater than road salt or sand. Testing should be done on these road salt alternatives and an assessment should be done to weigh their benefits against their environmental implications.

Streambank Erosion

There is the potential for substantial water quality benefits associated with lowering phosphorus export from streambank erosion, including reduced eutrophication and sedimentation, as well as improved biological habitat within reservoirs, lakes, wetlands, and river systems. Several methods can be implemented to help reduce streambank erosion: Careful land use planning that considers the potential adverse impacts associated with increased runoff volumes; well-designed stream road crossings that consider the potential hydrodynamic changes to the system; exclusion or controlled access of pastured animals and preservation of riparian vegetation; and rotational grazing. There are opportunities to reduce streambank erosion in watersheds that have experienced flow volume increases from land use changes.

ISTS/Unsewered Communities

Many of the counties in Minnesota have been delegated to implement Minnesota Rules Chapter 7080 for ISTS, which require conformance with state standards for new construction of ISTSs and disclosure of the state of existing ISTS when a property transfers ownership. Several counties require ISTS upgrades at property transfer. Owners of ISTS that pose an Imminent Threat to Public Health and Safety (ITPHS), through direct discharge to tile lines or surface ditches or system seeping to the ground surface should be identified through a statewide survey to help residents determine whether their ISTS are adequately treating and disposing of sewage below grade. Local Units of Government (LUGs), ISTS permitting authorities and inspection programs should be targeted with MPCA audits to determine adequacy of performance in a number of key areas, including spot checks for conformance on new ISTS installations, level of effort on ISTS inspections and follow-through on replacement of noncompliant systems, and dealing with problem ISTS professionals. Since septic system failure is a widespread problem, a basinwide approach to addressing nonconforming systems with potential for high delivery of pollutants to public waters, such as straight pipe discharges and other types of ITPHS should be given priority attention. The LUGs should work with the MPCA to develop, populate and maintain a database, similar to MPCA's feedlot database that shows the location of each nonconforming system, especially where straight pipe discharges and other types of ITPHS are located. LUG personnel should be provided with an incentive to inventory all systems within their jurisdiction, and track system performance and maintenance.

Non-Agricultural Rural Runoff

The protection of natural areas is needed to ensure they retain the hydrologic and ecologic functions that keep surface runoff volumes low, nutrient (phosphorus) export low and groundwater recharge rates high. Many natural areas are under stress due to development pressures, invasion by exotic species and increased nutrient loading associated with runoff coming from adjacent land uses. Conservation easements, such as CREP and RIM, provide additional opportunities for reducing phosphorus export from contributory watershed areas.

Urban Runoff

The design, construction and maintenance of watershed BMPs will help reduce pollutant (phosphorus) loads to surface waters in urban areas. Water quality protection requires that all urban development design use a water budget approach, where the preservation of the infiltration and evapotranspiration components of the hydrologic cycle are primary considerations. Site planning that reduces impervious surface area and preserves infiltration will help attain water quality protection. A number of stormwater management and urban best management practices manuals are available that provide design guidance for controlling the impacts of urban runoff and promoting infiltration (Metropolitan Council, 2001; Schueler, 1995; Brach, 1989; US EPA. 2001). The National Pollutant Discharge Elimination System (NPDES) permit administered by the MPCA regulates runoff from construction sites, industrial facilities and municipal separate storm sewer systems (MS4s) to reduce the pollution and ecological damage. Phase I of the program focused on large construction sites, 11 categories of industrial facilities, and major metropolitan MS4s. Phase II broadened the program to include smaller construction sites, small municipalities (populations of less than 100,000) that were exempted from Phase I regulations, industrial activity, and MS4s. At a minimum, compliance with the stormwater pollution prevention planning requirements of this permit program is critical to minimize the phosphorus loading increases associated with urban runoff.

Relative Phosphorus Source Loading Uncertainty/Recommended Refinements

This assessment assumes that there is some variability and uncertainty surrounding the phosphorus loading estimates used for this study. The variability and uncertainty of the phosphorus loading computations done for each source category can generally be attributed to natural variability (such as variations in watershed and climatic conditions), a lack of source-specific data or regional relationships with watershed characteristics, error associated with extrapolation of available data, and in some cases, a lack of understanding about all of the processes contributing to the phosphorus loadings under each flow condition.

The phosphorus loading estimates for commercial/industrial process water, streambank erosion, cropland and pasture runoff, feedlot runoff, agricultural tile drainage, ISTS/unsewered communities, and atmospheric deposition are expected to have moderate to high variability and uncertainty relative to the other phosphorus source categories. Table EX-2 shows that, of these categories, commercial/industrial process water, streambank erosion, cropland and pasture runoff, and atmospheric deposition represent significant phosphorus contributions to some of the major basins under more than one flow condition. Phosphorus loading estimates for human waste products are expected to have low variability and uncertainty relative to the other phosphorus source categories.

General recommendations intended to reduce the uncertainty of the phosphorus load estimates associated with the significant phosphorus source categories include:

- Continue to develop, populate and maintain intra- and inter-agency database information (preferably in geographic databases), similar to MPCA's Delta, environmental data access and feedlot databases, that can readily provide both information for resource-specific studies and data for the development of larger scale (such as agroecoregion, ecoregion, or regional) relationships based on existing programs

- Prioritize and complete source-specific studies to better understand the processes, identify and fill in data gaps for the phosphorus source categories with moderate to high uncertainty, and evaluate the effects of best management practices

- Enlist, train and coordinate new large-scale data collection efforts with volunteers and other state, county and local personnel to obtain chemical and biological data for future assessments (e.g., tracking nonconforming septic systems, streambank erosion inventories) that can be completed throughout the state

Overall Conclusions

The results of this assessment indicate that the estimated amounts of total and bioavailable phosphorus entering surface waters within each major basin and the state vary significantly, both by source category and by flow condition. The phosphorus loadings associated with several point and nonpoint source categories can be controlled to various levels, resulting in significant water quality improvements, depending on the water resource and flow condition. The following discussion provides some overall conclusions from this assessment:

- Because of the general nature of this analysis, it can be true that sources of phosphorus which are deemed minor at the basin scale, may actually contribute the majority of phosphorus to specific surface water bodies, at a localized scale. For example, point sources typically contribute little or no phosphorus to Twin Cities Metropolitan and most outstate lakes, but can represent a significant portion of the total phosphorus load to rivers under low flow conditions. Because of this, there is still a need to complete individual assessments of specific watersheds to evaluate specific loading conditions.

- Under average conditions, the point source total phosphorus contribution represents 31 percent of the loadings to surface waters, statewide, whereas nonpoint sources contribute 69 percent. Of these nonpoint sources, cropland and pasture runoff, atmospheric deposition, streambank erosion, human waste products, and commercial/industrial process water each represent between 10 and 30 percent of the total phosphorus loading. All of the remaining source category contributions are below 6 percent. The combination of household and commercial automatic dishwasher detergent represents approximately 3 percent of the total phosphorus contributions to surface waters in the state, during an average year.

- Under low flow conditions, the total point source phosphorus contribution represents 45 percent, compared to 31 and 19 percent for the statewide loadings to surface waters under average and high flow conditions, respectively. The bioavailable low flow point source phosphorus contribution represents 57 percent of the statewide loadings, confirming that point sources of phosphorus are more bioavailable than nonpoint sources. Comparing high flow to average and low flow conditions, the relative statewide nonpoint source contributions of total phosphorus increased significantly for streambank erosion, decreased somewhat for urban runoff, and decreased significantly for atmospheric deposition and ISTS/unsewered communities.

- Nonpoint source phosphorus loadings nearly double from low to average flow conditions, and again from average to high flow conditions.

- Human waste products represent a significant portion of the total and bioavailable phosphorus loadings in the Upper Mississippi and Cedar River basins under each flow condition; and on a statewide basis, for the low and to a lesser extent average flow conditions. During low flow conditions, human waste products contribute between 10 and 20 percent of the bioavailable phosphorus loadings in the Lake Superior and St. Croix, Lower Mississippi, Red, Missouri, and Minnesota River basins.

- Commercial/industrial process water represents a significant portion of the total and bioavailable phosphorus loadings in the Upper Mississippi, Lower Mississippi, Minnesota, and Des Moines River basins under each flow condition, and on a statewide basis, for the low and to a lesser extent average flow conditions.

- Phosphorus contributions from ISTS/unsewered communities are of relative importance in the St. Croix River basin.

- Cropland and pasture runoff represents a significant portion of the total and bioavailable phosphorus loadings in the St. Croix, Lower Mississippi, Red, Missouri, Minnesota, Cedar and Des Moines River basins, and on a statewide basis, under all flow conditions. The phosphorus contribution from cropland and pasture runoff is also significant in the Upper Mississippi River basin for the average and high flow conditions.

- Atmospheric deposition represents a significant portion of the phosphorus loadings in the Lake Superior, St. Croix, Red, and Rainy River basins for each flow condition.

- Non-agricultural rural runoff contributes a significant portion of the phosphorus loadings in the Lake Superior and Rainy River basins for each flow condition, although the typical rate of total phosphorus export from each acre of non-agricultural land is approximately four times lower than the corresponding load from each acre of contributing cropland and pasture runoff.

- Streambank erosion is an important source of phosphorus under high flow conditions for all of the basins, and is fairly significant in the Lake Superior, Lower Mississippi, Rainy and Missouri River basins under average flow conditions. Streambank erosion can also contribute somewhat significant amounts of total phosphorus statewide and to the Minnesota and Cedar River basins under average flow conditions.

- The concepts for lowering the phosphorus export from point sources address possible reductions of phosphorus discharged to POTWs as well as phosphorus discharged to the surface waters in each basin. Food soils would be very difficult to reduce, and dentifrices, noncontact cooling water and I & I contribute little to the influent phosphorus load discharged to POTWs. If residential and commercial/institutional ADWD and water treatment chemicals were eliminated completely, commercial and industrial process wastewater would still need to be reduced more than 64 percent to attain a 50 percent reduction in the total non-ingested phosphorus contribution to POTWs (the goal established in MN Laws 2003, Chap. 128 Art. 1, Sec. 122). Given the difficulties in completely eliminating phosphorus from commercial/institutional ADWD and water treatment chemicals, and reducing the commercial and industrial process wastewater loading by more than 64 percent, a 50 percent reduction of non-ingested influent phosphorus appears to be an ambitious goal. In addition, a 50 percent reduction in influent may not mean a 50 percent reduction in the effluent depending upon the type of wastewater treatment processes used.

- A large portion of the influent phosphorus load to POTWs is from human waste products and/or is largely uncontrollable. Continued implementation of enhanced biological phosphorus removal (EBPR) will significantly reduce effluent phosphorus concentrations.

- Public education about the use of ADWD based on hardness and the availability of no- and low-phosphorus content products should be encouraged.

1.0 Introduction

1.1 Background

Eutrophication of surface waters is a condition in which excess nutrients cause excessive growth of algae and other aquatic plants. Phosphorus is the nutrient primarily responsible for the eutrophication of Minnesota's surface waters. Too much phosphorus causes excessive growths of nuisance algae (blooms) and reduced water transparency, making waters unsuitable for swimming or other recreational activities. When there are excessive amounts of algae in surface waters and those algae die, the decay of the algae may consume dissolved oxygen in the water and stress the biological community. This may cause fish kills. Additionally, severe algal blooms may directly poison animals that ingest the algae, or cause allergic reactions in people who swim in the polluted water.

Phosphorus in lakes and streams comes from both point and nonpoint sources. Point sources are typically industrial and publicly-owned wastewater treatment plants (POTWs). Point sources usually have distinct pipe discharges to surface water and are discharged from wastewater treatment plants may come into the plant from a variety of sources. Phosphorus discharged from wastewater treatment plants may come into the plant from a variety of sources. Nonpoint sources of phosphorus are typically polluted runoff from cities and farmland, among other land uses. Nonpoint phosphorous sources do not generally have distinct discharge points and are not typically regulated under State Water Pollution Permit programs.

The amounts of phosphorus contributed to Minnesota surface waters by point and nonpoint sources are known to vary, both geographically and temporally, in response to annual variations in weather and climate, primarily. Variations in rainfall and watershed runoff alter both the amounts of runoff-borne non-point source phosphorus reaching surface waters and the waters' dilution capacities. Generally speaking, nonpoint sources of phosphorus comprise a much larger fraction of the aggregate total phosphorus load to Minnesota surface waters during relatively wet periods, while point sources become more important during dry conditions, compared to wet conditions. Previous work by the MPCA, completed as part of their *Minnesota River Basin Plan*, estimated that nonpoint sources of phosphorus loading monitored in the basin at Jordan, MN (comprising approximately 19 percent of the area of the state), predominate under high and average river flow conditions. Point source phosphorus loads dominated the basin's phosphorus budget under low flow conditions (Table 1-1), the MPCA further estimated, based on analyses of data collected at Jordan, MN near the river mouth.

Table 1-1 Minnesota River Point and Nonpoint Source Load Contributions at Various Flow Duration Intervals

Minnesota River Flow	Percentage of Duration Within Each Flow Interval	Nonpoint Source and Others Percent Contribution to Total Load	Point Source Percent Contribution to Total Load
High (>7,100 cfs)	18.5	90	10
Average (2,750 cfs)	70.7 *	74	26
Low (<1,275 cfs)	10.8	28	72

*Percent of time flow was between 7,100 and 1,275 cfs

Results of this study, using a variety of estimation techniques to calculate phosphorus loading to Minnesota surface waters, confirm these load distribution patterns for the Minnesota River basin and the nine other major river basins either wholly or partially within the state. The phosphorus load estimates reported here are aggregate totals contributed to all waters of the state, including lakes, ponds, rivers, streams and wetlands, and ditches.

The amount of phosphorus contributed to surface waters is not the only factor that determines adverse impact of the pollutant. The form of phosphorus and its ease of being utilized by algae and other plants are important. Excessive algal production is dependent on the availability of usable (bioavailable) phosphorus. Phosphorus from a point source may be more bioavailable and exert a larger impact on surface water quality than a similar amount of nonpoint source phosphorus that enters the same surface water. Phosphorus from point sources is largely in a chemical form readily useable by plants (ca. 97 percent bioavailable), while phosphorus from nonpoint sources may be only 30 to 60 percent bioavailable to plants. Other critical factors affecting the water quality impacts are the type of water body the phosphorus enters (lake, river, reservoir) and season of the year.

1.2 Legislative Mandate to Conduct this Study

This watershed-based study of phosphorus contributions to Minnesota surface waters was conducted to inventory the following:

1. **Sources and amounts of phosphorus entering three different sizes and categories of Publicly-Owned Treatment Works (POTWs; i.e., Wastewater Treatment Plants).**

    Sizes: (average daily flow rate)

    - Less than 0.2 million gallons per day (mgd)
    - 0.2 to 1.0 mgd
    - Greater than 1.0 mgd

Categories: (flow contributors)

- Primarily domestic
- Domestic with some commercial/industrial
- Predominately commercial/industrial

Sources: (individual and/or categorical)

- Automatic dishwasher detergents
- Other household cleaners or household non-ingested sources
- Commercial/industrial, including:
  - Process wastewater
  - Noncontact cooling water
  - Other additives
- Water supply, including water treatment chemicals
- Human waste products
- Groundwater intrusion to sanitary sewers

Information developed in this portion of the phosphorus inventory is intended to assist the MPCA in complying with MN Laws 2003, Chap. 128 Art. 1, Sec. 122:

The state goal for reducing phosphorus for non-ingested sources entering municipal wastewater treatment systems is at least 50 percent reduction based on the timeline for reduction developed by the commissioner under section 166, and a reasonable estimate of the amount of phosphorus from non-ingested sources entering municipal wastewater treatment system in calendar year 2003.

2. **Sources and amounts of phosphorus entering Minnesota surface waters for each of the ten major basins and for the entire state of Minnesota from point- and nonpoint-sources during low (dry), average, and high (wet) flow conditions; and the effect of various phosphorus source reduction options on water quality.**

Information developed in this portion of the phosphorus inventory is intended to assist the MPCA in complying with MN Laws 2003, Chap. 128, Art. 1, Sec. 16:

The commissioner of the pollution control agency must study the concept of lowering phosphorus in the wastewater stream and the effect on water quality in the receiving waters and how to best assist local units of government in removing phosphorus at public wastewater treatment plants, including the establishment of a timeline for meeting the goal in Minnesota Statutes, section 115.42 .

1.3 Organization of this Report

To facilitate the reading of this report, results have been organized around identification of the sources and amounts of phosphorus contributed both to POTWs and to surface waters of the state. Sources and amounts contributed to surface waters includes both point and nonpoint source contributions. Wastewater treatment plants (Publicly-Owned, Private and Industrial) are included as point source contributors, in this context. The report discusses phosphorus contributions to surface waters of the state, both in terms of source category and by major basin, for low, average and high flow conditions. The hydrology of each basin under low, average and high flow conditions is discussed in more detail in Appendix A. Detailed discussions about each source contribution category are included in Appendices B through J. The report further assesses the importance of each phosphorus source contributor in regards to the bioavailability of its contribution (described in detail in Appendix K). Finally, this report concludes with a brief assessment of effluent total phosphorus reduction efforts by wastewater treatment plants, recommendations for lowering nonpoint sources of phosphorus and reducing load calculation uncertainty as part of future efforts.

1.4 Frame of Reference for Quantifying Phosphorus Source Contributions to Surface Waters

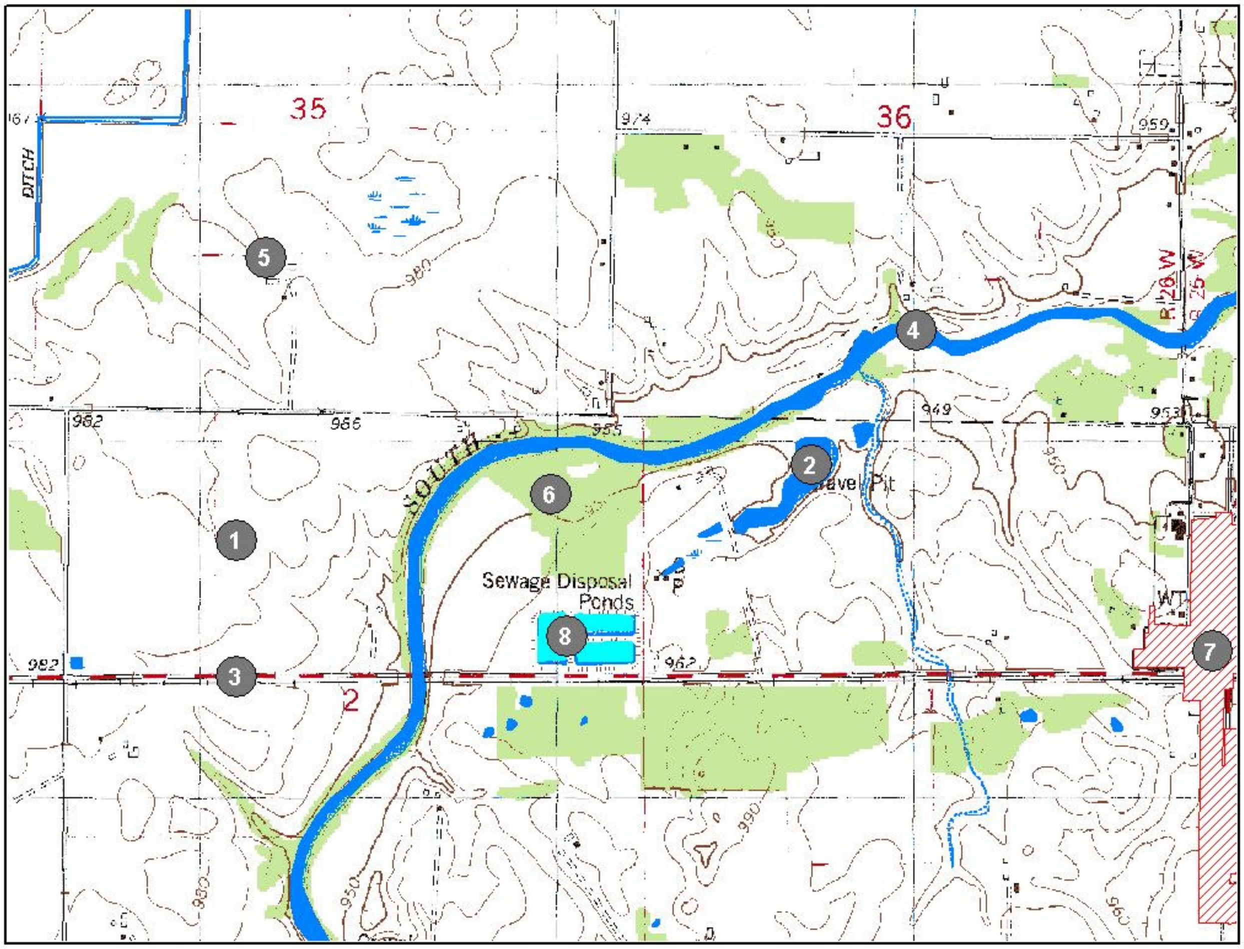
Estimating the phosphorus source contributions to Minnesota surface waters for each of the major basins requires the following information to establish a "frame of reference", or a basis for comparison by source category and by basin:

- A clear definition of surface waters and information about the locations of surface waters throughout Minnesota
- Knowledge about the amount of phosphorus produced and mode of transport for each point and nonpoint source category

Figure 1-1 illustrates an example of where each of the following phosphorus source categories (numbered to coincide with the figure) are typically located in relation to the various types of surface waters considered in this analysis:

1. Cropland, pasture and feedlot runoff
2. Atmospheric deposition
3. Deicing agents
4. Streambank erosion
5. Individual sewage treatment systems (ISTS)/unsewered communities
6. Non-agricultural rural runoff
7. Urban runoff
8. Point sources

Figure 1-1 Schematic for Phosphorus Source Contributions to Surface Waters

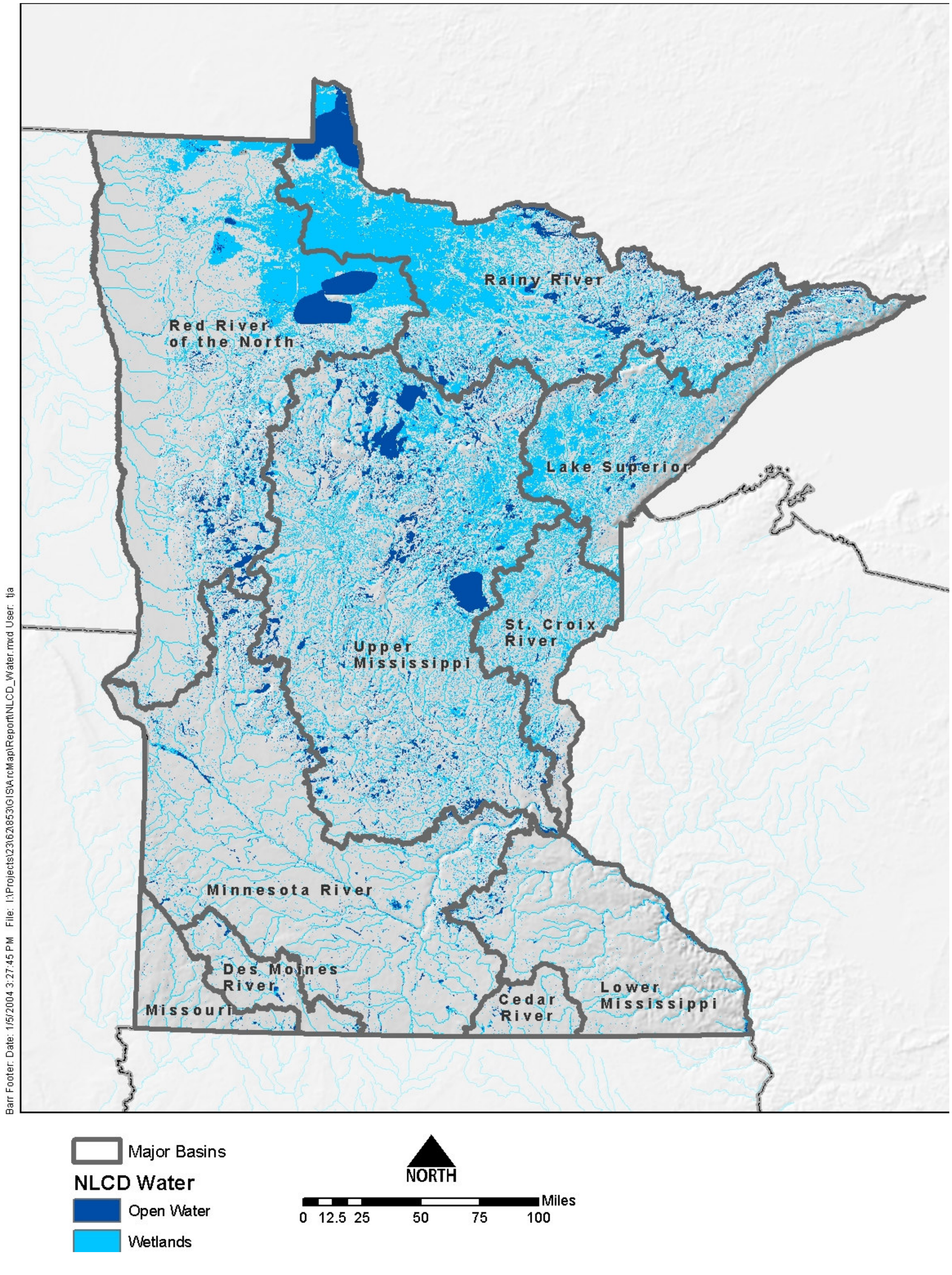


The analysis completed for this assessment consists of estimating the total amounts of phosphorus entering all of the various types of surface waters from each of the source categories within each major basin, as well as on a statewide basis.

1.4.1 Surface Waters Defined

For purposes of this analysis, all of the surface waters in Minnesota were mapped using ESRI ArcGIS software and were defined by using all of the various types of water bodies contained in the Minnesota Department of Natural Resources 24K Stream Layer (all records, including ditches and intermittent streams) and the USGS National Land Cover Database [NLCD] (1992). All land cover types identified as wetlands or lakes in the NLCD database were used as surface waters. As a result, all of the water surface areas shown (in dark blue) on Figure 1-1, including ditches, wetlands, lakes, rivers and intermittent streams, would be considered surface waters for the analysis discussed in this report. Figure 1-2 shows the areas of all of Minnesota's surface waters, within each of the ten major basins.

Figure 1-2 Major basins with surface waters



1.4.2 Context for Quantifying Phosphorus Source Contributions

As previously discussed, this assessment is intended to estimate the annual phosphorus loading (total and bioavailable), entering all of the various types of surface waters from each of the source categories under low, average and high flow conditions. The general nature and scale of this analysis allows for summarizing the estimated loadings for each major basin, and on a statewide basis. The characteristics of smaller watershed units (smaller than the major basin scale), or subwatersheds, were not utilized to estimate phosphorus loadings from the source categories. Since each of the various subwatersheds typically drain to wetlands, lakes, ditches or streams that each have their own unique processes for transformation or phosphorus uptake, no further breakdown of phosphorus inflow or outflow loadings by subwatershed or surface water type is possible with the scope of this analysis. As a result, the phosphorus loadings discussed in this report represent the total amount of phosphorus entering all of the combined surface water areas that are present within each major basin under each flow condition. For example, if urban runoff from the source area (#7) shown in Figure 1-1 is estimated to contribute 10 kg of phosphorus during average flow conditions, this analysis does not attempt to distinguish between how much of the 10 kg is going to the intermittent stream or to the river, nor does this analysis attempt to estimate how much this phosphorus load would be delivered to the mouth of the major basin. It should also be noted that the general nature of the results from this analysis means that minor sources of phosphorus, at the basin scale, may actually contribute the majority of phosphorus to specific surface water bodies, at a localized scale. For example, point sources typically represent contribute little or no phosphorus to Twin City Metropolitan and most outstate lakes, but can represent a significant portion of the total phosphorus load to rivers under low flow conditions. This explains the need to complete individual assessments of specific watersheds to evaluate specific loading conditions.

In addition, the phosphorus loadings estimated for this assessment are only intended to quantify the phosphorus source contributions originating in Minnesota for Minnesota surface waters. For example, no attempt has been made to estimate the phosphorus loadings to the St. Croix River basin, originating from Wisconsin, or the loadings to the Red River basin from North Dakota. While the context for this analysis does not allow for assessments to be made about the observed water quality at the mouth of each major river basin, it does allow for direct “apples to apples” comparison of the amounts of phosphorus originating from various source categories under various flow conditions. This analysis also facilitates comparison between basin, as well as statewide, so that the magnitude and proportional contribution of each source category can be compared throughout the state.

2.0 Methods

2.1 Basin Hydrology

This detailed assessment of phosphorus required an analysis of basin hydrology to properly evaluate the importance of the varying rainfall/runoff relationships for low, average and high flow conditions throughout the state. This section will discuss how these three flow conditions were defined and how rainfall and runoff volumes were determined for this analysis. The determination of flow conditions are especially important since they facilitate computation of nonpoint phosphorus sources and allow for the comparison of point and nonpoint phosphorus sources for the varied climatic conditions that occur across Minnesota. Following statistical analysis of the historical rainfall and runoff volumes, recent (1979-2002) water year (October 1 to September 30) data was identified to represent low, average and high flow conditions within each basin. A more detailed discussion about the approach and methodology for assessment of the basin hydrology is included in Appendix A.

2.1.1 Minnesota Basins

Figure 2-1 shows the ten major Minnesota basins considered in this analysis, along with locations of the USGS flow gaging sites used to estimate runoff during the various flow conditions. The ten major drainage basins within Minnesota vary greatly in their characteristics. Table 2-1 provides a summary of some of the characteristics of each basin. As shown in the table, there is significant variability of runoff and precipitation across the state. There is also a significant difference in land cover between basins, particularly between the southwest and northeast parts of the state.

2.1.2 Calculation of Basin Runoff Volumes

The phosphorus load estimates in this study were determined for low, average and high flow conditions, for each of the ten basins (further discussed in Appendix K). The phosphorus load estimates for each flow condition are based on the annual runoff volumes that have been determined from recent water year flow data. A characteristic of most of the basins is that water is received from upstream basins (such as the Lower Mississippi which receives flow from the Minnesota, St. Croix and Upper Mississippi basins) or water flows into the basin from neighboring states or provinces (Minnesota and Rainy River basins). The Upper Mississippi River is the only basin in the state that is a headwater basin (wholly within Minnesota). Therefore, flow and phosphorus data measured at the "outlet" or mouth of the basin will include both water and phosphorus originating from outside of Minnesota or from other upstream Minnesota basins. For example, 53 percent of the watershed area of the Red River of the North (which is the border between North Dakota and Minnesota), at the

Figure 2-1 Major Basins with USGS Flow Gaging Stations

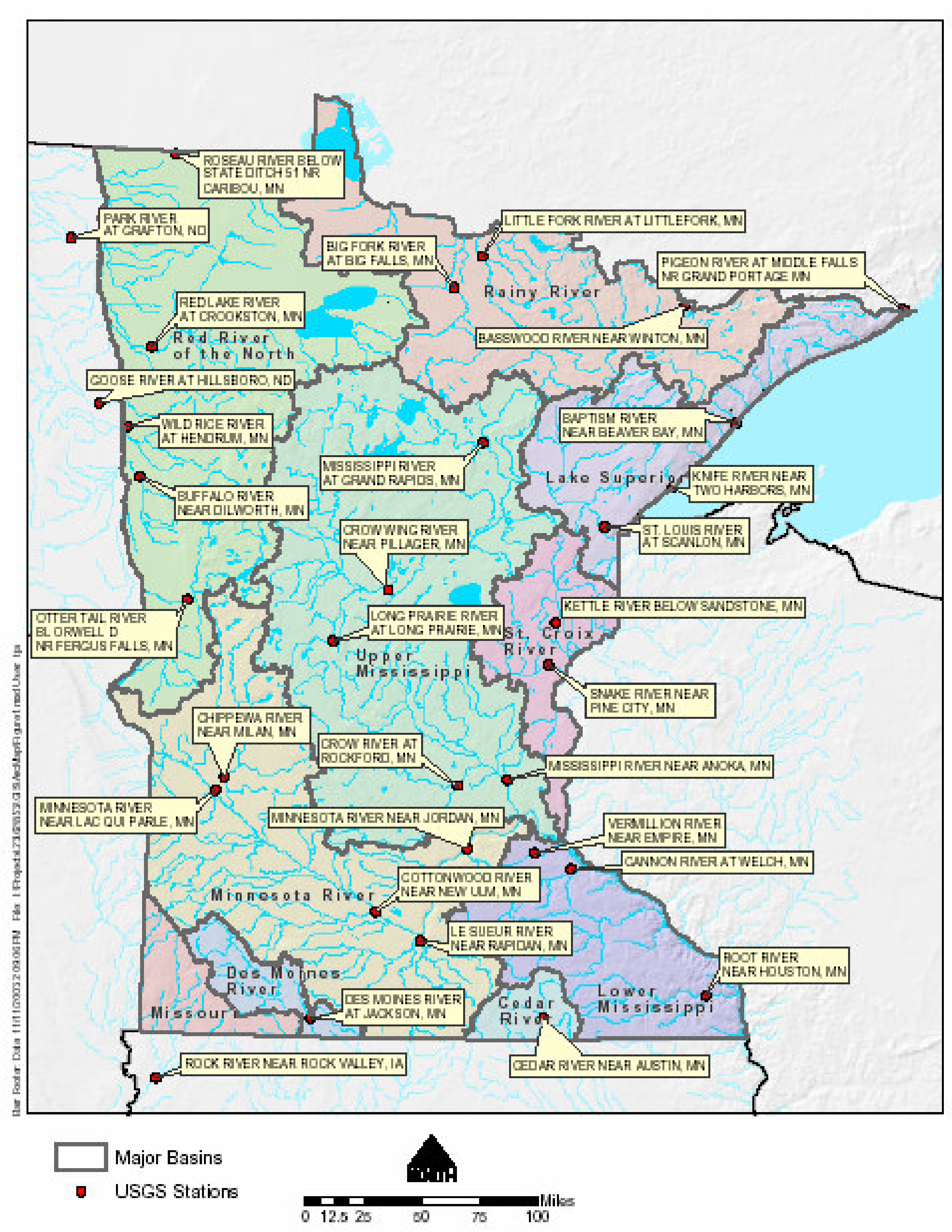


Table 2-1 Basin Characteristics

Basin	Area (Sq Miles)*	Average Precipitation (1979-2002)	Average Runoff (1979-2002)	Land Cover Percentages** Urban	Forested	Tilled Agricultural	Pasture/ Grassland	Wetland/Open Water	Other
Cedar River	1,028	32.06	9.80	3.4%	3.3%	83.4%	6.2%	3.7%	0.0%
Des Moines River	1,535	27.98	5.68	1.8%	1.8%	79.9%	11.0%	5.5%	0.0%
Lake Superior	6,149	29.11	12.44	1.4%	57.1%	2.6%	3.5%	33.3%	2.1%
Lower Mississippi	6,317	33.29	10.28	2.4%	15.4%	52.2%	24.8%	5.1%	0.1%
Minnesota River	14,943	28.14	5.61	2.2%	4.6%	72.7%	12.6%	7.8%	0.1%
Missouri	1,782	27.16	5.25	1.5%	1.0%	78.9%	16.0%	2.6%	0.0%
Rainy River	11,236	26.20	8.01	0.4%	41.4%	2.0%	2.3%	52.5%	1.3%
Red River	17,741	23.29	3.42	0.7%	12.0%	54.6%	8.8%	23.8%	0.2%
St. Croix River	3,528	30.61	9.71	1.3%	36.8%	10.8%	20.6%	30.1%	0.2%
Upper Mississippi	20,100	28.07	6.87	3.5%	29.1%	20.2%	16.7%	29.7%	0.7%
State Wide	**79,202**	**27.39**	**6.83**	**1.9%**	**22.7%**	**38.1%**	**12.0%**	**24.7%**	**0.6%**

*Drainage area within Minnesota
**Based on USGS National Land Cover Database (1992)

Manitoba border, is in the State of North Dakota. Since this study is only concerned with phosphorus contributions from Minnesota, a methodology was developed to estimate only Minnesota's contribution of water. Runoff from the Minnesota portions of the ten basins were calculated using state-wide flow maps for the three flow conditions. Each map, developed using ESRI ArcView software, consists of a state-wide 1 km x km grid of values representing runoff in inches. Using these grids, runoff averages over the basins were determined. The methods used to develop these maps are described below.

2.1.2.1 River Discharge Data

Monthly mean stream flow data were collected from the United States Geologic Survey for 27 gaging stations in Minnesota, two in North Dakota and one in Iowa for a total of 30 gages. The stations were selected based on their length of record and the location of the gage within each of the ten basins. Annual runoff in inches, for each gage was determined by summing the monthly mean flows for each water year (October 1 – September 30) and dividing by the contributing watershed area to arrive at runoff in inches per year. The watershed areas were delineated using the Minnesota Department of Natural Resources Division of Waters Watershed Basin (1995) GIS Layer. This layer was developed using data from USGS 1:24,000 Quadrangle Maps.

2.1.2.2 Precipitation Data

Basin-wide precipitation data were made available from the State Climatology Office of the Minnesota Department of Natural Resources. The data consisted of monthly values calculated from a grid-based archive of historical monthly precipitation totals for the period of 1892 – 2002. These data consisted of estimated monthly total precipitation over each watershed, in inches, for each of the ten basins. Data for the period of 1979 – 2002 water years were used in this study.

2.1.2.3 Runoff Frequency Curves

The result of the basin runoff computations was a table of annual runoff values, in inches over each of the 30 watersheds. These data were used to develop two frequency curves for each of the 30 gages and were based on these following periods of record:

- Using all water years data were available
- Using water years 1979 – 2002

For curve one, the time period of available flow data varied greatly. Some gages had data available for up to 100 years and others only a dozen or so years. The second curve was developed to reflect current climatic and drainage conditions. For the period from 1979 to 2002, a complete record of data was available for most of the gages used. Since this period reflected current watershed drainage characteristics and climatic trends, the 1979-2002 record was used to develop the runoff mapping.

The frequency curves were developed using a statistical analysis of the annual basin flows adopted from *Guidelines for Determining Flood Flow Frequency*, Bulletin #17B, U.S. Water Resources Council, Sept. 1981. The Weibull plotting position method, described in this reference, was implemented to assign an exceedence probability (the probability of the flow being greater than or equal to a value) to every annual flow record in the time series. The probabilities were then plotted on semi-log paper to fit a trend line to the data. Different statistical equations were analyzed to determine which equation best describes the data. The frequency curves were then based on the best-fit equation, typically a Pearson Type III distribution.

From the frequency curves developed for the 1979-2002 water year period, runoff values from the 90 (dry year), 50 (average year) and 10 (wet year) percent probability were determined. The 90 percent value means that, on average, 90 percent of the years will have runoff exceeding this value. The 50 percent value shows the runoff amount that would be exceeded during one-half of the years, on average. The 10 percent value is the flow which would be exceeded during only 10 percent of the years. The 90 and 10 percent probabilities were the respective probabilities selected to represent low and high flow conditions, because they do not represent extreme events; rather they represent typical dry and wet periods for the basins (a 1 in 10 chance of occurring on any given year), respectively.

2.1.2.4 Precipitation Frequency Curves

Frequency curves were also developed for the basin-wide precipitation data. The data were summarized by water year and the same methodology used to develop the flow – frequency curves was utilized for the precipitation data.

2.1.2.5 Runoff Maps

The centroid (or center of the watershed) for each of the 30 USGS gaged watersheds was determined. The resulting X and Y coordinates of the centroid (in UTM Coordinates) were determined and were assigned the runoff values for the watershed. A table was constructed with the UTM coordinates and runoff values. This table was imported into Surfer Software and interpolated using the Kriging routine to create three state-wide 1 kilometer x 1 kilometer grids representing the dry, average and wet condition runoff values. The resulting Surfer grid files were imported into ArcView Spatial Analyst extension and were overlain with the boundaries of the major basins to provide an estimation of the wet, average and dry condition flow volumes based on the 10, 50 and 90 percentile frequencies, respectively.

It is important to note that, in general, the year in which the 10th percentile wet year flow volume occurred does not necessarily coincide with the year in which the 10th percentile wet year precipitation amount was observed. River discharge is not only a function of precipitation, but is affected by a number of hydrologic conditions such as drought and floods occurring in preceding years. For example, if the preceding year was much dryer than normal, much of the current year's rainfall (even though above average) may be used in refilling lake and wetland basins and replenishing soil moisture. The intensity of rainfall is another factor in the generation of runoff. For a given amount of precipitation, more of it will run off if the precipitation occurs during a heavy thunderstorms rather than rain falling during a gentle day-long shower. Therefore, there may be below-normal flow in years where precipitation is above-average. In this study it was assumed that the 10th percentile flow does occur in the same year that the 10th percentile rainfall occurs. The same assumption was made for the 50th and 90th percentile years. This simplifying assumption had to be made to facilitate a direct comparison between the three flow scenarios examined.

2.2 Phosphorus Sources to POTWs and Minnesota Surface Waters

As discussed in Section 1.2, the requirement to study the concept of lowering phosphorus in the wastewater stream and the effect on water quality mandated that this assessment inventory the sources and amounts of phosphorus entering three different sizes and categories of POTWs, along with the sources and amounts of phosphorus entering Minnesota surface waters for each major basin and for the entire state of Minnesota from point- and nonpoint-sources. Section 2.2.1 presents the methodology used to inventory the sources and amounts of phosphorus entering POTWs, by size and category, as well as estimate the amount of phosphorus entering surface waters from point sources. Section 2.2.2 provides the methodology used to assess the sources and amount of phosphorus entering surface waters from nonpoint sources. Section 2.2.3 presents the methodology used to determine the bioavailability of the point and nonpoint sources that have evaluated for this analysis. Section 2.2.4 discusses the methodology used for an assessment of effluent total phosphorus reduction efforts by wastewater treatment plants.

2.2.1 Point Sources of Phosphorus

This section provides a discussion regarding determination of point sources of phosphorus to Minnesota watersheds and the sources of phosphorus discharged to Minnesota publicly owned treatment works (POTWs). A detailed discussion about the assessment of this source category is contained in Appendix B. For the purposes of this analysis, point sources of phosphorus include domestic (public and private) and industrial facilities that discharge treated wastewater to surface water through distinct discharge points and are regulated under state and federal pollution permit programs. Wastewater is generated by a number of sources and falls into two general categories: Domestic/Residential wastewater and Industrial and Commercial wastewater. Wastewater from these two sources is discharged to one of three categories of wastewater treatment facilities (WWTFs); POTWs, privately owned wastewater treatment systems for domestic sources, and industrial wastewater treatment systems. Land disposal of wastewater does not discharge to surface waters and was not considered as part of this analysis.

POTWs include wastewater treatment facilities owned and operated by public entities (cities and sanitary districts usually). These facilities treat varying proportions of domestic wastewater and commercial/industrial wastewater. For the purposes of this study, POTWs have been subdivided into the following additional categories:

1. Size (based on Average Wet Weather Design flow)
    a. Small – less than 0.2 million gallons per day (mgd)
    b. Medium – from 0.2 mgd to 1.0 mgd
    c. Large – greater than 1.0 mgd

2. Waste Treated (% by flow volume treated)
    a. POTWs that serve mainly households and residences - less than 20 % industrial or commercial contributions

b. POTWs that have some commercial or industrial contribution – between 20% and 50% industrial or commercial contributions

c. POTWs that are dominated by a variety of commercial and industrial contributions – greater than 50% industrial or commercial contributions

Privately owned wastewater treatment systems include those designated for treatment of domestic sources and that are privately owned and operated. This category of facility is generally small and serves a limited number of residences. Mobile home parks, resorts, and small communities are examples of privately owned wastewater treatment facilities.

Wastewater generated as a byproduct of an industrial or commercial process can either be discharged to a POTW for treatment or it can be treated (if needed) on site and discharged to a surface water under its own NPDES permit. In most cases, wastewater discharged from an industrial wastewater facility is from an industrial process. This category also includes noncontact cooling water.

2.2.1.1 Data Sources for Wastewater Treatment Facilities

Identification of the point sources of phosphorus and load estimates was accomplished with existing data and literature information. No direct monitoring of waste streams was undertaken for this portion of the study. The following sources of existing data were utilized:

- Minnesota Pollution Control Agency's Delta Database
- MNPRO Database
- Metropolitan Council Environmental Services
- Minnesota Department of Health (MDH)
- Individual contact with Minnesota Communities

The MPCA maintains a database of information required by NPDES permit holders and the monitoring data required by the permit, referred to as the Delta database. Data from the years 2001, 2002 and the first half of 2003 were used in this analysis. The Delta database contained data for more than 1,300 separate permits, many with multiple discharge points called stations, and all available flow and phosphorus data contained therein was used for this study. Since many permits do not include limits and/or monitoring requirements for phosphorus, there was no phosphorus data available for some permits. As a result, it was necessary to extrapolate phosphorus data from other permit information (e.g. permit application data and basin average phosphorus for similar facilities, etc.). Discussions with MPCA staff provided a list of the water sources for most of the noncontact cooling water dischargers in the state. Information on noncontact cooling water additives was also provided by MPCA staff.

The Minnesota Department of Trade and Economic Development maintains a database (MNPRO) that contains information regarding community profiles for each city in Minnesota. The MNPRO database was used to obtain the following information:

1. A complete listing of Minnesota communities
2. Information on the type of wastewater treatment system a community utilizes for wastewater treatment
3. Population of the community
4. A list of businesses and industries in each community, the NAICS code and number of employees for each business.

All population data obtained from the MNPRO database were from 2001 estimates. The other data obtained from the MNPRO database were provided by the communities and there may be some variation regarding the dates this information was reported.

The Metropolitan Council Environmental Services (MCES) owns and operates the eight Twin Cities Metropolitan Area wastewater treatment facilities. The Industrial Waste & Pollution Prevention (IWPP) Section, located within MCES's Environmental Planning and Evaluation Department, regulates and monitors industrial discharges to the sewer system to ensure compliance with local and federal regulations. IWPP Section staff issue Industrial Discharge Permits to industrial users of the Metropolitan Disposal System. For each MCES industrial permit holder, MCES provided the following information:

1. Name and location of permit holder
2. SIC code number for each permit holder (was converted to NAICS code number)
3. Flow and phosphorus estimates (phosphorus data were not available for all permit holders)
4. Employee counts

The Minnesota Department of Health (MDH), the agency that regulates the quality of drinking water supplies in Minnesota, provided a list of communities that supplement their water supply with continuous phosphate additions (for corrosion control and iron and manganese sequestration) from 2001 to 2003. The MDH list provided the water treatment facility's annual flowrate for all 360 of the systems that add phosphorus. In addition, they provided the residual phosphorus concentrations for the 120 systems that are required to add phosphorus for corrosion control. These data were used to calculate the total phosphorus contribution to the POTWs from the municipal water supplies.

A number of Minnesota communities were contacted to obtain data or to verify information regarding their wastewater treatment facilities. The types of information provided by these communities included:

- **Industrial Phosphorus Data.** Fourteen out-state (non-metro) communities with industrial phosphorus monitoring programs were contacted and provided data on influent loadings from industrial and commercial dischargers to their wastewater treatment facilities.
- **Population Data.** Many communities were contacted to determine the population served by the wastewater treatment facility.
- **Industrial Discharge Information.** Many communities and industries were contacted to verify the type and volume of wastewater discharge from an industrial source.

The following literature sources were reviewed to obtain information on the sources and amounts of phosphorus discharged to wastewater treatment facilities:

- **Chemical Economics Handbook – Industrial Phosphates** - The handbook provides detailed information on the mass of phosphorus consumed annually in the United States for major commercial, nonagricultural phosphate chemical products. The report provided historical data for the years 1984 through 2000 and forecasted data for the year 2005 for the following major commercial products:
  - Detergent builders
  - Water supply chemicals
  - Food and beverages
  - Dentifrices (oral hygiene products)
- Metcalf and Eddy, Inc. (1991) discusses the components that make up wastewater as well as typical wastewater flowrates and characteristics.
- A number of studies were conducted in the late-1970s and early-1980s that analyzed residential wastewater. These studies segregated wastewater from toilets (human wastes), garbage disposals, dishwashing water, food soils, baths and showers, laundry discharges, and automatic dishwasher detergent, and provided typical flowrates and pollutant characteristics (including phosphorus) for each of these sources. These studies found the following to contribute phosphorus to residential wastewater:
  - Human wastes
  - Garbage disposals
  - Dishwashing water

- Food soils
- Laundry discharges (completed prior to the ban on phosphorus in laundry detergent)
- And automatic dishwasher detergent

The data were provided in terms of daily per capita use rates. It was assumed that no major changes had occurred in the estimates for human waste, garbage disposal waste, and food soils and these data were used to estimate source amounts discharged to wastewater treatment facilities.

- Ligman, Hutzler and Boyle (1974) characterized the types of wastewater generated in a domestic household. They surveyed a total of 50 rural and urban households to determine the various sources and amounts of wastewater generated from the bathroom, the kitchen and the laundry and determined that there was no statistical difference in wastewater pollutant loads for each household.
- Siegrist, Witt, and Boyle (1976) characterized waste flows from individual rural households. They found that on average human waste contains approximately 1.6 grams of phosphorus per person per day.
- Boyle, Siegrist and Saw (1982) focused on treatment of graywater, but also provided a summary of the characterization of wastewater from households.
- Strauss (2000) provided information on the nutrient concentration in human waste and determined that humans excrete in the order of 2 grams of phosphorus per day.

2.2.1.2 Approach for Determining Phosphorus Discharged to POTWs

In addition to determining the point source loading of phosphorus to surface waters in each basin from each of the three types of treatment facilities (POTWs, privately owned treatment facilities, and industrial wastewater treatment systems), the other objective was to identify the sources and estimate the amount of phosphorus discharged to POTWs. Although not required by the legislation (see Section 1.2), the sources of phosphorus and an estimate of the amount discharged into privately owned treatment works was also completed. Finally, the major types of industrial discharge categories were also identified for the industrial wastewater treatment systems. Phosphorus loading to each type of treatment facility was categorized into the primary sources that were considered important (described below).

The following individual and/or categorical sources of phosphorus were evaluated for each POTW:

- Commercial/industrial process wastewater sources (including noncontact cooling water)
- Finished water supply and water treatment chemicals (such as polyphosphate compounds or orthophosphate compounds used for corrosion control purposes)

- Industrial and institutional automatic dishwasher detergent (ADWD)
- Residential automatic dishwasher detergent
- Dentifrices
- Groundwater intrusion into sanitary sewers
- Food soils and garbage disposal wastes (food soils include waste food and beverages poured down the sink, and food washed down the drain as a result of dish rinsing and washing)
- Ingested Human wastes

The following individual and/or categorical sources of phosphorus were evaluated for each privately owned treatment facility:

- Residential automatic dishwasher detergent
- Food soils and garbage disposal wastes
- Human wastes

It was assumed that these systems were small and that no industries would be discharging to a privately owned treatment facility and that the communities served by these systems would not be on a public water supply. Therefore, the commercial/industrial process wastewater sources, finished water supply and water treatment chemicals sources, industrial and institutional automatic dishwasher detergent and groundwater intrusion into the sanitary sewers sources were assumed not to contribute to these facilities.

Because much of the information gathered during the literature search for the various components of the influent wastewater was based on per capita values, it was necessary to accurately determine the population served for each of the POTWs and privately owned wastewater treatment facilities. The population served for each facility was not readily available for all of the permitted facilities. Therefore, the following stepwise approach was taken:

1. When available, the population served by a treatment facility as listed in the Delta database was used, unless comments from individual wastewater treatment plant operators required a modification to the estimates.
2. If population data were not available from the Delta database, the population of the community corresponding to the permit was assumed to equal the population served by the WWTF, which was obtained from the MNPRO database.
3. Communities and the populations served by individual sewage treatment systems (ISTS, [see Appendix H]) were compared to the communities having an NPDES permit as listed in the

Delta database. If a community had both a NPDES permit to discharge to a surface water and was also listed has being served by an ISTS, the difference of the City's population and the ISTS population was used as the population served by the treatment facility. If no information was available, the permit holder was contacted to verify the population served by each system.

4. The complete listing of communities within the state of Minnesota as contained in the MNPRO database were compared to both the NPDES list and the unsewered communities list to verify that all communities within the state were counted. Any unaccounted community with a population greater than 1,000 was contacted to determine their disposition wastewater treatment.
5. Communities with a population of less than 1,000 persons that did not have an NPDES permit and were not listed in the ISTS or unsewered community databases were assumed to be served by ISTS.

A wide variety of commercial and industrial operations discharge wastewater into POTWs under terms of wastewater discharge permits. Industrial process discharge monitoring data from MCES were collected for the eight MCES facilities. In addition to the MCES data, commercial and industrial process monitoring data were collected from the cities of Luverne, Melrose, Moorhead, St. Cloud, Winona, Faribault, Glencoe, New Ulm, Owatonna, Plainview-Elgin, Rochester, Zumbrota, Mankato and Marshall. In addition to the industrial monitoring data, the NAICS code number and number of employees were also obtained. Using this information, the estimated phosphorus load per employee was calculated for the various NAICS code numbers. This information was used to estimate the industrial/commercial process wastewater component of the POTW phosphorus loads. The quantities of phosphorus discharged to the sewer system by commercial and industrial operations for which data were obtained was estimated by extrapolating discharge data to an annual total. The data obtained for the various NAICS code industries were used to estimate the Industrial and Commercial wastewater components of the POTW phosphorus loads where no data were available. An average phosphorus load per employee was then calculated for each NAICS code number. The MCES industrial information received had employee count available for most of the facilities permitted. In addition, MNPRO listed the employee count for all the industries in their database. Employee count was used as the method of adjusting the phosphorus load for the variation of industry sizes within a NAICS code number (four to six digit matches). If there was no match found at the four-digit level, then no estimate of the phosphorus contribution was made.

Phosphorus-based chemicals are sometimes used for corrosion control and metal sequestration purposes in water supply systems. The Minnesota Department of Health provided a list of community water supplies and the average residual phosphorus concentration in the water supply for the systems that are required to monitor their phosphate additions for the years 2001 through mid-year 2003. The average residual phosphorus concentration from this data was used for each of the communities that were known to add phosphorus, but for which there was no concentration data available. Literature values (Metcalf and Eddy, 1991) indicate that, on average, 70 percent of the water supplied from a water treatment facility is discharged back into a wastewater treatment facility. The phosphorus contribution from municipal water supplies to a POTW was calculated by estimating the annual phosphorus mass used in treatment of the water supply from the MDH data and assuming 70 percent of it is discharged to the POTW.

To estimate the residential ADWD detergent component of the WWTF phosphorus loads, the 2000 data on annual phosphate utilization for ADWD detergent formulation in the United States from the SRI publication Chemical Economics Handbook - Industrial Phosphates (SRI, 2002) was used, along with the estimated U.S. population for 2000, to estimate a per capita ADWD detergent usage of 0.085 kilograms per capita per year (kg/p·yr). This use rate was applied to the population served by each of the POTWs and privately owned treatment facilities to estimate the ADWD detergent components of the phosphorus loads.

Commercial and institutional ADWD detergents are used in restaurants, cafeterias, hotels, hospitals and other institutions, etc. These facilities are not considered as part of the commercial and industrial process wastewater phosphorus contribution as discussed previously. To estimate the commercial and institutional ADWD detergent component of the influent POTW phosphorus loads, 2000 data on annual phosphate utilization for commercial and institutional ADWD detergent formulation from SRI (2002) was used, along with the estimated U.S. population for 2000, to estimate a per capita commercial and institutional ADWD detergent usage of 0.04 kg/p·yr. This per capita use rate was applied to the population served by each of the POTWs to estimate the commercial and industrial ADWD detergent components of the phosphorus loads.

Other consumer products such as scouring cleaners (Comet® and Ajax®) and home cleaners (Spic & Span® and Lime Away®) no longer contain phosphorus. Therefore, it was assumed that there was no phosphorus contribution from these products. Commercial and institutional cleaners may use phosphate-based cleaners, but it was assumed that discharge of this source would be accounted for in the industrial and commercial process wastewater component and was not categorized separately.

Several sources were reviewed to determine the phosphorus loading to WWTFs from garbage disposals and from food soils (Siegrist, 1976 and Boyle et al, 1982). For the purposes of this report, food soils are defined as waste beverages and food washed down the sink and food washed down the sink through dish rinsing and dish washing. The most recent per capita discharge rate of 0.1895 kgP/p·yr was applied to the populations served by each of the WWTFs to determine the phosphorus loading from this source.

Dentifrices are substances such as toothpaste and denture cleaners. Using 2000 data on annual phosphate consumed from dentifrices (from SRI, 2002) and the estimated U.S. population for 2000, the estimated per capita phosphorus contribution from dentifrices was 0.0115 kg/p·yr.

An attempt was made to determine the phosphorus loading from car and truck washes, but there was not enough data available to determine either the amount of flow or the number of car washes discharging to Minnesota POTWs. In addition, since it has become common for car washes to recycle or reuse wash water, no phosphorus load estimate for this source was made in this report.

Measurable effects from inflow and infiltration (I & I) at WWTFs will depend on the age of the sewer system piping, the total length of the sewer system piping and the joint construction of the sewer pipes. An average infiltration rate was obtained from data provided by MCES, based on average annual I & I flow estimates for their eight wastewater treatment facilities. These facilities vary in size and age and were considered to be representative of the systems throughout the state. The average I & I rate was approximately 10 percent of the total influent annually for the eight Twin Cities Metropolitan Area wastewater treatment facilities operated by MCES. The phosphorus concentration in I & I was estimated from phosphorus concentration data provided by the MPCA for each of the aquifers throughout the state. An average phosphorus concentration of 0.035 mg/L was assumed to be representative of the shallow groundwater throughout the state.

Human waste-derived phosphorus was separated from the total phosphorus load to each of the POTWs and privately owned treatment systems by difference, subtracting all other estimated phosphorus contributions from the total phosphorus inflows. This value was converted to a per capita value and then used to validate the computations for each WWTF by comparing it to literature values for blackwater (ingested human waste). Literature values ranged from 1.2 grams of phosphorus per capita per day (g/p·d) (Siegrist, 1978) to 2 g/p·d (Strauss, 2000).

2.2.1.3 Approach for Determining Phosphorus Loading to Surface Waters

Data on all municipal, private and industrial and commercial dischargers were obtained from the MPCA Delta database. As a first step, the stations for each permit were reviewed to verify that a valid discharge to a surface water was occurring for each station in each permit. As a result of this review, the following stations were deleted for this study:

1. Stations that represented land application of wastewater,
2. Stations that strictly represented a stormwater runoff discharge,
3. Permits that had no influent and effluent flow data. It was assumed that if there was no data for either the influent or the effluent stations, that there had been no discharge from that facility.

The NPDES discharges were separated into the following categories as part of the review process:

1. Domestic vs. industrial flow was verified. In a few cases, the Delta database designation was modified. For example, prisons and schools were changed from an industrial source to a domestic source
2. Noncontact cooling water sources were noted, and
3. Mine pit dewatering sources were noted

Next, the influent and effluent flowrates for the NPDES surface water permits and stations were reviewed. If only influent flow data were available from the Delta database, the effluent flow was assumed to be equal to the influent flow. Similarly, if only effluent flowrates were available from Delta, the influent flowrates were assumed to be equal to the effluent flowrates. Pond systems presented a challenge in that they discharge intermittently and, when they do, the flowrate is relatively high. For many pond systems there was no discharge information available because they had not discharged during the period of record. In other instances the average annual effluent flow from a pond system greatly exceeded the annual average influent flow, so the average annual effluent flowrate was assumed to be equal to the measured influent flowrates for pond systems. For industrial wastewater treatment systems, only effluent flow data were required for this analysis. Following flowrate database development all flowrate data were then validated. The average flowrate and standard deviation was calculated for each permit station. Permits with high standard deviations were manually reviewed to spot the general trend in discharge rates and correct obvious errors.

The approach used to determine the phosphorus loading from each of the three types of facilities to the basin is very similar and is described below. Phosphorus loads were determined by multiplying the influent and effluent flowrates by the influent and effluent phosphorus concentrations, respectively. Phosphorus concentration data was obtained from the Delta database. Since many permits do not include limits and/or monitoring requirements for phosphorus, there were no effluent phosphorus data available for these permits. In addition, many facilities that have an effluent phosphorus limit monitor only the effluent phosphorus and do not monitor the influent phosphorus concentrations. In these cases, it was necessary to estimate phosphorus concentrations from other sources. The annual influent and effluent phosphorus loads for each wastewater treatment facility and the effluent phosphorus loads for the industrial sources for which data were available were estimated as the products of the average phosphorus concentrations and flowrates extrapolated over the monitoring period. Missing POTW and privately owned treatment facility phosphorus concentrations were estimated by assuming the calculated basin average phosphorus concentration (as described in the previous paragraph) for similar facility types. In a limited number of cases calls were made to the permittee to verify phosphorus effluent concentrations.

The various types of industries discharging phosphorus from industrial wastewater treatment systems were identified. For each industrial wastewater discharger, their North American Industry Classification System (NAICS) code number was identified. This NAICS code allowed the data to be sorted by industry type. Effluent phosphorus concentrations for industrial wastewater treatment systems that did not have monitoring data were estimated from phosphorus data for industries with like NAICS codes. Noncontact cooling water dischargers were identified through review of the NPDES permit data. When available, the amount of phosphorus in these discharges was calculated from data contained in the Delta database. For each noncontact cooling water discharge, the source of the water was identified as were additions of phosphorus-based corrosion control chemicals. In calculating the phosphorus loads associated with noncontact cooling water, reported data on discharge volumes and phosphorus concentration were used whenever they were available. However, when the phosphorus concentration of noncontact cooling water was not specified in the permit data, the source of the cooling water was determined and any information on phosphorus additives was investigated with the MPCA. If the source of the cooling water was the municipal water supply and no phosphorus was added, it was assumed that the phosphorus concentration discharged was equivalent to the municipal water supply value. If the source of the cooling water was an on-site well, the phosphorus concentration was assumed to be equal to the groundwater phosphorus concentration. Finally, if the source of the cooling water was the same body of water that received the effluent and no phosphorus was added for water treatment, it was assumed that there was no additional phosphorus load to the surface water.

2.2.2 Nonpoint Sources of Phosphorus

This section provides a discussion regarding determination of nonpoint sources of phosphorus to Minnesota watersheds. For the purposes of this analysis, nonpoint sources of phosphorus include diffuse runoff associated with rainfall and snowmelt events as well as atmospheric fallout and discharge from distinct discharge points that are not individually regulated under state and federal pollution permit programs. Detailed discussions about the assessment of these source categories are contained in Appendices C through J.

2.2.2.1 Agricultural Runoff

Runoff from agricultural lands contributes phosphorus to surface waters primarily through rainfall and snowmelt runoff from pasture and cropland, as well as direct runoff from open feedlots. The complex nature of the source and transport factors that determine how much phosphorus might be associated with runoff from agricultural lands required that separate approaches be used to estimate phosphorus loadings to surface waters from cropland and pasture runoff, which is described in Section 2.2.2.1.1, and direct runoff from open feedlots, discussed in Section 2.2.2.1.2. Each section provides a general discussion about how the phosphorus contribution to surface waters from each source of agricultural runoff was quantified. More detailed discussions about the methodology used for each analysis is included in Appendices C and D.

2.2.2.1.1 Cropland and Pasture

A combination of transport and source factors directly influence phosphorus (P) movement from cropland and pasture to surface waters (Sharpley et al., 1993). The USDA developed a P Index that integrates both transport and source factors to identify areas vulnerable to P export (Lemunyon and Gilbert, 1993). Transport factors include the mechanisms by which P is delivered to surface waters, such as erosion and runoff. Source factors represent the amount of P available for transport, including soil test P and P applied (rate and method) in fertilizer and organic forms. The objectives of this analysis were to assess phosphorus loadings to Minnesota's ten major drainage basins from agricultural runoff and erosion, under various flow conditions, and evaluate the uncertainty of this assessment. This section discusses how the phosphorus contribution to surface waters from cropland and pasture runoff was quantified. A more detailed discussion about the methodology used for this analysis is included in Appendix C.

This analysis was accomplished by using and extending a regional phosphorus index approach published by Birr and Mulla (2001). Phosphorus index values were estimated for Minnesota watersheds and agroecoregions based on phosphorus transport and source factors such as erosion during dry, average and wet years, streamflow during dry, average and wet years, contributing distance from surface waterbodies during dry, average and wet years, soil test phosphorus, and rate and method of land applied phosphorus from fertilizer and manure. Phosphorus index values were compared with field data on phosphorus loss from four sites over five years to estimate phosphorus export conditions. Phosphorus export coefficients were multiplied by the cropland contributing area within 100 m of surface water bodies to obtain phosphorus loadings from the edge of this contributing area. It should be noted that throughout most of Minnesota, we believe that the risks of phosphorus transport to surface waters are greatest in the contributing corridor within about 100 m from surface waterbodies. Due to topographic variations along surface waterbodies, in some areas phosphorus contributions from overland runoff and erosion may occur from as far away as several hundreds of meters. In contrast, where berms are present along waterbodies it may be unlikely for a significant amount of surface runoff or erosion to enter surface water. Thus, the 100 m contributing corridor should be viewed as a regional average for contributions of P to surface waters from runoff and erosion on adjacent cropland.

Several alternative agricultural management scenarios were investigated and compared to a baseline scenario involving an average climatic year and existing rates of adoption of conservation tillage and existing rates of phosphorus fertilizer applications. The first alternative management was a scenario in which moldboard plowing is used on all row cropland. This is a worst case scenario for erosion, and exemplifies phosphorus losses typical of an era that existed twenty or more years ago. This scenario allows us to evaluate the extent of progress in controlling phosphorus losses over the last twenty years due to improvements in tillage management. The last scenario involves decreasing or increasing the area of cropland within 100 m of surface waterbodies. Decreases in area of cropland could correspond to land retirement programs such as those promoted in the Conservation Reserve and Conservation Reserve Enhancement Programs. Increases in cropland area would correspond to putting grass or forest riparian areas into production, alternatively this could be viewed as increasing the distance for cropland areas (now assumed to be 100 m) that contribute phosphorus to surface waters.

The following sections provide an overview of the modified phosphorus index, developed at the regional scale by Birr and Mulla (2001), and an approach for revising and utilizing the modified phosphorus index to estimate phosphorus loadings from agricultural sources to each of the ten major drainage basins in Minnesota during low, high and average flow conditions.

Birr and Mulla (2001) developed a modified version of the P Index, originally developed jointly by the USDA (ARS, CSREES, and NRCS), to prioritize phosphorus loss vulnerability at the regional scale from 60 watersheds located within Minnesota. This modified (regional) version of the P Index uses readily available data associated with the transport and sources of P. Transport factors include the mechanisms by which P is delivered to surface waters, such as erosion and runoff. Source factors represent the amount of P available for transport, including soil test P and P applied (rate and method) in fertilizer and organic forms. The following discussion describes how each of the transport and source factors were initially determined by Birr and Mulla (2001):

- Soil erosion potential was calculated using the Universal Soil Loss Equation (USLE) as outlined by Wischmeier and Smith (1978). The Minnesota state soil geographic database (STATSGO) was used to supply many of the variables needed to calculate erosion potentials for each of the watersheds (USDA, 1991). Erosion potential was calculated for each soil type within a STATSGO map unit. Rainfall runoff factors (R) for each county were based on values provided by Wischmeier and Smith (1978). The STATSGO database provided a soil erodibility factor (K) for each soil type within a STATSGO map unit. The slope-steepness factor (S) represents an average of the high and low slope values given for each soil type within a STATSGO map unit. The slope-length factor (L) was assumed to be 46 m. A 1:250,000 scale landuse/landcover coverage developed by the USGS in the late 1970s and early 1980s was used to determine erosion potentials spatially coincident with cropland and pastureland (USEPA, 1994). An erosion potential value for all cropland and pastureland within a watershed was determined using the percent of each STATSGO map unit covering a watershed. The landuse coverage did not differentiate spatially between cropland and pastureland; however, Census of Agriculture data indicate that pastureland represents about 11% of this classification category in Minnesota (National Agricultural Statistics Service, 1999). Differences in potential erosion for the two land uses were accounted for in the determination of the C factor based on the proportion of hay reported for a particular county. Cropping management factors (C) were adapted from values provided by the USDA (1975) and Wischmeier and Smith (1978) for corn, wheat, soybean, hay, sugar beet, potato, oat, and barley. The C factors were calculated for each county based on the area of each harvested crop covering the county. Watershed values for the C factors were weighted based on the proportion of the watershed that was covered by the county. The C factor calculations include crop rotation effects but not the variation in tillage effects. The conservation practice factor (P) was assumed to be 1, because it could not be accurately quantified at the regional scale. The overall erosion potential value for each watershed represents the product of the area-weighted C factor and the variables R, K, and LS for each watershed (A = RKLSCP).

- Average annual runoff values for each watershed were derived from the average annual discharge monitored from 1951 to 1985 for 327 stations distributed throughout Minnesota (Lorenz et al., 1997).

- The area of cropland and pastureland within 91.4 m of drainage ditches and perennial streams (the primary contributing corridor) was determined using hydrography coverages developed by the Minnesota Department of Transportation (1999) and the USGS (1999). The USGS landuse/landcover coverage (USEPA, 1994) was used to determine the percentage of cropland and pastureland within the 91.4 m proximity to watercourses for each watershed.

- Mean soil test P levels for each county represented a 5-yr database consisting of 22,421 Bray-1 extractable P (Brown, 1998) samples analyzed by the University of Minnesota's soil testing laboratory. Soil test P levels for each watershed were based on the area of the watershed covered by each county.

- Data for P-fertilizer sales by county were obtained from the Minnesota Department of Agriculture (1997). Fertilizer P values for watersheds were based on a summation of area-weighted county-based values intersecting the watersheds. The total area of fertilized land within each watershed was determined using the same procedure based on reported county values (National Agricultural Statistics Service, 1999). The aggregated fertilizer P value was divided by the aggregated reported fertilized land for each watershed to determine fertilizer P application rates.

- The P content of livestock manure was calculated based on the total number of cattle, swine, broilers, and turkeys reported within each county (Midwest Planning Service, 1985; Schmitt, 1999; National Agricultural Statistics Service, 1999). The total amount of manure P was derived for each watershed based on the summation of area-weighted county values intersecting the watersheds. The reported total cropland area was also determined using the same procedure (National Agricultural Statistics Service, 1999). The aggregated total P content of manure was normalized by the aggregated total cropland area for each watershed to determine organic P application rates.

- For the modified P Index, each site characteristic is assigned a weighting factor based upon the premise that site characteristics have a varying impact on P loss to runoff. Each site characteristic has an associated P loss rating value (very low, low, medium, high, and very high) using a base of 2 to reflect the higher potential for P loss associated with higher rating values. The P Index rating is the summation of the product of the rating value and corresponding weighting value for each site characteristic. Because P application method could not be accurately depicted at the regional scale, the highest organic and fertilizer P application method rating values were used to represent a worst-case scenario. Categories corresponding to the rating values were derived by segregating the distribution of statewide values for each site characteristic into five classes using the quantile classification method available in ArcView software (ESRI, 2000).

This section provides an approach for revising and utilizing the modified (regional) phosphorus index (from Birr and Mulla, 2001) to estimate phosphorus loadings from agricultural sources to each of the ten major drainage basins in Minnesota during low, high and average flow conditions. The following adjustments to the modified phosphorus index computations and supplementary tasks were used to improve and update the analysis of phosphorus loading:

- The MPCA has developed and updated a feedlot inventory and manure management database (with an associated GIS coverage), based on registered feedlot data obtained from each of the counties. The total amount of manure P was derived for each agroecoregion and watershed based on the summation of area-weighted township values intersecting the agroecoregions or watersheds. The aggregated total P content of manure can then be normalized by the aggregated total cropland area for each agroecoregion or watershed to determine and revise the organic P application rates.

- Phosphorus fertilizer sales data by county for the most current crop year (2002) were obtained from the Minnesota Department of Agriculture and used to update this part of the modified phosphorus index computations based on a summation of area-weighted county-based values intersecting the agroecoregions or watersheds.

- GIS coverages for runoff volumes in each agroecoregion or watershed under average, high and low flow conditions were developed to evaluate how phosphorus export from agricultural lands would be expected to change with varying climate conditions. Runoff volumes were estimated as described in Sections 2.1 and presented in Section 3.1. In addition, rainfall runoff erosivity (R values) was estimated for the USLE for dry, average and wet years corresponding to the low, average and high flow conditions. These estimates were based on an algorithm developed for monthly precipitation data by Renard and Freimund (1994). The modified phosphorus index values and total phosphorus export were then computed for each of the agroecoregions or watersheds under high and low flow conditions, using the corresponding values for runoff volume and rainfall runoff erosivity.

- Based on farm survey data collected by the Minnesota Department of Agriculture, phosphorus application methods are generally much better than those assumed by Birr and

Mulla (2001). A majority of farmers apply their phosphorus fertilizer with the planter or using incorporation before crop planting. In view of this, a statewide medium loss potential was applied for method of fertilizer P application method, corresponding to fertilizer applied before the crop and incorporated immediately. An initial scenario involving a medium loss potential for the method of manure application was developed for the entire state. Subsequently, a second scenario was developed assuming variability in the loss potential associated with method of manure application. Manure P application methods vary primarily in response to the type of animal species. Manure from beef, dairy, and poultry is high in solids, while manure from hogs is high in liquid. Beef operations tend to be small in scope, have a tendency towards inadequate manure storage facilities, and manure from these operations tends to be hauled on a daily basis. Beef operations also tend to involve cattle wading in streams. Dairy operations tend to have adequate manure storage facilities, and manure is applied followed by a tillage operation to incorporate manure. Poultry operations tend to have adequate manure storage facilities, and the manure is incorporated using tillage following land application. Hog operations tend to have adequate storage facilities, and the manure is land applied using injection. In terms of the phosphorus index, this means that beef operations tend to have a very high phosphorus loss potential, dairy and poultry operations tend to have a medium loss potential, while hog operations tend to have a low loss potential. The geographic variability in phosphorus loss potential associated with these variations in method of manure application was evaluated using the number of animal units of different species from the MPCA feedlot inventory database. The effect of this variability and/or uncertainty in method of manure application was estimated using the modified phosphorus index.

- Birr and Mulla (2001) states that spatial trends in soil erosion potential observed throughout Minnesota are potentially influenced by both the underlying assumptions used in the methodology and the exclusion of factors that control soil erosion. A lack of detailed information pertaining to the spatial variation in C and P factors may have caused the spatial distribution of erosion potential values to vary more gradually across the region than is realistic. The spatial variation in the C factor of the USLE was estimated by accounting for the effects of crop rotations, the effects of conservation tillage on crop residue levels, and the effects of existing acreage of land in Conservation Reserve Program (CRP). Typically the C factor for land in CRP is 0.001 or so, while row cropland has a C factor varying from 0.05 to 0.4 depending on the rotation and the amount of crop residue present. Three scenarios were evaluated to account for the influence of tillage methods on crop residue levels remaining after planting. These were a scenario involving conventional tillage with no residue left (worst C scenario), and a scenario involving conservation tillage leaving more than 50% of the soil covered by crop residue (best C scenario). This is not typical of existing crop rotations or tillage management systems in Minnesota, nor is it a goal of existing watershed restoration or conservation programs to achieve this high level of crop residue cover. Also estimated was a scenario for average crop residue cover (average C scenario) based on county tillage transect data for the percent of fields with conservation tillage (30% residue cover). In the average C scenario, we developed a weighted C factor based on the relative area of cropland in conservation tillage versus moldboard plowing. Data for the C factors of various crop rotations with varying levels of crop residue were estimated using tables provided by the USDA-NRCS. Thus, using information on crop rotations, crop residue levels, and acreage of land in CRP, we developed scenarios for both soil erosion by water and the modified phosphorus index involving the C factor of the USLE. Variability in the P factor of the USLE was estimated using the Local Government Annual Reporting System (LARS) database of conservation practices provided by the Board on Soil and Water Resources (BWSR). This database was edited to estimate the area of supporting conservation practices affecting the P factor implemented from 1997-present in Minnesota counties. These practices include terracing, contour strip cropping, filter strips, sediment basins, and restored wetlands. Each practice was assigned a typical P factor. Since supporting conservation practices have typically been implemented for the last 50 years, we assumed that the area where these practices were implemented was 10 times greater than the area determined using the LARS database. A county average P factor was then determined using the area weighted P factors for land with supporting practices and the land without supporting practices (P=1). The variability and/or uncertainty associated with conservation practices, such as conservation tillage, contour stripcropping, terracing, and other supporting practices was then estimated for agroecoregions and watersheds using the modified phosphorus index.

Two different approaches were tested for converting phosphorus index values to edge of field phosphorus losses to surface waters. The first method attempted to estimate phosphorus losses from the edge of field based on monitoring data for phosphorus loads in 53 Minnesota streams and rivers. This method did not successfully produce meaningful results. The second method estimated phosphorus losses from the edge of cropland fields based on export coefficients which were derived from the phosphorus index values. This is the method used for final estimates of basin wide phosphorus loadings to surface waters from the edge of cropland fields. The following discussion provides details about each methodology:

- Existing data for phosphorus loads measured by watershed water quality monitoring was summarized for 53 ditches, streams and rivers throughout Minnesota. The data was separated according to flow conditions into phosphorus loads for dry, average and wet years. Estimates for phosphorus losses discharged to surface waters in the same watersheds from non-agricultural rural, streambank erosion, and point sources of phosphorus were also obtained. The monitored phosphorus loads were adjusted by subtracting the losses from non-agricultural rural and point sources of phosphorus, and by subtracting half of the phosphorus losses from streambank erosion. Only half of the streambank erosion losses were subtracted because much of the sediment from streambank erosion is transported as bedload, which is not measured in most water quality monitoring studies. The remaining phosphorus loadings were then divided by the area of cropland within 91 m of streams and ditches to provide an estimate of the potential phosphorus losses from the edge of cropland fields. The resulting adjusted phosphorus yields were not very consistent with expected results, and were not deemed meaningful. Many of the adjusted phosphorus yields were negative in dry years because the point source loadings were larger than the monitored phosphorus loadings in the watershed. This could be due to phosphorus uptake by algae or plants. In wet years the adjusted phosphorus yields exhibited a huge range, from nearly zero to several hundreds of kg P/ha. This was most likely the result of several factors. The first factor is that the phosphorus monitoring load data were collected using a variety of methods, ranging from grab samples to automated water quality sampling. The second is that the monitored loads were collected over different lengths of time, ranging from a single season to multiple years. The third factor is that the adjusted phosphorus losses were not corrected to account for contributions of phosphorus from ISTS, atmospheric deposition, or urban runoff. This led to unrealistically high adjusted phosphorus loads during average and wet years. The fourth factor is that the phosphorus delivery ratio from each non-agricultural source should be varied by source and by flow regime when adjusting the monitored loads. For example, the delivery ratio for streambank erosion (assumed to be 0.5) would vary with flow regime. As a result, this approach for estimating edge of field phosphorus losses from agricultural sources was not used.

- Birr et al. (2002) found that there is a strong linear correlation (r^2 =0.82) between a version of the modified phosphorus index values (from Birr and Mulla, 2001) and the pathway (or field scale) phosphorus index values. The modified phosphorus index values are typically thirteen times higher than the pathway phosphorus index values. Similarly, there is a strong linear correlation between the estimated pathway phosphorus index values and the observed phosphorus export (expressed in kg/ha/yr) at the field scale. The pathway phosphorus index values are typically five times higher than the total phosphorus export, at the field scale (Mulla, 2003). This suggests that we can estimate phosphorus losses from the edge of cropland fields by dividing the phosphorus index results by a factor of approximately 65. This gives an estimate of the losses of total phosphorus to surface waters from cropland and pastureland in units of kg/ha/yr, which represents the phosphorus export coefficient for agricultural land. Since the version of the modified phosphorus index used in this study is slightly different from the one used by Birr et al. (2002), we decided to develop a relationship between the phosphorus index and the phosphorus export coefficient using phosphorus loss data compiled from University of Minnesota research at four sites in or near Minnesota. The sites are located near Morris, Minnesota (Ginting et al., 1998), Lancaster, Wisconsin (Munyankusi, 1999), and two sites in Scott County, Minnesota (Hansen et al., 2001). These sites involved measurements of total phosphorus losses from the edge of agricultural fields (typically a corn and soybean rotation) ranging in area from 0.5 to 1.6 ha. Data from these sites were collected between 1996 and 2000. Two of these years experienced average climatic conditions, two were a little wetter than average, and one was a little drier than average. Fields were treated using a range of tillage and manure management methods. The tillage treatments included moldboard plowing, chisel plowing, ridge tillage, and no-tillage. Manure treatments included no manure, heavy rates of manure, and variations in timing of manure application. Total phosphorus losses from the fourteen individual treatments at these four sites ranged from 0.1 to 2.3 kg/ha/yr, with an average of 0.68 kg/ha/yr in total phosphorus loss from the edge of field. The counties where these four research sites are located have a range of tillage practices, with the percent of farmland having at least 30% crop residue cover ranging from about 47% in Scott and Stevens counties to about 64% of cropland with at least 30% residue cover in Houston county, the nearest county in Minnesota to Lancaster, Wisconsin. The phosphorus index values for an average climatic year and the existing residue cover adoption rates indicated above are 24, 32, and 43 in the Chippewa, Root and Lower Minnesota watersheds, respectively. If we take the P Index values for each watershed and divide them by the average phosphorus losses for the study sites in that watershed, the resulting conversion factor (or divisor) is 78. If on the other hand, we take the average phosphorus index value for these three regions of 33 and divide this by the average phosphorus loss from the edge of field in these experiments at four sites (0.68 kg/ha), we obtain 48.5 as the conversion factor between the phosphorus index and the phosphorus losses from the edge of field. This conversion factor is somewhat lower than both the conversion factor of 65 initially obtained using the relationship between the matrix and pathway versions of the phosphorus index, and the conversion factor of 78 obtained by averaging the divisors obtained for each watershed. Taking the divisor of 48.5 as the most realistic estimate for the conversion factor, and rounding this conversion factor up to 50 for significant digits, we then divided all the phosphorus index values for each watershed and agroecoregion in Minnesota by 50 to obtain phosphorus export coefficients. The resulting phosphorus export coefficients for an average year are 0.43 kg/ha/yr for major watersheds and 0.44 kg/ha/yr for agroecoregions. For wet years the export coefficients are 0.65 kg/ha/yr for watersheds and 0.68 kg/ha/yr for agroecoregions. For dry years the export coefficients are 0.21 kg/ha/yr for watersheds and 0.22 kg/ha/yr for agroecoregions. According to Heiskary and Wilson (1994), recommended phosphorus export coefficients for Minnesota agricultural lands are 0.2, 0.4, or 0.6 kg/ha/yr for low, mid, and high export risk conditions. Hence, our statewide average export coefficients for low, mid, and high export risk conditions (0.21, 0.43, and 0.65 kg/ha/yr) compare favorably with those recommended by Heiskary and Wilson (1994).

The procedure for estimating basin wide loads of phosphorus exported from the edge of agricultural fields is to multiply the export coefficients described above by the area of cropland within a distance of 100 m of surface water bodies (perennial and intermittent streams, ditches, wetlands, and lakes). On average, about 32% of all cropland lies within this distance of surface water bodies statewide, with a range of from 21 to 52% in major river basins. This procedure accounts for the variability in risk of phosphorus loss from the edge of field due to climatic effects as well as the variability in soil, management and hydrologic factors. Variability in the phosphorus index values across the state are translated into variability in phosphorus losses from the edge of field using the export coefficient. On top of this, we added another 10% to the phosphorus loadings to account for contributions from cropland farther than 100 m from surface waterbodies. This is consistent with results from research conducted by Sharpley et al. (1994), Daniel et al. (1994) and Gburek et al. (2000), who concluded (in SERA-17, 2004) that only 10% of the phosphorus loadings to surface waters from overland transport on agricultural lands arise from outside the primary contributing corridor (100 m or farther from surface water bodies). The added 10% does not include additional phosphorus contributions that arise from surface tile inlets or subsurface tile drains. As previously discussed, we believe that the risks of phosphorus transport to surface waters are greatest in the contributing corridor within about 100 m from surface waterbodies. Due to topographic variations along surface waterbodies, in some areas phosphorus contributions from overland runoff and erosion may occur from as far away as several hundreds of meters. In contrast, where berms are present along waterbodies it may be unlikely for a significant amount of surface runoff or erosion to enter surface water. Thus, the 100 m contributing corridor should be viewed as a regional average for contributions of P to surface waters from runoff and erosion on adjacent cropland.

As mentioned above, the current methods of estimation do not consider the influence that surface tile intakes farther than 100 m may have on phosphorus loadings. To include the effects of surface tile intakes we would need to know the number of tile intakes per unit area, the area of cropland contributing to tile intake flow, and the phosphorus export coefficients for surface tile intakes. These data are not available for Minnesota in enough detail to be confident about their representativeness. Since depressional areas around tile inlets generally trap 60-80% of the sediment and phosphorus flowing to the inlets, the phosphorus export coefficient for surface tile intakes is smaller than that for direct overland flow to surface waters (Ginting et al., 2000). Ginting et al. (2000) studied phosphorus loads carried by surface tile intakes in two small catchments located in the Watonwan watershed of the Minnesota River basin. They found that, over a three year period with slightly below precipitation amounts, phosphorus loads carried by surface tile intakes averaged 0.099 kg/ha annually, with measured concentrations of phosphorus in surface tile intakes as high as 4 mg/L. This loading (0.099 kg/ha) is significantly smaller than the amounts of phosphorus transported by surface runoff and erosion in the same region (0.68 kg/ha). There were three surface tile intakes studied by Ginting et al. (2000), and the average phosphorus load transported by each tile intake annually was 2.82 kg/yr. Surveys of surface tile intake density in 32 small watersheds within the Minnesota River basin (MPCA, 1994) show that there is one surface tile intake for every 23 to 1210 acres in the watershed. The average is one surface tile intake for every 100 or so watershed acres (the acreage that actually contributes to surface tile intake P loads is smaller than this, but few data exist to know what the contributing acreage actually is). If we assume that there is one surface tile intake for every 100 acres within the poorly drained soils of the Minnesota River basin, we estimate that there are roughly 33,333 surface tile intakes in the basin. Assuming a phosphorus load of 2.8 kg/yr for each tile intake, the total phosphorus loading from surface tile intakes to surface water bodies in the Minnesota River basin would result in 94,000 kg per year. This is approximately 18% of the phosphorus loading from cropland within 100 m of surface waters in the Minnesota River basin during an average year (517,862 kg/yr).

Similarly, the current methods do not consider the influence of subsurface tile drainage on phosphorus export to surface waters. Randall et al. (2000) studied losses of phosphorus in subsurface drainage in a four year manure and fertilizer study on a Webster clay loam typical of the poorly drained soils in the Minnesota River basin. According to Randall et al. (2000), on average over half of the drainage flows carry non-detectable amounts of phosphorus. The remainder of drainage flows have a concentration of total phosphorus averaging about 0.03 mg/L (with maximum observed concentrations of about 0.12 mg/L), for an average annual loss of 0.027 kg P/ha. If this rate is applied to the area of cropland in the Minnesota River basin having tile drainage, it gives a phosphorus loading of about 30,000 kg/yr, which is quite small (6% of total) compared to the phosphorus loading from cropland within 100 m of surface waters during an average year (517,862 kg/yr). Subsurface drainage phosphorus loads from other major basins would be much smaller, because tile drainage is of limited extent in basins other than the Minnesota River basin. The plains of the Cedar, Lower Mississippi and the southern watersheds in the Upper Mississippi River basins have similar geomorphology, precipitation and land uses that would also control drainage practices, but no attempt was made to quantify the phosphorus loads from subsurface drainage in these basins as part of this analysis. The phosphorus loadings from subsurface tile drains collected by Randall et al. (2000) are the only data published in peer reviewed journals from Minnesota studies. Other studies of phosphorus losses in Minnesota subsurface tile drainage include those conducted by Alexander and Magdalene (1998) from 1995 to 1997 at the Rollings East Tile (RET) site, and by the Minnesota Department of Agriculture from 1998 to 2001 at the Red Top farm, both of which are located in the Minnesota River basin. The study by Alexander and Magdalene (1998) does not estimate phosphorus loadings from subsurface tile drainage, instead, it reports only the concentrations of phosphorus measured. The concentrations of phosphorus measured in subsurface tile drainage by Alexander and Magdalene (1998) are very comparable in seven out of ten storms they monitored to the concentrations measured by Randall et al. (2000) over a four year period. In two other storms monitored by Alexander and Magdalene (1998), the phosphorus concentrations ranged between 0.42 and 1.5 mg/L, much higher than those measured by Randall et al. (2000). At the Red Top farm study, based on 9 field years of water quality monitoring data for average climatic years, the annual average phosphorus loading from subsurface tile drains was 0.11 kg/ha. These larger field drainage systems were constructed of concrete tiles which differ from the smaller plot based plastic drain tiles studied by Randall et al. (2000). Based on this comparison, we conclude that more research is needed to accurately define the mean and range in phosphorus loading from subsurface drainage tiles in the Minnesota River basin. Not enough research data are available to reliably estimate the phosphorus loadings from surface tile intakes or subsurface tile drains to surface waters in the Minnesota River basin during dry or wet climatic years. As a first approximation, we can scale the phosphorus loadings from tile drains so that they have the same relative ratio as the phosphorus index based loadings for the Minnesota River basin in dry, average and wet years (262,851; 517,862; and 759,749 kg/yr, respectively). This gives phosphorus loadings from subsurface tile drains of 15,227 kg/yr during dry years and 44,013 kg/yr during wet years. Using the same approach, phosphorus loadings from surface tile inlets during dry and wet years would be 47,711 and 137,906 kg/yr, respectively. As previously discussed, this approach substantially overestimates the phosphorus loadings in dry years.

2.2.2.1.2 Feedlot Runoff

The primary way that feedlots contribute phosphorus to surface waters, apart from land application of manure, is through open lot runoff during precipitation and snowmelt events. Overall, a small fraction of the total manure phosphorus generated at feedlots enters waters during precipitation and snowmelt events. Many feedlots do not have an open lot because they keep animals inside the barn most or all of the time, while many of those with outdoor open lots collect runoff in impoundments or treat the runoff as it passes through downslope vegetation. Yet many feedlots still maintain open lots. This section discusses how the phosphorus contribution to surface waters from feedlot runoff was quantified. A more detailed discussion about the methodology used for this analysis is included in Appendix D.

Most of this manure phosphorus (P) generated will be applied to cropland. However, a fraction of the manure P can be lost in feedlot runoff during precipitation or snowmelt events. Most feedlots with open lot runoff are from smaller beef, dairy and swine feedlots, with much fewer instances of non-compliance observed for moderate and large sized feedlots (Mulla et al., 2001). Phosphorus runoff loading from open lot feedlots can be estimated with a feedlot evaluation model developed in Minnesota (Young et al., 1982). The (FLEval) model was developed to estimate pollutant loadings at the feedlot edge and to account for any contaminant retention/treatment that occurs in downslope vegetation and cropland. The Board of Water and Soil Resources developed an equation to estimate annual loadings and annual runoff from the FLEval model predictions. The model predicted that between 0.1 and 1.1 percent of phosphorus generated at feedlots with inadequate runoff controls will enter surface waters.

The following discussion summarizes the steps taken to develop estimates of P loading to surface waters from open lot runoff:

- **Step 1.** Determine the number of beef, dairy and swine animal units found at all feedlots with open lots (excluding feedlots with 1000 or more animal units).

  Step 2. Multiply the results in step 1 by the annual manure P generated by each type of livestock. This provides P generated by livestock in all open lots.

  Step 3. Multiply the results in step 2 by the estimated percentage of open lot feedlots that contribute phosphorus during certain storm events. This provides P generated by livestock at feedlots that contribute P to waters.

Step 4. Multiply the results in step 3 by the typical fraction of P that is lost to surface waters during low, average and high flow years. This provides the estimated P loading to surface waters from open lots.

A more detailed discussion of the results of each of the above steps is included in Appendix D. The results of each of the calculations for the 4 steps is shown and discussed in Section 3.3.2.2.

2.2.2.2 Atmospheric Deposition

Phosphorus in the atmosphere can be derived from a number of sources, including natural sources such as pollen, soil (from wind erosion) and forest fires, as well as anthropogenic sources such as fertilizer application and oil and coal combustion. Agricultural activities (pre-planting field preparations, harvesting) can increase the amount of soil-derived phosphorus in the atmosphere. Phosphorus can also be released into the atmosphere in vapor form from various materials (sewage sludge, landfills) by microbial reduction processes. The atmosphere contributes phosphorus and phosphorus-containing material to terrestrial and aquatic ecosystems by wet (precipitation in various forms such as rain, sleet or snow) and dry (very small particles) deposition. This section provides a general discussion about the methodology used to quantify the amount of phosphorus entering surface waters from this source category. A more detailed discussion of the methodology used for this analysis is included in Appendix E. The results of the phosphorus loading computations for this source are discussed in Section 3.3.3.

A literature review indicated that limited data are available from Minnesota sources to estimate phosphorus deposition to the surface waters. The previous best source of information for precipitation input (wet deposition) of phosphorus to Minnesota watersheds is Verry and Timmons (1977). No data on dry deposition of phosphorus in Minnesota was identified. The following sources of data were considered to be the best available for providing estimates of atmospheric phosphorus inputs to Minnesota's surface waters.

MPCA:

1. Nutrient (including phosphorus) and metal concentrations in precipitation from a special study conducted from August 1999 to September 2001 at four monitoring sites in Minnesota
2. PM10 air concentrations determined from particulate filters and elemental speciation of the PM10 mass by X-ray Fluorescence (XRF) analysis for the 30 sites included in the Statewide Air Toxics Monitoring Study (1996-2001).

National Atmospheric Deposition Program (NADP):

1. Annual volume weighted calcium concentrations in precipitation for the period of record from NADP sites located in, and adjacent to, Minnesota.
2. Monthly volume weighted calcium concentrations for four sites (Fernberg, Marcell, Camp Ripley, Lamberton) for use in establishing the relationship between phosphorus and calcium in precipitation for NADP sites.

Minnesota Department of Natural Resources, State Climatology Office: Annual normal precipitation amount for each river basin basis was obtained from the State Climatology Office.

The phosphorus concentrations from the special study, along with NADP calcium data, were used to derive the relationship between phosphorus and calcium in precipitation for the four NADP monitoring sites. The relationship between phosphorus and calcium in precipitation at these four NADP sites was then applied to the entire state.

Data files for PM10 air concentrations and elemental speciation of the PM10 mass by XRF analysis were obtained from the MPCA for the 30 sites included in the Statewide Air Toxics Monitoring Study (1996-2001). The two key parameters to be obtained from the particulate filters were calcium and phosphorus concentrations. Calcium concentrations were typically available for each sampling period. However, upon review of the individual site data files, phosphorus concentrations were not available, so an alternative method for deriving phosphorus concentrations for the particle filters was employed for this analysis. This alternative method assumes that the relationship between phosphorus and calcium in precipitation is transferable to the particulate filter data (i.e., the same material being washed out in the precipitation is the same material being dry deposited and collected on the particulate filters). The critical assumptions and the details of calculating phosphorus air concentrations from the particulate filter data is further described in Appendix E.

2.2.2.2.1 Dry Deposition

The following steps were taken to estimate the areal phosphorus deposition rate from dry fallout:

1. Establishing the relationship between phosphorus and calcium on particle filters.
    a. The relationship of phosphorus and calcium on the particle filters is assumed to be the same as the relationship of phosphorus and calcium in precipitation; the soil dust being washed out in precipitation is the same dust being dry deposited and collected on the PM10 filters.
    b. The best source of phosphorus and calcium in precipitation data is the special study conducted by the St. Croix Watershed Research Station. The total phosphorus and

calcium concentrations (hereafter denoted as total [P]) and total [Ca] in precipitation data) were determined from August 1991 – September 2001 at 4 sites: Fernberg (Ely), Marcell, Camp Ripley, Lamberton; referred to as "reference sites".

c. The relationship on a sample-by-sample basis (milligrams per square meter; mg/m^2) between total [P] and total [Ca] in precipitation at the 4 reference sites was established through regression analysis:

$$y = 0.0289x \quad \text{(through zero)} \quad (R^2 = 0.42)$$

Where: y = Total phosphorus in micrograms per square meter ($\mu g/m^2$)
x = Total calcium in $\mu g/m^2$.

2. Extrapolating the relationship of [P] and [Ca] from precipitation to the particulate filters.
    a. Since the regression equation for [P] and [Ca] in precipitation goes through zero, this regression equation can be applied to data from other media under the assumption that the ratio is the same (i.e., particulate filter data) without having to convert units. Essentially forcing the regression equation through zero creates a ratio of [P] to [Ca] that can be applied to other data.
    b. In this regard, the regression equation from above can be modified as follows for application to the particle filter data.

$$y = 0.0289x \quad \text{(through zero)} \quad (R^2 = 0.42)$$

Where: y = Total phosphorus in micrograms per square meter cubic meter ($\mu g/m^3$)
x = Total calcium in $\mu g/m^3$.

3. Estimating [P] in air at the MPCA's air monitoring locations.
    a. The regression equation from 2.b. was then used to estimate [P] in ambient air at the MPCA air monitoring sites. Annual [Ca] concentrations in micrograms per cubic meter were calculated for each monitoring site based on the individual sample [Ca] concentrations. The annual average [Ca] in air is then used in the regression equation to derive an estimate of annual average [P] in air.
4. Calculating dry phosphorus deposition
    a. Monitoring sites locations were mapped with respect to basin boundaries:

Cedar River: Albert Lea

Des Moines River: Pipestone

Lake Superior: Virginia (2 sites), Duluth (2), Silver Bay, Hibbing

Minnesota River: North Mankato, Brandon Township, Granite Falls, Willmar, Swift County

Mississippi (Upper) St. Paul (3), Minneapolis (3), Bemidji, Elk River, Fort Ripley, Alexandria, Hutchinson, St. Cloud, St. Michael, Grand Rapids, Little Falls

Mississippi (Lower): Rochester, Goodhue County, Apple Valley, Winona

Missouri River: Pipestone

Rainy River: Warroad, International Falls

Red River: Fergus Falls, Moorhead, Perham

St. Croix River: West Lakeland, Pine County (Sandstone)

b. Calculation components for phosphorus deposition in a basin:

- Estimated phosphorus air concentration; if more than one site assigned to a basin then the average phosphorus in air concentration used in the deposition calculation.
- The estimated phosphorus air concentration (or the average phosphorus air concentration if more than one site is in a basin) is to be split into two size fractions based on MPCA collocated PM10 and PM2.5 samplers (average from 5 sites):

  42% fine fraction (< 2.5 microns)

  58% coarse fraction

- A deposition velocity for each particle size fraction was estimated based on the information from Meyers (2003):

  Fine fraction deposition velocity = 0.5 centimeters per second (cm/s);

  Coarse fraction deposition velocity = 3 cm/s.

- The coarse and fine particle deposition is summed together to provide a "total" particle deposition estimate.
- Conversion factors: convert seconds to years, cm to meters, and $\mu g/m^3$ to kg/ha.

The reader should note that for the dry deposition estimate, no adjustments were made in the estimation of dry deposition in a dry or a wet year; data are not available at this time to derive estimates of dry deposition during different precipitation regimes. The dry deposition rates were applied to area estimates of surface waters (open water + wetland as designated in USGS NLCD GIS coverage) in each basin.

2.2.2.2.2 Wet Deposition

The following steps were taken to estimate the areal phosphorus deposition rate from wet deposition:

1. Establishing the relationship between phosphorus and calcium in precipitation.

   a. NADP routinely analyzes rain samples for pH, alkalinity, major cations (including calcium and potassium) and major anions (including sulfate, nitrate). Since calcium concentrations are available for all samples that were analyzed, and calcium is a signature for soil contributions, the relationship between phosphorus and calcium would need to be established. The use of NADP data also provides some consistency in the data used for estimating wet phosphorus deposition.

   b. The best source of phosphorus in precipitation data is the special study conducted by the St. Croix Watershed Research Station. The total phosphorus concentrations (hereafter denoted as total [P]) in precipitation data) determined from August 1991 – September 2001 at 4 sites: Fernberg (Ely), Marcell, Camp Ripley, Lamberton; referred to as "reference sites". The special study also provided measurements on total [Ca] in precipitation.

   c. An initial analysis identified that the total [Ca] from the special study was approximately two times greater than the [Ca] reported by NADP for the same time period. The NADP does not acidify samples; therefore the NADP reports dissolved [Ca]. To compensate for NADP reporting dissolved [Ca], and to provide the best estimate of [P] in precipitation from the auxiliary (NADP) sites, it was determined that the relationship between [P] and [Ca] in precipitation should be determined by using the total [P] concentrations from the special study conducted by the St. Croix Watershed Research Station and the dissolved [Ca] reported by NADP for these same "reference" sites.

   d. The volume-weighted relationship on a sample-by-sample basis between total [P] in precipitation and dissolved [Ca] in precipitation from NADP at these same reference sites (collocated sampling occurred) was established by MPCA staff (Dr. Ed Swain, 2003) through regression analysis:

$$y = 0.0671x - 0.4586 \quad (R^2 = 0.47)$$

   Where: y = Total phosphorus in micrograms per liter (µg/L)

   x = NADP calcium (dissolved) in µg/L.

2. Extrapolating the relationship of [P] and [Ca] in precipitation to other locations.

   a. The regression analysis based on total [P] and dissolved [Ca] concentrations for the reference sites was then used to estimate [P] in precipitation at other NADP monitoring sites (referred to as "auxiliary sites"). Annual volume-weighted [Ca] in precipitation data (annual volume weighted average) were obtained for the auxiliary sites from NADP and the regression equation from above was then used to estimate total [P] in precipitation for each auxiliary site.

b. The auxiliary monitoring sites will supplement the information from the reference sites in calculating wet phosphorus deposition to specific basins.

3. Calculating wet phosphorus deposition

a. Monitoring sites locations were mapped with respect to basin boundaries and assignments to watershed made based on site locations:

Cedar River: Lamberton
Des Moines River: Lamberton
Lake Superior: Hovland, Wolf Ridge, Fond du Lac
Minnesota River: Lamberton
Mississippi (Upper): Marcell, Camp Ripley, Cedar Creek
Mississippi (Lower): Wildcat Mountain
Missouri River: Lamberton
Rainy River: Voyageurs Nat. Park, Marcell, Fernberg
Red River: Icelandic State Park
St. Croix River: Grindstone Lake, Cedar Creek

b. Calculation components for phosphorus deposition in a basin:

- Annual average precipitation for the basin (obtained from State Climatology Office)
- [P] in precipitation (annual, volume weighted average; measured at one of the reference sites or estimated for one of the auxiliary sites; if more than one site assigned to a basin then the average [P] in precipitation used in the deposition calculation)
- Area estimate (hectares or acres) of open surface water (surface water + wetland as designated in GIS) in a basin.

2.2.2.3 Deicing Agents

The use of deicing chemicals has increased in the U.S. since the 1940s and 1950s to provide "bare pavement" for safe and efficient winter transportation. As more and more transportation agencies adopted the "bare pavement" policy, the use of salt, salt and sand mixtures, liquid brines and alternative deicers increased with the need to maintain this standard for pavement conditions during inclement weather. Other road agencies in Minnesota such as cities, townships and counties use deicing agents to maintain a similar standard for pavement conditions during inclement weather. The search for alternatives to salt for road deicing has been prompted primarily due to the infrastructure corrosion concerns and the impacts of chloride on water quality and vegetation. Recently, some limited research has documented water quality concerns related to phosphorus and other chemicals present in deicing agents, as well as the alternative compounds. This section provides a general discussion about the methodology used to quantify the amount of phosphorus entering surface waters from this source category. A more detailed discussion of the methodology used for this analysis is included in Appendix F. The results of the phosphorus loading computations for this source are discussed in Section 3.3.4.

Review of the existing scientific literature with regard to deicing agents as a phosphorus source was concerned with three major areas; 1) usage patterns of deicing agents in Minnesota and other states with regard to road types and road management agency, 2) the phosphorus content of deicing agents – salt, sand, and deicing alternatives, and 3) the impact of weather patterns on usage levels.

Phosphorus loading computations were primarily based upon the MnDOT data sources as this was the most detailed data set and extended over the longest time period. Loading calculations for TCMA counties were obtained from published data and other road types were extrapolated using the MnDOT data trends, applications rates and deicing mixtures. The MnDOT database was the most comprehensive and most useful in determining application rates across the range of conditions for wet, dry and average years. The applications rates for each MnDOT District, and thus for each basin, is based upon the use of statewide averages based upon their relationship to snowfall amounts over a winter. Application rates for salt and sand were then adjusted to account for the wet, dry and average conditions based upon the ratios derived from the 1971 – 2003 time period and the relationship between the years of detailed information provided in the Salt Solutions Report and MnDOT's Work Management System Reports (SRF Consulting Group, 1998; MnDOT, 2003). The use of brine for deicing has increased in recent years, but the period of record for its application is limited and thus 2002 rates were used in the calculations as insufficient data was available to attempt to adjust for year-to-year variability in its application rate.

MnDOT's road classes (service levels) were used to further define the application assumptions for the mix ratios of deicers used on the three road types maintained by MnDOT. Based upon an examination of the 2003 – 02 deicer usage report the total salt plus sand application, in tons per lane mile, was modified for the three types of roads maintained by MnDOT (MnDOT, 2003).

01 - Interstate Trunk Highway – uses a 100% salt assumption (assuming "super commuter" service level)

02 - U.S. Trunk Highway – uses a 70% salt assumption (assuming "urban commuter" service level)

03 - Minnesota Trunk Highway – uses a 50% salt assumption (assuming "rural commuter" service level)

County and local road agency specific data was less readily available for use in this analysis, except for the TCMA counties. An analysis was undertaken using the 1994 – 1997 data available for the TCMA to develop usage rates for the County State Aid Highway (CSAH) system. The TCMA deicer usage rates were summarized based upon average conditions (1994 – 95) for both salt and sand usage on a lane mile basis. The 1995 – 1997 period was used for calculation of the wet year conditions. The dry year conditions were used based upon the 90th percentile summary statistics. These usage numbers were applied to all CSAH miles across the state as they were viewed as the more heavily traveled and thus more highly maintained roads in both the TCMA and out-state areas. Deicer usage rates for other county highways and local roads were developed based upon an even smaller database of actual usage rates. As such, the usage rates for the "rural" counties in the TCMA – Scott, Carver and Chisago counties – were used to develop usage rates for other roads included in this analysis. An analysis was undertaken using the 1994 – 1997 data available for these TCMA in manner consistent with the CSAH analysis described above.

As the concern over and documentation of the environmental impacts of deicing agents has increased, a number of authors and agencies have attempted to document the concentrations of other elements or compounds of concern that are introduced into the environment through road deicing. This analysis summarized and utilized the phosphorus concentrations from these analyses of the various deicers.

As a review of existing literature was undertaken it became obvious that the application rates and mixtures of deicers used are strongly predicated by weather conditions. An examination of the MnDOT records indicated that the number of "events" per season appeared to be the driving factor in the quantities of material applied. The high variability in the number of events between regions of the state in any given year, as well the year-to-year variability in the number of events precluded the use of events in this analysis. The MnDOT application guidelines provided some insight into how the variations in weather patterns impacted usage levels by counties and local units of government. Based upon an assessment of the snow data and usage levels provided by MnDOT for the period of 1971 to 2003 the amount of winter snow was used as a surrogate for the number of events. The winter snow fall amount at MSP Airport was used to define average, dry (low snowfall – 90th percentile) and wet (10th percentile) conditions.

2.2.2.4 Streambank Erosion

The stability of stream channels is a complex issue that is highly influenced by the dynamics of natural and anthropogenic disturbances. The banks of unstable streams typically undergo erosion, both in the form of particle detachment from hydrodynamic drag and mass failure following erosion of the bank toe. The phosphorus attached to eroded streambank material is immediately delivered to the receiving water where it may ultimately become available for biologic uptake, re-deposited downstream, or transported with the flow out of the system. This section provides a general discussion about the methodology used to quantify the amount of phosphorus entering surface waters from streambank erosion. A more detailed discussion of the methodology used for this analysis is included in Appendix G. The results of the phosphorus loading computations for this source are discussed in Section 3.3.5.

Simon and Hupp (1986) developed a six-stage, semi-quantitative model of channel evolution in disturbed channels, for bed-level trends, that qualitatively recognizes bank slope development. The third and fourth stages represent stream degradation, characterized by the lowering of the channel bed and basal erosion, with a subsequent increase in bank heights and slopes, leading to mass-wasting from slab, pop-out and deep-seated rotational failure.

Several researchers have determined that the stream sediment load is proportional to stream discharge (Lane, 1955; Glysson, 1987; Tornes, 1986; Kuhnle and Simon, 2000; Syvitski et al., 2000). Instantaneous flow and sediment transport data are used to develop sediment-transport rating curves, which are typically based on logarithmic regression relationships. A steep regressed slope to the rating relationship indicates both high sediment availability and high transport capacity. The slope of the suspended-sediment rating relationship varies (Simon, 1989a; Simon et al., 2003), depending upon the stage of channel evolution. Simon (1989a) determined that the highest slope of the suspended-sediment rating relationship corresponds to the stream stages (III and IV) that are undergoing the highest degree of degradation. Migration of knickpoints (or vertical step-changes in bed surface elevation) up tributary streams during Stage III, and bank failures by mass wasting during Stage IV, both serve to significantly increase sediment yield (Simon, 1989a). For re-stabilized streams (Stage VI), the slope of the suspended-sediment rating relation is approximately 1.5, as opposed to 1.0 for “natural” streams (Stage I).

The approach used to assess this source of phosphorus utilized the data and techniques from the available literature to estimate total phosphorus loadings to the surface waters within each of the ten major basins in Minnesota. The literature search and review of available monitoring data involved a compilation of streambank erosion studies completed within Minnesota, along with an evaluation of the literature pertaining to sediment yield from Minnesota watersheds, to define the contribution of streambank erosion to the total phosphorus budget. Wherever possible, streambank erosion studies completed for Minnesota streams were used to determine the phosphorus load under low, average and high flow conditions for the respective basins. Sediment yield literature specific to the various regions of the state was consulted to develop an approach and assist with the assessment of the remaining unstudied watersheds.

Five published studies were found that specifically addressed streambank erosion for streams that originate in Minnesota. Wherever possible, average annual streambank sediment erosion, average annual erosion per stream mile, slope of suspended sediment rating relation, sediment erosion as a percentage of observed downstream suspended solids loading, and EPA Level III Ecoregion were expressed for each stream studied. Most of the estimates of streambank sediment erosion were the result of stream channel surveys (including aerial photos) to evaluate streambank retreat (or migration) and eroding bank area to determine the average annual volume of material eroded. One study (Sekely et al., 2002) also produced a probability plot of annual streambank erosion rates.

In addition to the streambank sediment erosion studies, two regional studies have been completed involving sediment yield data for Minnesota watersheds (Tornes, 1986; Simon et al., 2003). Tornes (1986) analyzed the average annual sediment yield data for 33 USGS gaging stations, in or adjacent to Minnesota, while Simon et al. (2003) determined sediment yield, on the basis of the 1.5-year recurrence interval flow rate, for each of the EPA Level III Ecoregions. Tornes (1986) determined the average annual sediment yield for each of the gaging stations by developing sediment-transport curves for each of the stations and applying the relationships to flow-duration curves to calculate and sum the sediment loadings at each interval. Simon et al. (2003) determined sediment yield quartiles, minimum, and maximum yields, on the basis of the 1.5-year recurrence interval (or effective discharge) flow rate, for each of the EPA Level III Ecoregions.

The approach for determining phosphorus loading from streambank erosion generally involved the following steps:

- Convert published streambank erosion estimates into average annual sediment yield

- Using the published sediment-transport curves from Tornes (1986), determine the relationship between average annual sediment yield and the slope of the sediment-transport curve segment containing the 1.5-year recurrence interval flow rate, as a surrogate for the effective discharge

- Apply average annual sediment yields from published streambank erosion estimates and Tornes (1986) to respective watershed units in GIS and determine average annual area-weighted monitored sediment yield for each of the EPA Level III Ecoregions in Minnesota

- Compare average annual monitored sediment yield for each of the EPA Level III Ecoregions in Minnesota to the effective discharge rate sediment yields published by Simon et al. (2003) for the same ecoregions and make adjustments, if necessary

- Apply average annual sediment yield for each of the EPA Level III Ecoregions to the unmonitored portions of the state and estimate streambank sediment erosion component based on difference between average annual sediment yield for ecoregion and estimated annual sediment yield for stable (Stage VI) stream, with slope of suspended sediment rating relation equal to 1.5 (per Simon, 1989a)

- Estimate annual streambank sediment erosion for all watersheds under low and high flow conditions, based on the probability plot relationship (taken from Sekely et al., 2002) of annual streambank erosion rates

- Combine the streambank erosion sediment loadings associated with each watershed with the average soil test phosphorus concentration (based on 16 surface samples collected from Blue Earth River escarpments, as described in Sekely et al., 2002) to calculate the total phosphorus load associated with sediment loading estimated from streambank erosion in each basin for each flow condition

2.2.2.5 Individual Sewage Treatment Systems/Unsewered Communities

"Undersewered" areas are communities or residential areas which have a crude sewage collection system with little or no treatment component and/or have individual systems which are non-conforming. Individual sewage treatment system (ISTS) refers to a sewage treatment and disposal system located on a property, using subsurface soil treatment and disposal for an individual home or establishment. MPCA (2002a) states that most undersewered communities and many failing septic systems outside of undersewered areas have relatively direct connections to surface waters through tiles lines and road ditches, resulting in a very high delivery potential. "Failing" ISTS are specifically defined as systems that are failing to protect groundwater from contamination, while those systems which discharge partially treated sewage to the ground surface, road ditches, tile lines, and directly into streams, rivers and lakes are considered an imminent threat to public health and safety (ITPHS). This section provides a general discussion about the methodology used to quantify the amount of phosphorus entering surface waters from the ISTS/unsewered communities source category. A more detailed discussion of the methodology used for this analysis is included in Appendix H. The results of the phosphorus loading computations for this source are discussed in Section 3.3.6.

The conventional ISTS consists primarily of a septic tank and a soil absorption field. Septic tanks remove most settleable and floatable material and function as an anaerobic bioreactor that promotes partial digestion of retained organic matter (EPA, 2002). Septic tank effluent, which contains significant concentrations of pathogens and nutrients, has traditionally been discharged to soil, sand, or other media absorption fields for further treatment through biological processes, adsorption, filtration, and infiltration into underlying soils which are suitable for treatment and disposal. Phosphorus is present in significant concentrations in most wastewaters treated by ISTS. Monitoring below ISTS systems has shown that the amount of phosphorus leached to groundwater below an operating ISTS depends on several factors: the characteristics of the soil, the thickness of the unsaturated zone through which the wastewater percolates, the applied loading rate, and the age of the system (EPA, 2002). The amount of phosphorus in ground water varies from background concentrations to concentrations comparable to that of septic tank effluent. Phosphorus export to surface waters from ISTS and unsewered communities is dependent on the following factors:

- Phosphorus content of waste load
- Population served by ISTS or unsewered communities
- Compliance of treatment systems with performance standards
- Characteristics of soil absorption field, groundwater conditions and proximity to surface waters

Data pertaining to the phosphorus content of the untreated waste load from unsewered communities was addressed in the Point Sources Technical Memorandum (Appendix B), prepared for this project. For the purposes of this analysis, the phosphorus contained in untreated sewage discharge from non-conforming ISTS or unsewered communities consists of the following sources, with the corresponding per capita loadings of phosphorus (see Appendices B and H):

Source	Phosphorus Load (kg/cap/yr)
Automatic dishwasher detergent	0.1250
Dentifrices	0.0115
Food soils and garbage disposal wastes	0.1895
Ingested Human wastes	0.5585
Total	0.8845

Dentifrices include toothpaste and other dental care products. Food soils include waste food and beverages poured down the sink, and food washed down the drain as a result of dish rinsing and washing. The total per capita phosphorus load of 0.8845 kg/yr (1.946 lbs/cap/yr), was assumed to apply to the population served by ISTS or unsewered communities throughout the state.

The number of people served by ISTS was estimated from a variety of data sources. Two of the data sources were spreadsheets provided by the Minnesota Pollution Control Agency, another was the 1990 Census (United States Census Bureau, 1990), and the last was estimated based on the POTW population served from the Point Sources Technical Memorandum (Appendix B). This last method using the difference between the 2000 Census (United States Census Bureau, 2000) population and the POTW population served were used in the study to estimate phosphorus loadings from ISTS. This data showed good consistency with the other data available for ISTS in Minnesota. By using the third method, a total accounting of domestic waste disposal is provided in this study.

The MPCA developed a spreadsheet, updated in September, 2003, providing a list of unsewered communities within Minnesota (MPCA, 2003). The major basin for each of these communities was estimated by assigning an approximate geographic location based on a city, township, lake/county, or township-range-section location (whichever provided the most detailed location).

The Minnesota River basin had a significant number of households served by sewage treatment systems that involved direct discharge to a tile drain line (Tetra Tech, 2002). The majority of these systems, referred to as direct-to-tile ISTS, include a septic tank with no other treatment. Assuming that most of the direct-to-tile ISTS are located in rural areas with tile lines, Tetra Tech (2002) extracted data from the Minnesota River Assessment Project, or MRAP (MPCA, 1994), to develop a relationship between the number of direct-to-tile ISTS and cropland. The ISTS densities and cropland were then mapped by minor watersheds across the Minnesota River basin. The geographic trend in density was assumed to be consistent with the MRAP designations for three nutrient source regions, and the average density of direct-to-tile ISTS per 10,000 acres of cropland was determined for each source region. For this analysis, the assumptions about direct-to-tile ISTS density per 10,000 acres of cropland for each source region were retained for the Minnesota River basin. Since no assessments of direct-to-tile ISTS had been published for any other basins in Minnesota, several of the minor watersheds in surrounding basins were assumed to have direct-to-tile ISTS densities comparable to the three Source Regions, based on knowledge of the presence of drain tiles, cropland and their proximity to the MRAP study areas. The amount of cropland and area of each Source Region was determined and multiplied to determine the total number of direct-to-tile systems for each basin. The population served by direct-to-tile ISTS was estimated by multiplying the number of systems by the average household size for each basin.

The MPCA maintained a spreadsheet with the number of ISTS by local units of governments (LUG) with ISTS ordinances in 2002 (MPCA, 2002). Included in the spreadsheet was the LUG name and type (e.g. city, township or county). An estimate of the number of full time and seasonal residences served by ISTS was included in the spreadsheet. There was also an estimate of the number of systems failing to protect groundwater and an estimate for the number of systems which are considered an ITPHS. The population served was estimated by multiplying the number of full time residences by the population per household values (for the 2000 census) for the LUG's respective county.

Based on the availability of data and the potential for variation in phosphorus export from undersewered communities and the various types of conforming and nonconforming ISTS, phosphorus loadings were estimated for each of the following source categories:

- Unsewered communities
- Direct-to-tile ISTS
- Conforming and nonconforming seasonal ISTS
- Remaining conforming and nonconforming ISTS

The populations associated with unsewered communities and direct-to-tile ISTS in each basin were assumed to receive treatment from septic tanks before discharging to surface waters. The number of seasonal residences had also been estimated in the MPCA ISTS LUG spreadsheet (MPCA, 2002). Since no data was available for the population served by seasonal ISTS, a household size of 2.1 was assumed and applied to the number of seasonal residences in each basin. No literature was found, so it was assumed that seasonal residences are occupied for four months each year. It was further assumed that, since seasonal residences are typically located in close proximity to surface waters, nonconforming ISTS (both failing and ITPHS) would contribute all of the 43 percent of phosphorus passing through a septic tank to surface waters. Conforming seasonal ISTS were assumed to remove 80 percent of the total phosphorus loading, due to treatment from the septic tank and soil absorption field, before discharging to surface waters in each basin.

Since most of the permanent residences are not typically located as close in proximity to surface waters as seasonal residences, it was assumed that both fully conforming and failing ISTS would provide higher phosphorus attenuation for permanent residences than what was assumed for seasonal residences. Conforming ISTS were assumed to remove 90 percent of the overall total phosphorus loading, while failing ISTS were assumed to remove 70 percent of the overall total phosphorus loading, before discharging to surface waters in each basin. The nonconforming ISTS, considered an ITPHS, were assumed to be contributing all of the 43 percent of phosphorus passing through a septic tank to surface waters.

2.2.2.6 Non-Agricultural Rural Runoff

Section 2.2.2.1 discusses the methods used to estimate the phosphorus loadings associated runoff from agricultural lands, while Section 2.2.2.7 describes the methodology used to quantify the amount of phosphorus in runoff from urban land cover types. This section provides a general discussion about the methodology used to quantify the amount of phosphorus entering surface waters in runoff from unincorporated areas that are not considered agricultural land cover types (referred to as non-agricultural rural). The major natural land cover types included in the non-agricultural rural land use group are forests (coniferous, deciduous and mixed), grasslands and shrublands. Rural residential areas, transportation infrastructure, and other typically urban land uses such as residential and commercial developed areas outside the boundaries of incorporated urban areas are also included in this assessment. A more detailed discussion of the methodology used for this analysis is included in Appendix I. The results of the phosphorus loading computations for this source are discussed in Section 3.3.7.

Within some of the major basins of Minnesota, forests and grasslands still cover up to 60% of the watershed area. The hydrologic cycling of annual precipitation in natural vegetation moves most of the water to infiltration and thus promotes stable stream base flows and reduces surface runoff. In natural plant communities, much of the phosphorus pool is retained within the plant community and the soil profile, with plant biomass creation, senescence and subsequent decomposition processes cycling nutrients back into the soil profile. The high soil infiltration rates in these plant communities lead to low surface runoff rates and little soil loss via erosion, and thus low rates of nutrient export to surface waters. In most cases the surface runoff rates are less than 10% of the annual precipitation for these plant communities and phosphorus export rates are below 0.169 kilograms of phosphorus per hectare per year (0.151 pounds per acre per year).

The scientific literature was reviewed to determine the hydrologic regimes, nutrient cycling mechanisms and phosphorus loading factors for each of the land cover types included in the Non-Agricultural Rural Runoff category. The hydrologic and nutrient export relationships examined for the rural land cover types are generally discussed in this section, while the hydrologic and nutrient export relationships for rural residential and commercial/industrial/transportation land cover types are discussed in Section 2.2.2.7.

Interception of rainfall occurs at multiple levels within the forest – tree canopy, tree and shrub layer stems, shrub canopy, herbaceous layer and ground litter – to reduce overland flows (Brooks, et al, 2003; Verry 1976). Other authors have reported little or no overland flow from intact deciduous or coniferous forests due to interception (Binkley, 2001; Knighton and Steigler, 1980; Metcalfe and Butle, 1999; Verry, 1969).

While a fair amount of literature exists on forest hydrology and nutrients, comparable literature for shrublands and grasslands is much less extensive. Many authors suggest that runoff rates and nutrient exports form these communities are low, however the supporting evidence is limited. Brye, et al. (2000) and Brye, et al. (2002) evaluated the water and phosphorus budgets of a restored prairie near Madison WI. The authors reported that rainfall interception by plant residue was a significant component of the annual water budget (nearly 70%). Higher soil storage and ET rates led to lower soil drainage and runoff volumes. Runoff volumes were 11% to 18% of the water budget, with a mean of 14.5% for the test plots. Snowmelt was responsible for nearly all of the runoff volumes. Timmons and Holt (1977) reported that phosphorus losses from grasslands to be in a range of 0.100 kg P/ha/yr to 0.250 kg P/ha/yr, with a phosphorus concentration in runoff of 0.200 mg P/L. Using the water budget data from Brye, et al (2000) and Brye, et al (2002) and phosphorus concentration data from Timmons and Holt (1977), an export loading rate of 0.169 kg P/ha/yr for ecoregion VIII was calculated. Using the water budget information from Winter and Carr (1980), Winter, et al, (2001), Winter, Rosenberry (1995 and 1998) and Shjeflo (1968) and concentration data from USACE (2001), a phosphorus export of 0.060 kg P/ha/yr was calculated for ecoregion VI. Data from Olness, et al (1988) and Menzel, et al (1978) provided an export rate 0.175 kg P/ha/yr for grassland pasture.

A search of the literature provided no reported shrubland phosphorus export rates (Holechek, et al, 1977; Dodds, et al, 1996: Burke, et al, 1990). Most shrublands are composed of a herbaceous layer of grasses and forbs with a sparse over story of trees and/or low shrubs. MN DNR (1993) and Leach and Givnish (1999) suggest that many of the hydrologic and ecologic attributes of forest and prairie communities are present in shrublands. Low runoff rates, high annual evapotranspiration and limited nutrient losses of the two shrubland community components provide a basis to conclude that shrublands are intermediate with regard to phosphorus export. Based upon these assumptions, the nutrient export rate for shrubland was determined from the average of the grassland and deciduous forest communities. The calculated value used for this assessment is 0.129 kg P/ha/yr.

This investigation of phosphorus loadings from non-agricultural rural land uses draws upon ecoregion-based loading and export rates for phosphorus in Minnesota. The use of ecoregions allows the similarities in underlying ecological conditions to be aggregated across basin boundaries and state boundaries to develop accurate estimates of loadings. Ecoregions are defined as regions of relative homogeneity in ecological systems, such that geographic characteristics such as soils, vegetation, climate, geology, and land cover are relatively similar within the bounds of each ecoregion (Omernik, 2000). The US EPA has developed generalized "nutrient Ecoregions" that are aggregations of the Level III Ecoregions (EPA 2000d, EPA 2000e). Within Minnesota there are three EPA Level III Aggregate Ecoregions (shown in Figure 2, Appendix I). As the number of phosphorus export studies completed in Minnesota is relatively small, the use of export rates from the larger Level III aggregate regions provides a wider data set that can be extrapolated across the basins (MPCA, 2003).

The Corn Belt and Northern Great Plains – Aggregate Ecoregion VI – is comprised of rolling plains and flat lake beds, dominated by extensive, highly productive cropland (EPA, 2000a). Nutrient-rich soils significantly influence surface and subsurface water quality and high concentrations of nitrate and phosphorus cause water quality problems in many basins. The Mostly Glaciated Dairy Region – Aggregate Ecoregion VII – is dominated by forests, dairy operations, and livestock farming (EPA, 2000b). This ecoregion was mostly glaciated and includes flat lake plains, rolling till plains, hummocky stagnation moraines, hills, and low mountains. The Nutrient Poor Largely Glaciated Upper Midwest and Northeast – Aggregate Ecoregion VIII – is characterized by extensive forests, nutrient-poor soils, a short growing season, limited cropland, and many marshes, swamps, lakes, and streams.

An assessment was completed on the literature values for phosphorus export rates to examine any differences between the three aggregate level ecoregions. The literature data was statistically summarized, where available, and the ecoregion mean value was determined for each plant community. These values were used for the phosphorus load calculations.

For the purposes of defining and quantifying the phosphorus loads to Minnesota basins, the non-agricultural rural land uses within these three Aggregate Ecoregions were classified and enumerated using the USGS National Land Cover Data (NLCD). The National Land Cover Data Set for the Conterminous United States is derived from the Landsat thematic mapper data system (Vogelmann, 2001). The NLCD cover classes included in the non-agricultural rural category include the following:

- Unincorporated Urban Areas
    - Low intensity residential (outside incorporated urban areas)
    - High intensity residential (outside incorporated urban areas)
    - Commercial/Industrial/Transportation (outside incorporated urban areas)
- Deciduous Forest
- Evergreen Forest
- Mixed Forest
- Shrubland
- Grasslands/Herbaceous
- Urban / Recreational Grasses
- Other
    - Quarries/Strip Mines/Gravel Pits
    - Transitional

The development of nutrient loading estimates in the absence of direct monitoring has generally been completed by applying areal based nutrient export rates to the watershed area to calculate the annual nutrient mass (Beaulac and Reckhow, 1982: Reckhow, et al, 1980; Panuska and Lillie, 1995; Clesceri, et al, 1986a; Clesceri, et al, 1986b; McFarland and Hauck, 2001). Phosphorus export coefficients assume 100% of the land transports phosphorus that will reach surface waters. The phosphorus export coefficient is part of the total phosphorus loading equation:

$$L = \sum_{i=1}^{m} c_i \bullet A_i$$

L is total phosphorus loading from land (in kilograms per year), *m* is number of land use types, c_i is the phosphorus export coefficient for land use *i* (in kilograms per hectare per year), and A_i is area of land use *i* (in hectares).

Over large watershed areas, the phosphorus export is not proportional to watershed area and some attenuation of phosphorus occurs, especially in natural vegetation that have low runoff rates. Recently, authors who have examined the nutrient export issue on landscape level scales (large watersheds and higher order streams) have raised concerns over the applicability of export coefficients across large watershed areas (Birr and Mulla, 2001; Cammermeyer, et al, 1999; Johnson and gage, 1997; Jones, et al, 2001; Mattson and Isaac, 1999; McFarland and Hauck, 1998; Richards, et al, 2001; Sharpley, et al, 1993; Soranno, et al, 1996; Worrall and Burt, 1999). The underlying issue related to this concern is that not all areas in a large watershed contribute nutrients and sediment equally. Novotny and Chester (1989) showed that the sediment delivery rate decreases with increasing watershed size. They report that in humid regions only a portion of a watershed contributes to surface runoff; they called these contributory areas of a watershed the "hydrologically active areas". Soranno, et al. (1996) and Cammermeyer, et al, (1999) suggest two adjustments to account for the attenuation by including a transmission coefficient (*T*) that represents the proportion of phosphorus transported down slope along the path of overland flow and a phosphorus flux coefficient (f_i), that represents the phosphorus production and transport that reaches a surface water body. While this equation applies more strictly to watershed modeling with GIS software, the underlying premises apply directly to the loading assessment methodology used here. The authors suggest that the phosphorus loading equation can be modified:

$$L = \sum_{i=1}^{m} \sum_{p=1}^{n} f_i \bullet A_{p,i} \bullet T_i^p$$

T is the transmission coefficient ($O<T<1$) representing the proportion of phosphorus transported, f_i is the phosphorus flux coefficient, *n* is the number of pixels, and *p* is the pixel distance of overland flow.

Soranno, et al (1996) reported that the greatest contribution of loadings was derived from land uses within the riparian corridor, a corridor that varies in width depending upon topography and runoff conditions. Based upon modeling of monitored watersheds they found that the total annual rainfall affected the phosphorus loading by creating variability as to the effective contributory area. In most cases, the transmission coefficient is determined through GIS modeling of the watershed area. The GIS-based development of transmission coefficients for use in this assessment was beyond the scope of the project. In the absence of a calculated T, an estimate of the contributory area of a watershed based upon land use and the application of a basin runoff factors were chosen for the load calculations. The basin runoff factor accounts for the differences in effective flow length and thus runoff volumes between the three precipitation scenarios (Soranno et al, 1996; Cammermeyer, et al, 1999; Barr Engineering, 2003b). The phosphorus loading estimation methodology used in this assessment assumes that c_i will be equal to f_i through the use of calculated loadings from the 100 meter contributory areas only.

The phenomenon of contributory area and variability in nutrient mass over a range of flow scenarios is a central question to the estimation of large basin loads. The literature was reviewed for a consensus on the size of this contributory area and the impact of hydrologic conditions upon the size and export estimation. Novotny and Chester (1989) calibrated and verified hydrologic models for a number of Milwaukee area basins and found that sediment delivery ratios ranged from 0.01 for pervious areas and 1.0 for completely storm-sewered urban areas. Johnson, et al (1997) found that landscape factors within the 100 meter ecotone adjacent to streams were sufficient predictors of stream water chemistry. Tufford, *et al*, (1998) reported that the land within 150 meters of streams was a better predictor of nutrient concentrations. Many authors have suggested that riparian land cover within 100 meters can mediate upslope impacts on water quality (Schmitt, et al, 1999; Cole et al, 1997; Castelle, et al, 1994; Roth, et al, 1996; Osborne and Kovacic, 1993).

Based upon the literature review conclusion that the 100 meter riparian zone has the greatest influence on water chemistry, we have chosen to estimate phosphorus loads from the 100 meter zone of land use immediately adjacent to perennial streams, lakes and wetlands in all of the basins. It should be noted that throughout most of Minnesota, it is believed that the risks of phosphorus transport to surface waters are greatest in the contributing corridor within about 100 m from surface waterbodies. Due to topographic variations along surface waterbodies, in some areas phosphorus contributions from overland runoff and erosion may occur from as far away as several hundreds of meters. In contrast, where berms are present along waterbodies it may be unlikely for a significant amount of surface runoff or erosion to enter surface water. Thus, the 100 m contributing corridor should be viewed as a regional average for contributions of phosphorus to surface waters from runoff and erosion on adjacent lands.

The NLCD land use coverage for the non-agricultural rural was determined using ArcView to create land cover quantities for all lands within 100 meters of all surface waters (as defined in Section 1.4.1). This 100 meter wide area was used for the calculation of the effective contributory area for each land cover types for each basin.

The phosphorus load for each land use was calculated by multiplying the phosphorus export coefficient by the 100 m contributory area and basin runoff factor for each land use category. The basin runoff factor is based upon the percent differences between runoff in the wet and dry precipitation scenarios compared to the average conditions for each basin. This information was generated from the calculation of runoff volumes as part of the basin hydrology (discussed in Sections 2.1 and 3.1). Use of the basin runoff factor and contributory watershed area for loading calculations, allowed for the following adjustment of the loadings based upon the annual runoff:

*Basin natural area load (kg) = Export rate (kg/ha/yr) * Contributory area (ha) * Basin runoff factor*

2.2.2.7 Urban Runoff

The conversion of land areas to urban land uses leads to changes in watershed hydrology and pollutant load rates. The areal increase in impervious surfaces in urban areas over undeveloped rural and natural land uses leads to greater surface water runoff volumes. The increased runoff coupled with human activities increases the types of pollutants and delivery rate of these pollutants to surface waters. Impermeable surfaces shed water as surface runoff, lowering the infiltration and evapotranspiration components of the hydrologic cycle. Surface runoff is generally directed to storm sewers and other conveyance systems to rapidly move the large volumes to receiving waters and prevent flooding. This section provides a general discussion about the methodology used to quantify the amount of phosphorus entering surface waters from urban runoff. A more detailed discussion of the methodology used for this analysis is included in Appendix J. The results of the phosphorus loading computations for this source are discussed in Section 3.3.8.

The methodology used for this analysis involved review of the literature to document urban runoff quality in Minnesota, determining the extent of each urban land cover type present within each basin, and calculating the variation of the estimated phosphorus loadings under each flow condition. It was apparent from the literature review that the quality and quantity of the data available was insufficient for the use of quantifying basin-specific data for this assessment. The need to quantify phosphorus loadings across basins with regard to three different hydrologic conditions (low, average and high flow conditions) required that a method be developed to model phosphorus loadings with regard to land use and hydrologic conditions. The scientific literature was thus reviewed to determine the hydrologic regimes, nutrient cycling mechanisms and phosphorus loading factors for each of the urban land cover categories.

In an attempt to determine the range of phosphorus concentrations in urban runoff, the summary data was reviewed and the site specific data from previous or ongoing monitoring studies was examined. The available monitoring data included a combination of flow-weighted mean or event mean concentrations, expressed as median, geometric or arithmetic means. The inconsistency in data reporting limited the use of many of the data sets found during the literature review process. Schwartz and Naiman (1999) suggest using the mean concentration as the representative concentration introduces significant bias into the annual load estimates and report that the use of flow-weighted mean concentration (FWMC) provides an unbiased estimate of annual load. Data collected in the literature review, chosen for inclusion in the database, had to meet the following criteria:

- Phosphorus data was collected for the duration of individual storm events and was reported as Event Mean Concentration (EMC)
- Numerous samples had to be collected at the same monitoring location throughout a given year
- Land use was either reported in adequate detail or land use could be determined using ArcView with delineated watersheds and USGS National Land Cover Data (NLCD)
- A large fraction of the runoff generated from a monitored watershed was not routed through storm water treatment BMPs such as detention ponds

Precipitation data was also gathered from the rain gage nearest to the chosen monitoring sites. Driver and Tasker (1990) found that, in developing linear regression equations for the estimation of storm water loads, the total storm rainfall and total contributory drainage area were the most significant factors, while impervious area, land-use and mean annual climatic characteristics were also significant. The high level of correlation between land use type and effective impervious area has also been noted by many investigators (Schueler, 1987; Driver and Tasker, 1990; Beaulac and Rechkow, 1982). Likewise nutrient loadings increase with increasing impervious surface area, most likely due to the ease of washoff and transport in curb and gutter systems and on other hard surfaces

(Brezonik, *et al*, 2002; Schueler, 1994). Higher impervious percentage watersheds yield lower phosphorus concentrations, but the larger volume of water leads to the higher phosphorus loading rates (Bannerman, *et al*, 1992; Swenson, 1998; Beaulac and Rechkow, 1982). McFarland and Hauck (2001) suggest that use of multiple regression analysis using measured flows and water quality data for heterogeneous land uses allows the estimation of loads that represent average conditions accurately. For this assessment, an evaluation was completed for the monitoring data collected at the same location for multiple years and under different hydrologic conditions. This data showed that the concentration of phosphorus in stormwater at the same site is often higher during dry years compared to an average year, and is lower during a wet year compared to an average year. From the available studies that had multiple years of monitoring data, a ratio was developed by dividing the concentration of total phosphorus in runoff for a wet year by the average year, and by dividing the concentration of total phosphorus in runoff for a dry year by the average year. Overall, the wet to average ratio was 0.8 and the dry to average ratio was 1.18. To quantify the relationship between annual precipitation, land use (the four urban NLCD land uses: low intensity residential, high intensity residential, commercial-industrial-transportation, and urban recreational grasses), impervious percentage, and the annual flow-weighted total phosphorus concentration, single variable and multivariate linear regressions were performed, based on estimated impervious percentages for each land cover type. There was a significant relationship between annual flow-weighted mean total phosphorus concentration, impervious percentage, and annual precipitation.

Export coefficients are commonly reported according to land use and are developed during a given year under a particular hydrologic condition (Beaulac and Reckhow, 1982: Reckhow, et al, 1980; Panuska and Lillie, 1995; Clesceri, et al, 1986a; Clesceri, et al, 1986b; McFarland and Hauck, 2001). In some cases the export coefficient is adjusted to reflect a normal climatic year. The most common approach to estimating loads is based upon Schueler's (1987) regression of rainfall runoff volume and percentage imperviousness of a watershed combined with a flow-weighted mean concentration. The equation is widely used for loading estimates and is used in this assessment to determine runoff coefficient based upon impervious percentage:

$$\text{Runoff coefficient } (R_v) = 0.05 + 0.009 \text{ (Impervious Percentage)}$$

The pollutant load is calculated by multiplying runoff volume with the pollutant concentration to obtain a mass load. For the purposes of defining and quantifying the phosphorus loads to Minnesota basins, the land uses within incorporated areas were classified and enumerated using the USGS National Land Cover Data (NLCD). The National Land Cover Data Set for the Conterminous United

States is derived from the Landsat thematic mapper data system (Vogelmann, 2001). The NLDC cover classes included in the land uses within incorporated areas assessed are:

- Urban Developed Areas
  - Low intensity residential
  - High intensity residential
  - Commercial/Industrial/Transportation
- Deciduous Forest
- Evergreen Forest
- Mixed Forest
- Shrubland
- Grasslands/Herbaceous
- Urban / Recreational Grasses
- Agricultural lands
  - Pasture/Hay
  - Row Crops
  - Small Grains
- Other
  - Quarries/Strip Mines/Gravel Pits
  - Transitional (new development)

The percent imperviousness applied to each of these urban land uses and then used in calculation of the runoff coefficient for this assessment are as follows:

Land cover class	Percent impervious
Low intensity residential	32%
High intensity residential	42%
Commercial/Industrial/Transportation	57%
Urban / Recreational Grasses	32%
Transitional	57%

(adapted from Zielinski, 2002 and analysis of TCMA GIS coverage)

For this assessment, all of the developed urban uses are assumed to have storm water conveyance systems in place – minimally drainage ditches and conveyance channels up to full curb and gutter with piping. The number of acres for each of the four developed urban land uses was determined for the incorporated areas in each of the ten basins. To calculate the expected concentration of total phosphorus in urban runoff for each basin, the average percent imperious area for the four developed urban land uses (high and low intensity residential, commercial/industrial/transportation and urban/recreational grasses) in each basin and the annual precipitation for the dry, average, and wet year were used as inputs to the regression model.

Phosphorus loading from the four developed urban land uses in each basin was then calculated according to the following equation:

*Basin load = Concentration * Contributory area * Runoff coefficient * Annual Rainfall Depth*

where: concentration is based upon the concentration regression equations developed for urban runoff in each of the basins,

contributory area is equal to the total area for each land use class,

runoff coefficient = 0.05 + 0.009 * impervious percentage,

annual rainfall depth is the annual precipitation for the loading flow condition scenario by basin.

The phosphorus load for each of the other non-agricultural land uses within incorporated areas were calculated by multiplying the phosphorus export coefficient by the contributory area and basin runoff factor, as described in Section 2.2.2.6. Phosphorus loads from agricultural land uses within incorporated areas were calculated using the same methodology as for the remaining agricultural areas statewide, as described in Section 2.2.2.1.

2.2.3 Bioavailability of Phosphorus by Source

The purpose of this section is to provide a discussion about the bioavailable fraction of phosphorus from individual point and nonpoint sources of phosphorus. A more detailed discussion of the methodology and results of this analysis are included in Appendix K. The results of the bioavailable phosphorus determinations for each source category are also presented in Section 3.2. This discussion is based on a review of the available literature and the results of POTW-specific and basin-specific sampling and analysis. This section is intended to:

- Provide an introduction to the forms of phosphorus in the aquatic environment
- Describe the results of the literature review for each category of point and nonpoint sources

- Present the results of POTW-specific and basin-specific sampling and analysis for bioavailable phosphorus

- Compare and summarize estimates of bioavailable phosphorus fraction for each source type

2.2.3.1 Forms of Phosphorus in the Aquatic Environment

In general, bioavailable phosphorus is defined as the portion of the total phosphorus in surface waters that is available for plant growth. Excess bioavailable phosphorus in freshwater systems can result in accelerated plant growth. Phosphorus is the principal nutrient causing excessive growth of algae and other aquatic plants in Minnesota's surface waters.

Phosphorus exists in water in either a dissolved phase or a particulate phase. Dissolved phosphorus in natural waters is usually found in the form of phosphates (PO_4^{-3}). Dissolved phosphates exist in three forms: inorganic (commonly referred to as orthophosphate or soluble reactive phosphorus- SRP), inorganic polyphosphate (or metaphosphate) and organically bound phosphate. Particulate phosphorus contains phosphorus sorbed to inorganic (mineral) and organic particles, including phosphorus contained within algae. Dissolved inorganic phosphate (orthophosphate) is the form required by plants for growth. The analytical procedure for measuring total phosphorus, which includes a sulfuric acid extraction, accounts for all forms of phosphorus, both dissolved and particulate, including phosphorus contained in algae.

Orthophosphates are immediately available in the aquatic environment for algal uptake. Natural processes produce orthophosphates, but major man-influenced sources include: partially treated and untreated sewage; runoff from agricultural sites; and application of some lawn fertilizers. Orthophosphate concentrations in a water body vary widely over short periods of time as plants take it up and release it. Polyphosphates are used for treating boiler waters and in detergents. Also, polyphosphates are used in drinking water treatment in many municipalities. In water, polyphosphates are unstable and will eventually convert to orthophosphate and become available for plant uptake.

Organic phosphates (particulate and dissolved) are bound or tied up in plant or animal tissue, waste solids, or associated with other organic matter. Organic phosphates are formed primarily by biological processes. They are contributed to sewage by body waste and food residues, and also may be formed from orthophosphates in biological treatment processes or by receiving water biota. After decomposition, the organic form can be converted to orthophosphate as a result of microbially-induced mineralization of phosphorus-containing organic matter.

Not all forms of phosphorus are utilized to the same degree or at the same rate by plants and microbial communities. Association of phosphorus with particulate or organic matter reduces bioavailability; such forms of phosphorus are immediately unavailable for uptake by algae. While a significant amount of phosphorus can enter water bodies in an immediately unavailable form, there is the potential for this unavailable phosphorus to undergo physical or chemical cycling processes that may convert it (all or partially) to the readily bioavailable form of phosphorus, orthophosphate. For example, the decomposition of organic matter by microbial activities can result in mineralization of phosphorus to orthophosphate. Desorption or dissolution of particle-associated phosphate represents another mechanism of conversion from unavailable to bioavailable forms.

DePinto *et al*. (1986) characterized phosphorus into three forms: orthophosphate – immediately bioavailable for algal uptake; external ultimately-available phosphorus – not immediately available but ultimately converted to orthophosphate at a specific rate; and external refractory phosphorus – not available while in the water column. Total bioavailable phosphorus is then comprised of orthophosphate and the external ultimately-available phosphorus. It is indeed the bioavailable phosphorus that affects the algal production in the aquatic environment in combination with other nutrients (e.g. nitrogen and silicon), light, and temperature.

Different sources provide water bodies with a variety of the forms of phosphorus described above, in variable proportions. Phosphorus in lakes and streams comes from both point and nonpoint sources. Point sources are typically publicly-owned wastewater treatment plants (POTWs) and permitted industrial discharges. Phosphorus discharged from wastewater treatment plants may come into the plant from a variety of sources. Nonpoint sources are typically polluted runoff from cities and farmland, erosion and sedimentation, atmospheric deposition, direct input by animals and wildlife, and natural decomposition of rocks and minerals.

A comprehensive literature search and review was conducted to compile available information on the bioavailable phosphorus fractions of individual point and nonpoint sources of phosphorus to surface waters. The results of this literature review are presented in the following discussion.

2.2.3.2 Bioavailable Phosphorus in POTW Effluent

The bioavailable phosphorus fraction in POTW effluent is generally assumed to be high compared to that of other sources to surface waters (Lee *et al*., 1980). Young *et al*. (1982) sampled the effluent from four municipal treatment plants in the vicinity of the Great Lakes during the summer of 1979 for bioavailable phosphorus. They conducted bioassays where measurement of phosphorus taken up by *Scenedesmus* sp. provided the measure of bioavailable phosphorus fraction. They developed a series of relationships among different forms of phosphorus.

On average, 82% of the dissolved phosphorus was bioavailable in the short term (less than 30 days from sample collection). Orthophosphate was a major component of the dissolved phosphorus (69% on average). Moreover, the regression coefficient relating bioavailable dissolved phosphorus to orthophosphate was unity, indicating that the orthophosphate fraction was totally available.

For particulate phosphorus, they found that the bioavailable particulate phosphorus correlated closely with the total particulate phosphorus fractions. On average (with the samples taken from the effluent of the four wastewater treatment plants), 55% of the total particulate phosphorus was bioavailable in the short term (again, less than 30 days).

The ultimately bioavailable dissolved phosphorus (became bioavailable after 30 days) represented approximately 99 percent of the total dissolved phosphorus. The ultimately bioavailable particulate phosphorus was approximately 63 percent of the total particulate phosphorus.

Data from the wastewater treatment plants indicated that 83% of the total wastewater phosphorus in those effluent samples was ultimately available.

In addition to the information gathered from the literature review, effluent from eight Minnesota POTWs was sampled between October 13 and October 17, 2003. The samples were analyzed for total phosphorus and orthophosphate. The ultimately bioavailable particulate phosphorus was estimated using the relationship developed by Young *et al*. (1982) described above. The results of this analysis are presented in Table 2-2. The bioavailable phosphorus fraction in these samples ranged from 75-96%, with an average of 85.5%, which is typical for POTW effluents based on the results of the literature review. Measured particulate phosphorus concentrations also are consistent with expected range based on the literature. Chemical and biological phosphorus removal is implemented at all of these POTWs with the exception of Albert Lea and Wilmar. Albert Lea and Wilmar also have industrial discharges to the POTW that contain high phosphorus levels.

Table 2-2 Estimated Bioavailable Phosphorus (BAP) Fractions of Samples Collected from the Final Effluent of Eight Minnesota POTWs

City	TSS (mg/L)	Total P (mg/L)	Orthophosphate (mg/L)	Particulate P (mg/L)	Ultimately Bioavailable Particulate P (mg/L)	Particulate BAP fraction	Total BAP fraction
Albert Lea	<5.0	5.32	4.31	1.01	0.65	0.64	0.93
Alexandria	<5.0	0.187	0.102	0.085	0.07	0.78	0.90
St. Cloud	<5.0	0.250	0.068	0.182	0.13	0.70	0.78
Fergus Falls	<5.0	0.166	0.019	0.147	0.11	0.72	0.75
Mankato	11	2.04	1.57	0.47	0.31	0.66	0.92
MCES-Metro	<5.0	0.293	0.130	0.163	0.12	0.71	0.84
Rochester	13	0.948	0.286	0.662	0.43	0.65	0.76
Wilmar	10	7.24	6.41	0.83	0.54	0.65	0.96

2.2.3.3 Bioavailable Phosphorus in Runoff

The transfer of phosphorus from terrestrial to aquatic systems in runoff can occur in dissolved and particulate forms. Phosphorus loading from nonpoint sources depends on a large number of factors, such as geology and hydrology of the region, land use, and population density. For example, sandy soils have less retention of phosphorus than clays and high slope and high runoff lead to lower retention. Caraco (1995) found that population density was related to orthophosphate export from watersheds and predicted 47% of the variation in orthophosphate export in the dataset from 32 large rivers. Other variations could be related to the geochemical factors that alter orthophosphate in rivers or could be due to variability in human behaviors that lead to variable phosphorus export. For example, human agricultural practices, soil composition, diets, detergent use, and extent of sewer services and sewage treatment can vary greatly between different areas. Phosphorus loss from land not only affects the surface runoff, but also gets transferred in subsurface flow (Gaynor and Findley, 1995; Lennox *et al*., 1997; Haygarth *et al*., 1998; and Withers *et al*., 1999).

It has been shown that the orthophosphate concentration in surface runoff is related to the soil phosphorus concentration in the topsoil (McDowell and Sharpley, 2001). For example, Pote *et al*. (1996) found that that the orthophosphate concentration in surface runoff was linearly related to phosphorus extracted by Mehlich-3 (r^2 of 0.72), Bray-I (r^2 of 0.75), Olsen (r^2 of 0.72), distilled water (r^2 of 0.82), iron oxide paper (r^2 of 0.82), acidified ammonium oxalate (r^2 of 0.85), and phosphorus sorption saturation (r^2 of 0.77).

Surface runoff from grassland, forest land or nonerosive soils carries little sediment and is generally dominated by dissolved phosphorus, although phosphorus transport attached to colloidal material also may be important where land is overstocked (Haygarth and Jarvis, 1997; Simrad *et al*., 2000). Sharpley *et al*. (1995) also reported that runoff from grass and forestland carries little sediments, and is therefore, generally dominated by orthophosphate.

As reported by Sharpley *et al*. (1995), the discharge of organic and inorganic phosphorus in runoff from several Atlantic Coastal Plain watersheds was related to soil phosphorus composition. The high organic phosphorus content of forest soils (331 mg/kg; 70% of total phosphorus) contributed 51% of total phosphorus loss in runoff (0.31 kg/ha/y) as particulate organic phosphorus and 10% as dissolved organic phosphorus. For agricultural soils of lower organic phosphorus content (161 mg/kg, 25% of total phosphorus), only 32% of total phosphorus loss in runoff (2.41 kg/ha/y) was particulate organic phosphorus and 1% was dissolved organic phosphorus (Vaithiyanathan and Correll, 1992). Similarly, from 16 to 38% of phosphorus in runoff from Polish meadows and cultivated fields and as much as 70% of lake water phosphorus was bound to organic compounds (Szpakowska and Zyczynska-Baloniak, 1989). These losses varied seasonally, with both inorganic and organic phosphorus concentrations in canal and lake water decreasing during summer months (Ryszkowski *et al.*, 1989).

Estimates for urban runoff particulates, tributary particulates and lake sediments in the lower Great Lakes basins by bioassay methods have reported an average of 30% bioavailable phosphorus (Cowen and Lee, 1976; Williams *et al*., 1980).

2.2.3.4 Bioavailable Phosphorus in Agricultural Runoff

The sources of phosphorus from agricultural land can include soil phosphorus, manure or fertilizer applications. Those sources of phosphorus emanate from a number of source areas within the landscape and their amount, form, and timing are very variable as a result of short-term and often unpredictable changes in hydrological conditions and farming practices, including crop rotation, the application of fertilizers and manures, or the movement of animals from one field to another (Lennox *et al*., 1997). Phosphorus may be transported to a water body from agricultural lands by leaching, runoff or erosion. The loss of phosphorus in surface runoff from agricultural lands occurs as particulate and dissolved forms (Haygarth and Sharpley, 2000). Particulate phosphorus includes phosphorus associated with soil particles and large molecular-weight or organic matter eroded during flow events and constitute the major proportion of phosphorus transported from most cultivated lands (60-90%, Pietilainen and Rekolainen, 1991). Several studies have reported that the loss of dissolved phosphorus in surface runoff from agricultural land depends on the phosphorus content of surface soil (STP- soil test P concentration), but that the relationship varies with soil type, tillage, and crop management (Pote *et al*., 1996; Sharpley *et al*., 1996). Moreover, it will depend on the topography and soil hydrology.

James *et al*. (2002) used fractionation procedures and phosphorus adsorption-desorption assays to delineate bioavailable forms and refractory or unavailable forms of phosphorus in the runoff of the Redwood River basin, an agriculturally-dominated tributary of the Minnesota River. Over several storm periods monitored in 1999, 75% of the phosphorus load originating from the watershed was in bioavailable forms while only 25% was in refractory forms. Bioavailable particulate forms included phosphorus loosely bound to suspended sediments (19%), phosphorus bound to iron (11%), and bioavailable particulate organic phosphorus (14%). After runoff discharges to receiving waters, the former two forms of bioavailable particulate phosphorus can be transformed to dissolved forms that are available to biota for uptake via eH and pH reactions and kinetic processes, while the latter form can be mineralized via decomposition processes. Bioavailable dissolved forms included orthophosphate and dissolved organic phosphorus.

Several studies have suggested that agricultural management may influence the bioavailability of phosphorus transported in runoff (McDowell and McGregor, 1980; Wendt and Corey, 1980). Concentration and amounts of bioavailable phosphorus in runoff from corn (*Zeamays* L.) were lower from no till compared to conventionally tilled plots under simulated rainfall (Andraski *et al*., 1985; Mueller *et al*., 1984). Bioavailable phosphorus in these studies was measured by resin extraction of unfiltered runoff, and thus includes dissolved phosphorus plus phosphorus desorbed from sediment (Huettl *et al*., 1979). However, Andraski *et al*. (1985) calculated that bioavailable phosphorus averaged 20% of total phosphorus and was not affected by tillage treatment.

Sharpley *et al*. (1992) assessed the impact of agricultural practices on phosphorus bioavailability in runoff by determining dissolved phosphorus, bioavailable particulate phosphorus, and particulate phosphorus in runoff from 20 watersheds (in the Southern Plains region of Oklahoma and Texas) unfertilized and fertilized, grassed and cropped watersheds over a 5-yr period. Although bioavailable phosphorus and bioavailable particulate phosphorus losses in runoff were reduced by agricultural practices minimizing runoff and erosion, the proportion of phosphorus transported in bioavailable forms increased. Both total phosphorus (14-88% as bioavailable phosphorus) and particulate phosphorus (9-69% as bioavailable particulate phosphorus) bioavailability varied appreciably with agricultural practices. Thus, bioavailable phosphorus is a dynamic function of physical and chemical processes controlling both dissolved phosphorus and bioavailable particulate phosphorus transport. Dissolved phosphorus transport depends on desorption-dissolution reactions controlling phosphorus release from soil, fertilizer reaction products, vegetative cover, and decaying plant residues. Bioavailable particulate phosphorus is a function of physical processes controlling soil loss and particle-size enrichment and chemical properties of the eroded soil material governing phosphorus sorption availability. The authors also found that the percent bioavailability of particulate phosphorus transported in runoff from each of these watersheds decreased with an increase in sediment concentration of runoff averaged for each watershed. They found a linear regression relationship between particulate phosphorus availability and logarithm of sediment concentration (with r^2 =0.84):

$$\textit{Particulate Phosphorus Bioavailabilty}\ (\%) = 82 - 15 \log \textit{sediment conc.}\ (g / L)$$

This relationship may be attributed to an increased transport of silt- and sand-sized (>2 µm) particles, of lower phosphorus content than finer clay-sized (<2 µm) particles, as sediment concentration of runoff increases. Further, particulate phosphorus bioavailability may decrease with an increase in size of eroded soil particles, which contain less sorbed phosphorus and more primary mineral phosphorus (i.e., apatite) of lower availability compared with finer clay-sized particles (Dorich *et al*., 1984; Sharpley *et al*., 1981; Syers *et al*., 1973).

O'Connor *et al*., (2002) compared phosphorus bioavailability of biosolids, manures and fertilizer. They found that phosphorus bioavailability was greater for phosphorus-fertilizer than manures and biosolids. However, if biological phosphorus removal is implemented in the treatment process, phosphorus in biosolids tends to be as bioavailable (74% to 132%) as fertilizer phosphorus.

A study conducted by Ekholm and Krogerus (2003), with samples from different sources, concluded that phosphorus in agricultural runoff appeared to be more bioavailable to algae (31%) than phosphorus in forest runoff (16%).

2.2.3.5 Bioavailable Phosphorus in Atmospheric Deposition

For Lake Michigan, Murphy and Doskey (1975) reported a 30-fold greater total phosphorus concentration in rainfall than in lake water. Since 25-50% of the total phosphorus in rainfall is soluble, it is directly available to organisms in the lake (Murphy and Doskey 1975; Peters 1977).

The bioavailability of dry deposition or the particulate fraction of wet deposition can be characterized by the bioavailability of phosphorus in the soils in the region.

Increases in the atmospheric deposition of phosphorus may result from annual climatic changes (Sharpley *et al*. 1995). For example, the input of phosphorus in rainfall to an Oklahoma watershed in 1981 (208 g/ha/yr) was much greater than that in either 1982 (49 g/ha/yr) or 1983 (41 g/ha/yr) (Sharpley *et al*. 1985). This increase was attributed to the low annual rainfall in 1980 (642 mm, 105 mm below average). The drier soil was more susceptible to wind erosion and the airborne material increased the phosphorus content of subsequent rainfall and dry deposition.

2.2.3.6 Comparison of Phosphorus Bioavailability from Different Sources

Many forms of particulate matter in the waters of the State of Minnesota contain a certain amount of bioavailable phosphorus, the actual rate and extent of release of the bioavailable component depends on the physical and chemical characteristics of the material. It also depends on the biological characteristics as well as the population of the microorganisms in the suspended material mineralizes the organic detritus material. Young *et al*. (1995) have compared the relative bioavailability of particulate phosphorus from various sources to the Great Lakes by comparing the bioavailable phosphorus in particulate matter from point sources (wastewater suspended solids), and nonpoint sources (suspended solids and bottom sediments from tributaries, lake bottom sediments, and eroding bluff solids from the region). A wastewater treatment plant at Ely, Minnesota was also sampled and it showed the highest rate of release of bioavailable particulate phosphorus (0.27 grams released/gram particulate phosphorus/day, or 0.27/day) among the point and nonpoint sources sampled in that study (Young and DePinto, 1982). The release rate did appear to decline in magnitude as treatment of wastewater progressed from the raw influent → biologically treated effluent → final effluent (i.e., 0.30 /day → 0.27 /day → 0.20 /day). Young and DePinto (1982) summarized the results on relative bioavailability of particulate phosphorus for the point and nonpoint sources (Table 2-3).

Ekholm and Krogerus (2003) analyzed 172 samples (during 1990-2000) representing phosphorus in point and nonpoint sources and in lacustrine matter. The bioavailability of phosphorus expressed as the proportion of potentially bioavailable phosphorus ranged from 3.3 to 89% (Table 2-4).

Table 2-3 Relative Bioavailability of Particulate Phosphorus from Various Sources to the Lower Great Lakes (Young and DePinto 1982)

Source	Bioavailable Percentage	Release Rate (1/day)
Wastewater (≤ 80%)	≤ 80%	≤ 0.4
Bottom sediments (≤ 50%)	≤ 50%	≤ 0.2
Tributary suspended sediment	≤ 40%	≤ 0.1
Eroding bluff	~0	~ 0

Table 2-4 Proportion of Bioavailable Phosphorus in Total Phosphorus by Different sources (Ekholm and Krogerus 2003)

	Bioavailable P (% of Tot-P)	
Source	**Mean**	**Min.-Max.**
Wastewater effluent from rural population	89	74-98
Biologically treated urban wastewater effluent	83	61-103
Dairy house wastewater	69	27-93
Biologically and chemically treated wastewater effluent	36	0-67
Field runoff	31	15-50
Industrial wastewater effluent	30	4-89
Fish fodder and feces	29	9-72
Large Rivers water	20	3-45
Agricultural rivers	20	12-30
Field surface soils	19	6.8-24
Forest runoff	16	0-55
Lake settling matter	7.9	1.6-21
Lake bottom sediments	3.3	0.1-11

2.2.3.7 Summary of Literature Review

The above review covers as much research and data from phosphorus bioavailability studies as could be found in the available time and resources. There is a desire to estimate the fraction of phosphorus in each potential source category identified by the MPCA as contributing phosphorus to Minnesota waters. However, the bioavailability of some of these individual source categories has not been studied; therefore, we were not able to find directly applicable estimates for bioavailable fractions in the literature. The general categories for which data are available include: municipal wastewater treatment plants, agricultural, forest and urban runoff, and atmospheric deposition.

While the dissolved phosphorus from any of these sources can generally be assumed to be 100% bioavailable, the particulate phosphorus associated with these various source categories in general exhibit a wide range of bioavailability.

For point sources, the fraction of total phosphorus in the discharge that is bioavailable is not only governed by the sources of phosphorus to the treatment plant influent (e.g., human wastes, household cleaners, groundwater infiltration, etc.) but it will be dependent on the treatment train being employed within the plant. Data are generally available for wastewater treatment plant influent and effluent, however not for all individual phosphorus source categories. Knowing, however, that household cleaners and detergents are amended with polyphosphates, it is reasonable to assume that virtually 100% of these categories will ultimately become available by hydrolysis to orthophosphates.

For nonpoint sources, the input of total phosphorus and bioavailable phosphorus will be strongly dependent on the land use from which the phosphorus load is derived (e.g., agricultural runoff will be different from forestland runoff). Furthermore, agricultural practices can affect bioavailable phosphorus appreciably. Another determinant is the surficial geology within the watershed. We have seen, for example, that phosphorus associated with calcareous minerals like apatite is much less bioavailable than phosphorus adsorbed to iron-oxide minerals. In general, the particulate phosphorus in non-point sources derived from land runoff tends to be less bioavailable than point source particulate phosphorus.

Bioavailable phosphorus fractions for each of the specific source categories of interest were estimated by combining the results of the literature review with best professional judgment to specify a most likely value for a number of the remaining phosphorus source categories. A range was also estimated in an attempt to cover the potential range site-specific determinations might show. These estimates are presented in Table 2-5. These estimates of bioavailable fraction should be used with care, understanding the uncertainty inherent in each estimate. Nevertheless, they can be used to assess relative contributions of bioavailable phosphorus from the source categories to assist in planning additional data collection or targeting specific sources for control. As evident from the literature review, wide ranges of bioavailable fractions were noted for runoff sources, while estimation techniques for the bioavailable fraction from POTW effluent were better quantified.

Table 2-5 Estimates of Bioavailable Phosphorus Fractions for Specific Source Categories

Phosphorus Sources			Fraction of PP that is Bioavailable (Range)	Fraction of PP that is Bioavailable (Most Likely)	Fraction of DP that is Bioavailable (Most Likely)	Fraction of TP that is Particulate (Most Likely)	Estimate of TP that is Bioavailable (Most Likely)
Point Sources	Phosphorus Sources to POTWs	Automatic Dishwasher Detergent	NA	NA	1.0	0.0	1.0
		Dentifrices (toothpastes)	0 – 0.1	0.05	NA	1.0	0.05
		Other Household Cleaners or Non-ingested Sources	NA	NA	1.0	0.0	1.0
		Food Soils/Garbage Disposal Wastes	0.7 – 0.9	0.8	1.0	0.9	0.8
		Human Waste Products	0.7 - 0.9	0.8	1.0	0.3	0.94
		Raw/Finished Water Supply	0.4 - 0.6	0.5	1.0	0.1	0.95
		Groundwater Intrusion (I&I)	0.2 - 0.5	0.3	1.0	0.5	0.65
		Process Water	0.2 - 1.0	0.7	1.0	0.1	0.97
		Noncontact Cooling Water	0.4 - 0.8	0.6	1.0	0.3	0.88
		Car Washes	0.2 - 0.8	0.5	1.0	0.3	0.85
	POTW Effluent		0.6 – 0.8	0.7	1.0	0.5	0.855
	Privately Owned Wastewater Treatment Systems for Domestic Use (effluent)		0.6 - 0.9	0.8	1.0	0.3	0.94
	Commercial/Industrial Wastewater Treatment Systems (effluent)		0.2 - 0.8	0.6	1.0	0.3	0.88
Non-Point	Individual Sewage Treatment Systems		0.6 - 0.9	0.8	1.0	0.2	0.96

Phosphorus Sources			Fraction of PP that is Bioavailable (Range)	Fraction of PP that is Bioavailable (Most Likely)	Fraction of DP that is Bioavailable (Most Likely)	Fraction of TP that is Particulate (Most Likely)	Estimate of TP that is Bioavailable (Most Likely)
Sources	Agricultural Runoff	Improperly Managed Manure	0.5 - 0.7	0.6	1.0	0.5	0.80
		Crop Land Runoff	0.2 - 0.7	0.4	1.0	0.7	0.58
	Urban Runoff	Turfed Surfaces	0.2 - 0.7	0.4	1.0	0.7	0.58
		Impervious Surfaces	0.10 - 0.5	0.2	1.0	0.5	0.60
	Forested Land		0.2 - 0.5	0.3	1.0	0.8	0.44
	Roadway and Sidewalk Deicing Chemicals	salt	0.2 - 0.8	0.6	1.0	0.2	0.92
		sand	0.1 - 0.3	0.2	1.0	0.8	0.36
	Stream Bank Erosion		0.1 - 0.5	0.3	1.0	0.8	0.44
	Atmospheric Deposition	Dry	0.05 – 0.4	0.2	NA	1.0	0.2
		Wet	0.05 – 0.4	0.2	1.0	0.6	0.5

2.2.4 Assessment of Effluent Total Phosphorus Reduction Efforts by POTWs

This section provides a general discussion about the methodology used to assess the effluent total phosphorus reduction efforts of POTWs. A more detailed discussion of the methodology used for this analysis is included in Appendix L. The results of this assessment are discussed in Section 3.5.

This discussion is intended to provide the Minnesota Pollution Control Agency (MPCA) with information on current practices of cities to reduce the phosphorus concentration in their wastewater treatment plant (WWTP) effluent through such approaches as reduction in the influent phosphorus loading, chemical phosphorus precipitation, and enhanced biological phosphorus removal (EBPR). Information was collected from six Minnesota cities and two Oregon cities on their programs to reduce their effluent phosphorus loading. A small sampling of Minnesota cities was used due to the limited number of cities that had data available on phosphorus reduction and its costs. The two Oregon cities were included because of their ability to meet a very stringent effluent phosphorus limit of 0.07 mg/L. Where available, costs for the specific phosphorus reduction efforts are provided. Finally, conclusions are drawn on the effectiveness of effluent phosphorus reduction efforts based on the data provided.

As mentioned above, three approaches were used either separately or in combination by the communities surveyed to reduce their effluent phosphorus concentrations: source reduction, chemical precipitation, and EBPR. Source reduction efforts varied significantly between cities in the survey. The simplest approach was a public education campaign to promote reductions in the use of household products with high concentrations of phosphorus. The more aggressive cities implemented fees based on the phosphorus content of the sewered discharge for their significant industrial users (SIU). Pretreatment was also required in one city if a SIU exceeded a pre-defined phosphorus loading threshold.

Chemical phosphorus precipitation is the use of metal salts to promote the precipitation of metal phosphates. Iron or aluminum are the most commonly used metals. The metal salt can be added at many different points in the WWTP treatment train. The most common point of application is immediately prior to secondary clarification. The chemical used and point of application are identified for each plant surveyed. The equipment required for chemical precipitation is minimal with systems adding metal salts prior to secondary clarification needing only a bulk storage tank and a chemical dosing pump. The largest cost for chemical precipitation phosphorus treatment is operations, which includes chemical cost and the cost of additional sludge disposal. The chemical costs are provided for all WWTPs surveyed using chemical precipitation.

EBPR is achieved in the activated sludge system by promoting the growth of bacteria that can hyper-accumulate phosphorus. This is achieved by creating an initial anaerobic zone in the activated sludge system followed by the traditional aerobic zone. In addition, low molecular weight organic acids must be present in the anaerobic zone to achieve EBPR. These acids can be produced in the sewer system, in the primary clarifier, or in a separate sludge fermenter. EBPR can be implemented using a wide range of approaches. The simplest approach can be to adjust air flow within the activated sludge basins to create the anaerobic zone. The more sophisticated approaches can require separate anaerobic basins and separate sludge digestion tanks. Phosphorus is ultimately removed from the EBPR system when the bacteria, which have hyper-accumulated phosphorus, are wasted from the activated sludge system.

It should be noted that WWTPs that have not implemented phosphorus treatment (i.e., either chemical phosphorus precipitation or EBPR) will likely see a reduction in the effluent phosphorus concentration proportional to the reduction in influent phosphorus concentration. WWTPs using chemical precipitation to meet effluent phosphorus limits will not likely experience a reduction in effluent phosphorus concentration if the influent phosphorus concentration is reduced because chemical precipitation will continue to be required to meet the effluent phosphorus limit. A reduction in influent phosphorus (soluble) concentration will reduce the amount of chemical required to achieve the effluent phosphorus limit, which will ultimately result in a reduction in chemical cost for phosphorus treatment. However, if the influent phosphorus was not soluble, which is precipitated chemically, but was particulate phosphorus, which is precipitated by flocculation, there may not be a direct reduction in chemical costs. Finally, WWTPs using EBPR will not likely experience a reduction in effluent phosphorus concentration if the influent phosphorus concentration is reduced because of the limits of this technology. The cost for operating EBPR will not be affected by the reductions in the influent phosphorus concentration.

3.0 Results and Discussion

3.1 Basin Hydrology

This section presents the results of statistical analyses done on the historical rainfall and runoff volumes to develop frequency curves and runoff maps that represent low, average and high flow conditions within each basin. The variability of basin hydrology is important since the phosphorus load estimates for each flow condition are based on the annual runoff volumes that have been determined from recent water year flow data. A more detailed discussion about the results of the assessment for the basin hydrology is included in Appendix A.

3.1.1 Frequency Curves

The runoff and precipitation frequency curves for each of the watersheds are shown in Appendix A. The curves show that for gages in the south and west portions of the state, the period of 1979-2002 flows were consistently above the long-term period of record. The frequency curves for much of Northeast Minnesota, particularly the Rainy River, the North Shore of Lake Superior, and St. Croix River basins did not show this trend. The curves indicate that there is a general trend of decreasing runoff from east to west. The Lake Superior basin has the highest runoff rate in the state, with the Baptism River watershed having the highest values within that basin (average annual runoff of 15.3 inches). The Red River of the North basin had the least runoff, with the Buffalo River watershed experiencing 2.8 inches of runoff in an average year, which is the lowest of the Minnesota gages used in this analysis. Decreasing runoff from east to west also occurs in southern Minnesota, but the trend is less dramatic than in the north. The Root River watershed in extreme southeast Minnesota has nearly 11 inches of runoff for the period of 1979-2002, while the Rock River in southwest Minnesota and northwest Iowa has average annual runoff of 5.6 inches. Increases in runoff are more dramatic moving south in the state, as flows approach high flow conditions.

3.1.2 Runoff Maps

As discussed in Section 2.1.2.5, the runoff frequency curves were used to develop maps showing the statewide runoff values. The maps showing the estimated runoff volumes during low (dry), average and high flow (wet) conditions are shown in Figures 3-1, 3-2, and 3-3, respectively. The runoff mapping confirms what the frequency curves indicated: there is a general trend of decreasing runoff from east to west, but the trend is less dramatic in the south, compared to the northern part of the state for each flow condition. Also, comparing the runoff volume gradients in the east and west

Figure 3-1 Annual Runoff, Low Flow Conditions

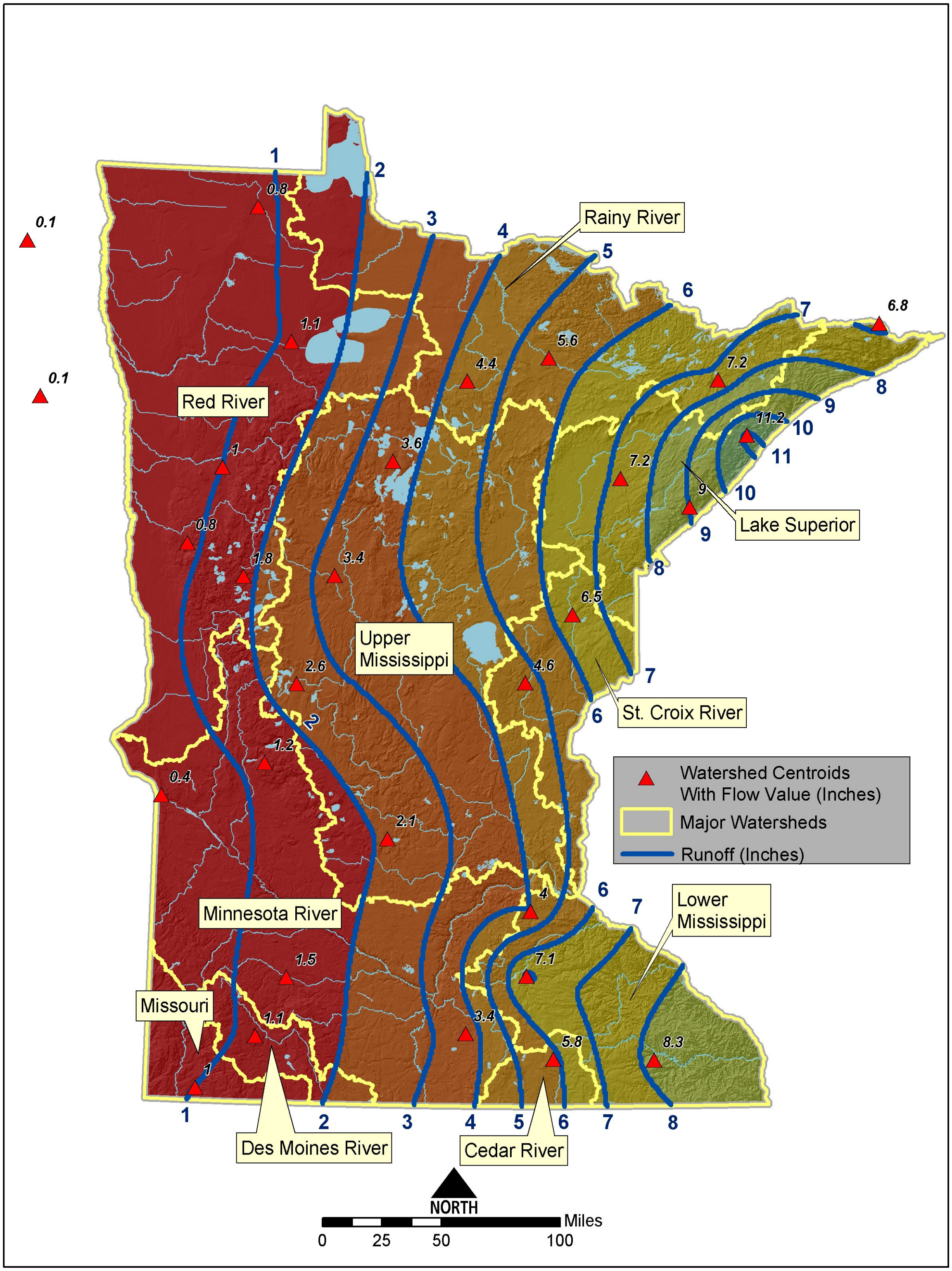


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Figure 3-2 **Annual Runoff, Average Flow Conditions**

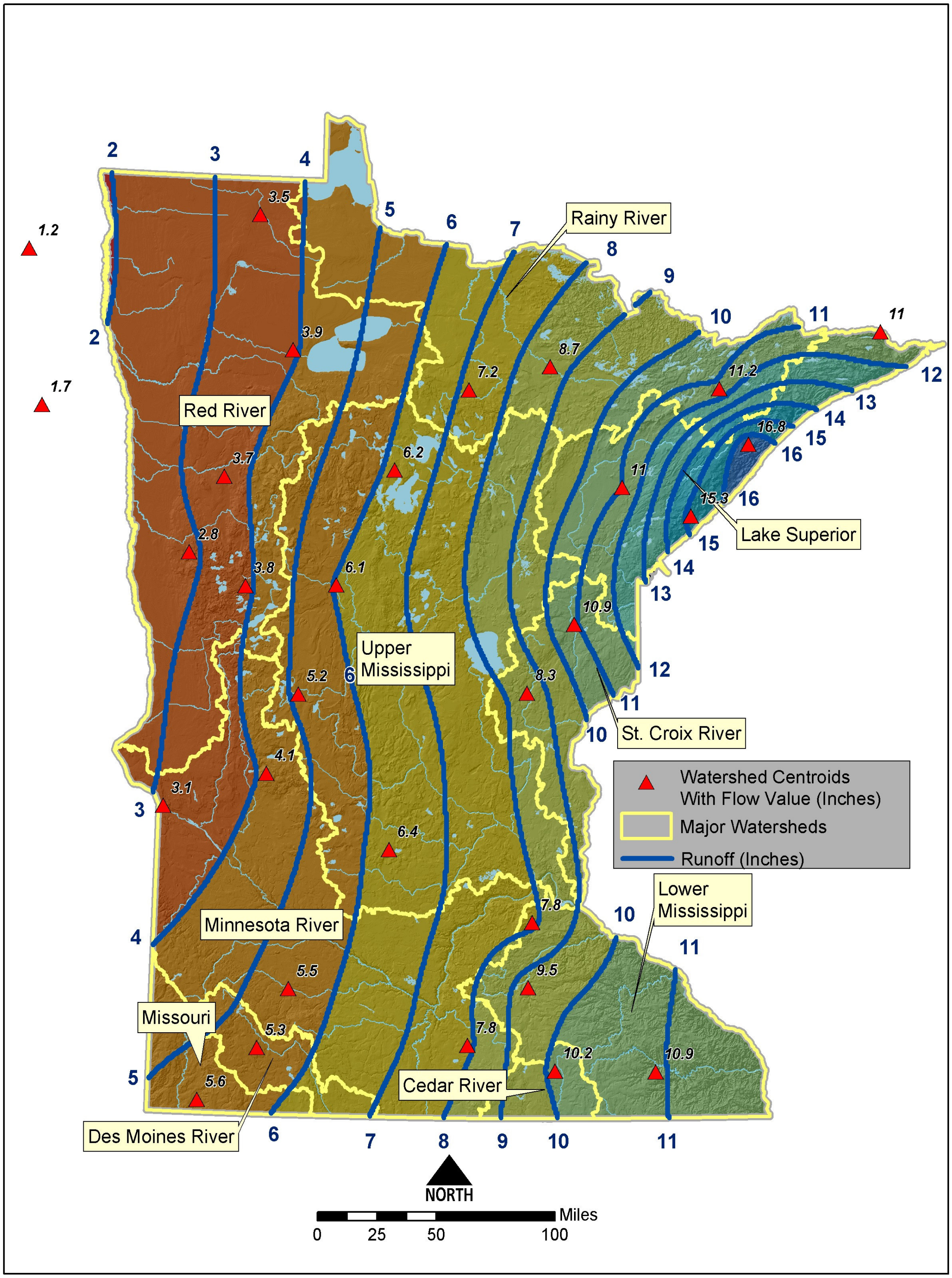

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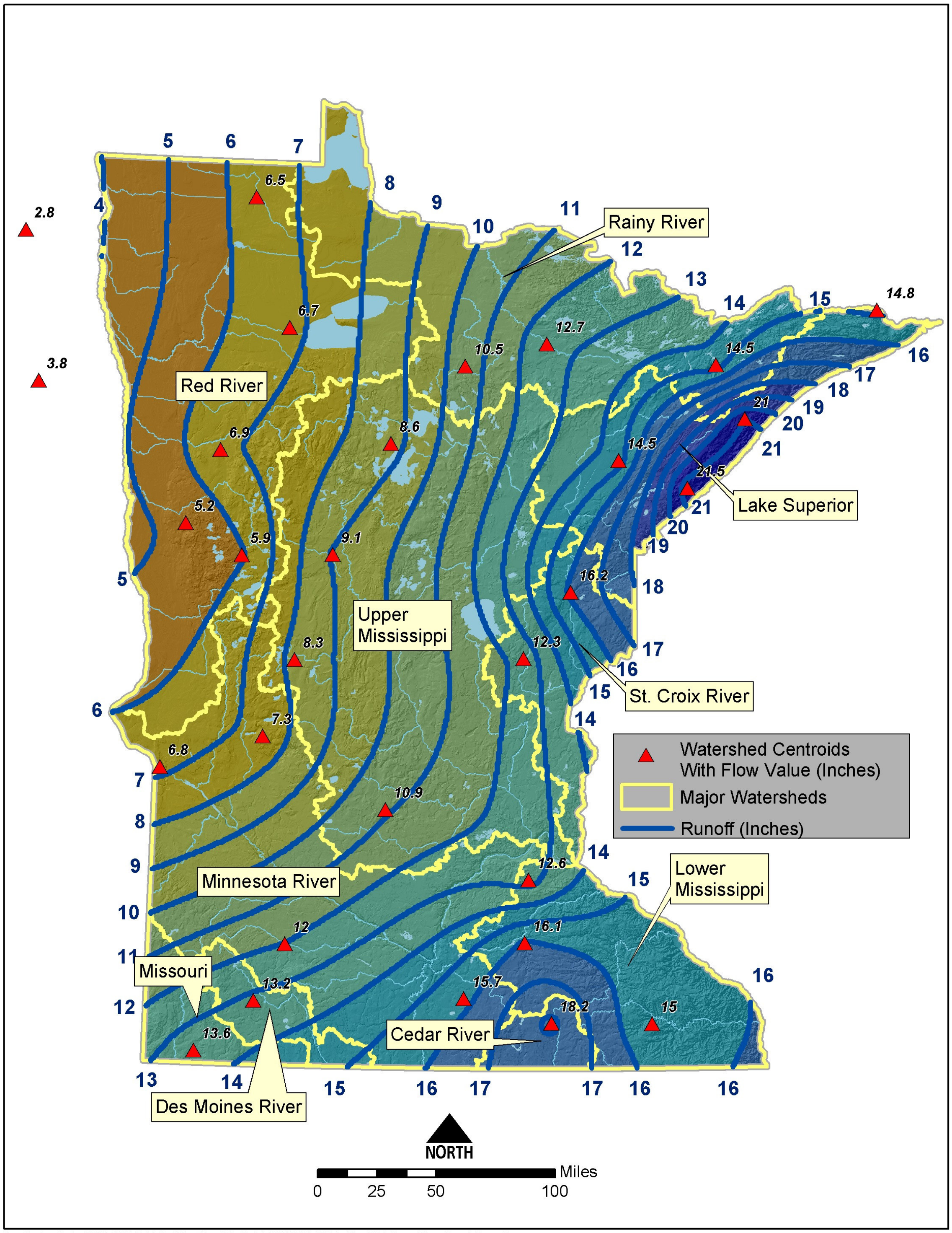
Figure 3-3 Annual Runoff, High Flow Conditions



Barr Footer: Date: 11/20/2003 2:14:57 PM File: I:\Projects\23\62\853\GIS\ArcMap\HighAnnualRunoff.mxd User: tja extremes of the state, shows that the gradient increases significantly from low to average flow, and from average to high flow, conditions.

Table 3-1 shows the 10 basinwide average values developed from these maps for the wet (high flow), average and dry (low flow) conditions. Table 3-1 also provides a summary of basin wide average precipitation for the wet, average and dry years based on the frequency determinations. Also shown in Table 3-1 is the runoff percentage calculated using the ratio of runoff to rainfall. This runoff percentage is significantly lower (less than 9 percent) for the Des Moines, Minnesota, Missouri, and Red River basins, compared to the remaining basins under low flow conditions. With the exception of the Upper Mississippi River (approximately 16 percent), the runoff percentage in the remaining basins exceeds 20 percent under low flow conditions. Comparing the runoff percentages from low flow to average and high flow conditions, the percentages increase more significantly (to between 21 and 37 percent) for the Des Moines, Minnesota, Missouri, and Red River basins, than they do for the remaining basins (between 30 and 48 percent). The runoff percentages under high flow conditions, with the possible exception of the Red River basin (21 percent), indicate that a large percentage of the rainfall volumes (between 30 and 48 percent) would be measured as runoff at a downstream gaging location. However, it should be noted that some portion of the runoff volumes shown in Table 3-1 does not represent runoff from land surfaces, and are actually entering surface waters from groundwater or other subsurface flow paths.

Table 3-1 Basinwide Runoff and Precipitation

	Dry Conditions			Average Conditions			Wet Conditions		
Basin	Rainfall (inches)	Runoff (inches)	Percent Runoff	Rainfall (inches)	Runoff (inches)	Percent Runoff	Rainfall (inches)	Runoff (inches)	Percent Runoff
Cedar River	27.5	5.6	20.4%	32.1	9.8	30.6%	41.3	17.5	42.4%
DesMoines River	22.0	1.4	6.4%	28.0	5.7	20.3%	36.8	13.4	36.4%
Lake Superior	25.5	7.9	30.8%	29.1	12.4	42.7%	35.1	16.7	47.7%
Lower Mississippi	27.0	7.1	26.5%	33.3	10.3	30.9%	39.8	15.6	39.1%
Minnesota River	22.1	1.9	8.7%	28.1	5.6	19.9%	34.8	11.2	32.2%
Missouri River	21.1	1.0	4.6%	27.2	5.3	19.3%	35.6	12.8	36.0%
Rainy River	22.4	4.8	21.4%	26.2	8.0	30.6%	32.1	11.4	35.6%
Red River	18.6	1.1	5.7%	23.3	3.4	14.7%	28.9	6.1	21.1%
St. Croix River	23.7	5.6	23.7%	30.6	9.7	31.7%	37.6	14.3	38.1%
Upper Mississippi River	22.6	3.6	15.8%	28.1	6.9	24.5%	34.3	10.4	30.5%

3.2 Estimated Basin Total Phosphorus Amounts Contributed to POTWs and Surface Waters (by Source)

This section is intended to present the results of the total phosphorus loading estimates to surface waters in each basin by source category. The following sections provide a detailed discussion of the results of the phosphorus loading estimates for each source category, including assessments of which major basins are specifically influenced by each source category. The phosphorus loading estimates are also further described in Appendices B through J.

3.2.1 Point Sources

3.2.1.1 Sources and Amounts of Phosphorus Discharged to POTWs

The sources of phosphorus to POTWs and to privately owned treatment facilities were identified and quantified by the methods described in Section 2.2.1.2. The total phosphorus load discharged to POTWs in each basin is presented in Table 3-2. The annual amount of total phosphorus discharged into POTWs in Minnesota is estimated to be 4,468,000 kg/yr. Table 3-2 shows that 53 percent (2,384,900 kg/yr) of the total phosphorus load discharged to POTWs originated from the Upper Mississippi River basin, which includes a majority of the loading to POTWs in the Twin Cities Metropolitan Area. The influent load to the Metro plant represents 75 percent (1,794,400 kg/yr) of the total phosphorus load discharged to POTWs in the Upper Mississippi River basin.

Table 3-2 Total Phosphorus Load Discharged to POTWs

Basin	Total (kg/yr)
Cedar River	105,200
Des Moines River	46,200
Lake Superior	227,000
Lower Mississippi River	501,900
Minnesota River	952,200
Missouri River	26,400
Rainy River	20,100
Red River	150,600
St. Croix River	53,500
Upper Mississippi River	2,384,900
Total	4,468,000

As part of this study, the influent phosphorus discharged into POTWs and publicly owned treatment facilities was separated into its major constituent sources. Figure 3-4A and 3-4B illustrates the contributions of various phosphorus sources to the influent phosphorus loads for the POTWs and privately owned treatment facilities. Both figures show that human waste, followed by commercial and industrial process wastewater, is the largest contributor of phosphorus to POTWs and privately owned treatment facilities in most of the basins. The influent phosphorus load discharged to POTWs and privately owned treatment facilities is also broken down by source category for the entire state in Table 3-3 and 34, respectively. Table 3-3 shows that human waste represents approximately 42 percent of the phosphorus load to POTWs in the state, while commercial and industrial process wastewater represents approximately 27 percent of the influent phosphorus load. Table 3-4 shows that human waste represents approximately 60 percent of the influent phosphorus load to the privately owned treatment facilities throughout the state. Comparing Table 3-3 to Table 3-4 reveals that the total influent phosphorus load to POTWs is approximately 500 times higher than the influent load to privately owned treatment facilities throughout the state.

The human waste component of the influent phosphorus loading to POTWs and privately owned treatment facilities is the single largest influent source in all ten basins. The human waste component comprises between approximately 36 percent and 69 percent on a basin basis and averages approximately 42 percent statewide of the total influent phosphorus loading.

Next to human wastes, a variety of industrial and commercial dischargers constitute the next highest contribution of phosphorus in influent to POTW wastewater. The commercial and industrial dischargers comprised between 5 percent and 35 percent, on a basin basis, and approximately 27 percent of the total phosphorus loads entering POTWs, statewide. The POTWs in the Minnesota River basin receive an average of 35 percent of the influent phosphorus load from commercial and industrial process wastewater sources. This is the only basin in which the commercial and industrial process wastewater contribution approaches the human waste contribution.

Figure 3-4A Average Influent Phosphorus Loading to POTWs & Privately Owned Treatment Facilities by Basin; less than 250,000 kg/yr

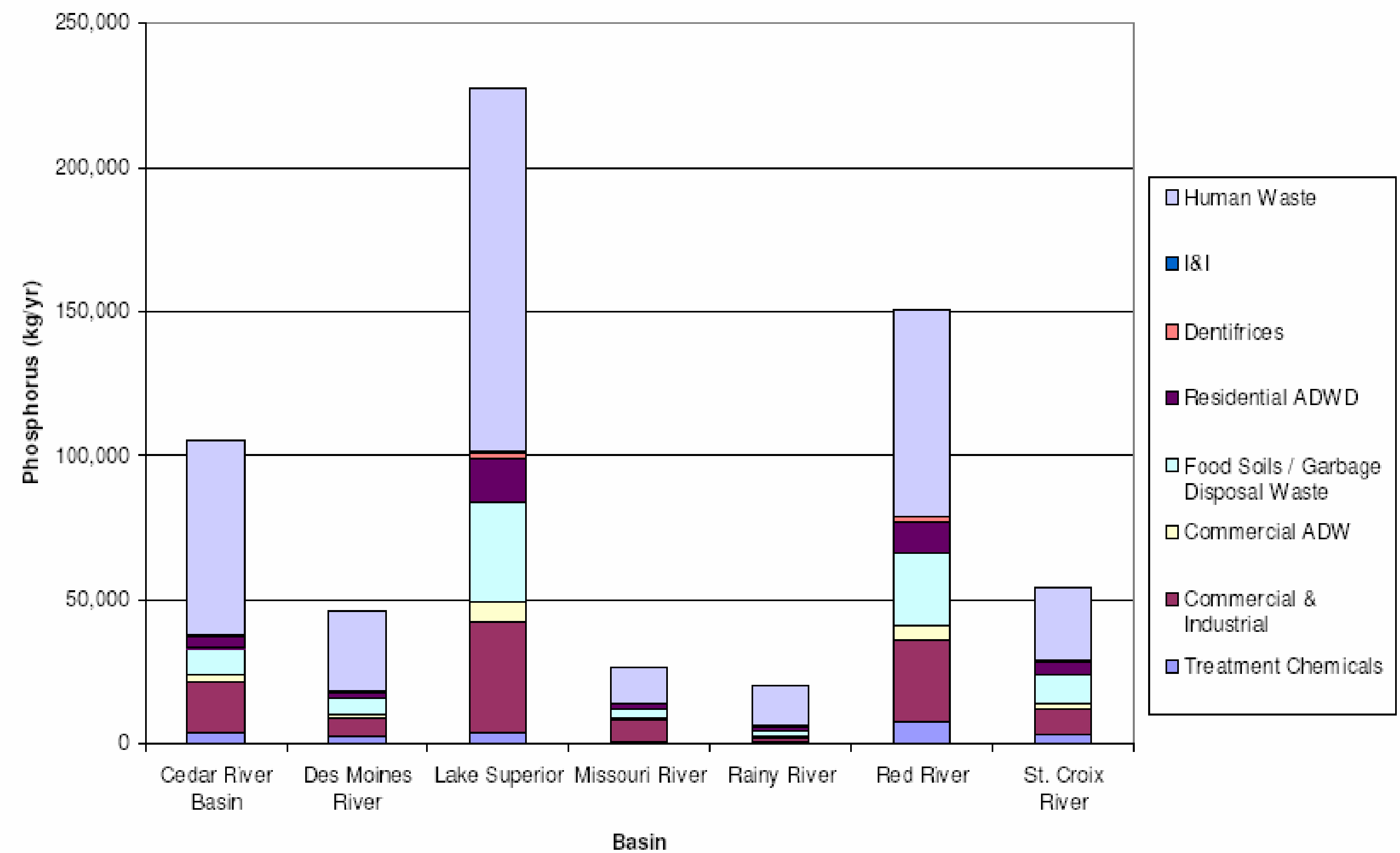


Figure 3-4B Average Influent Phosphorus Loading to POTWs & Privately Owned Treatment Facilities by Basin; greater than 250,000 kg/yr

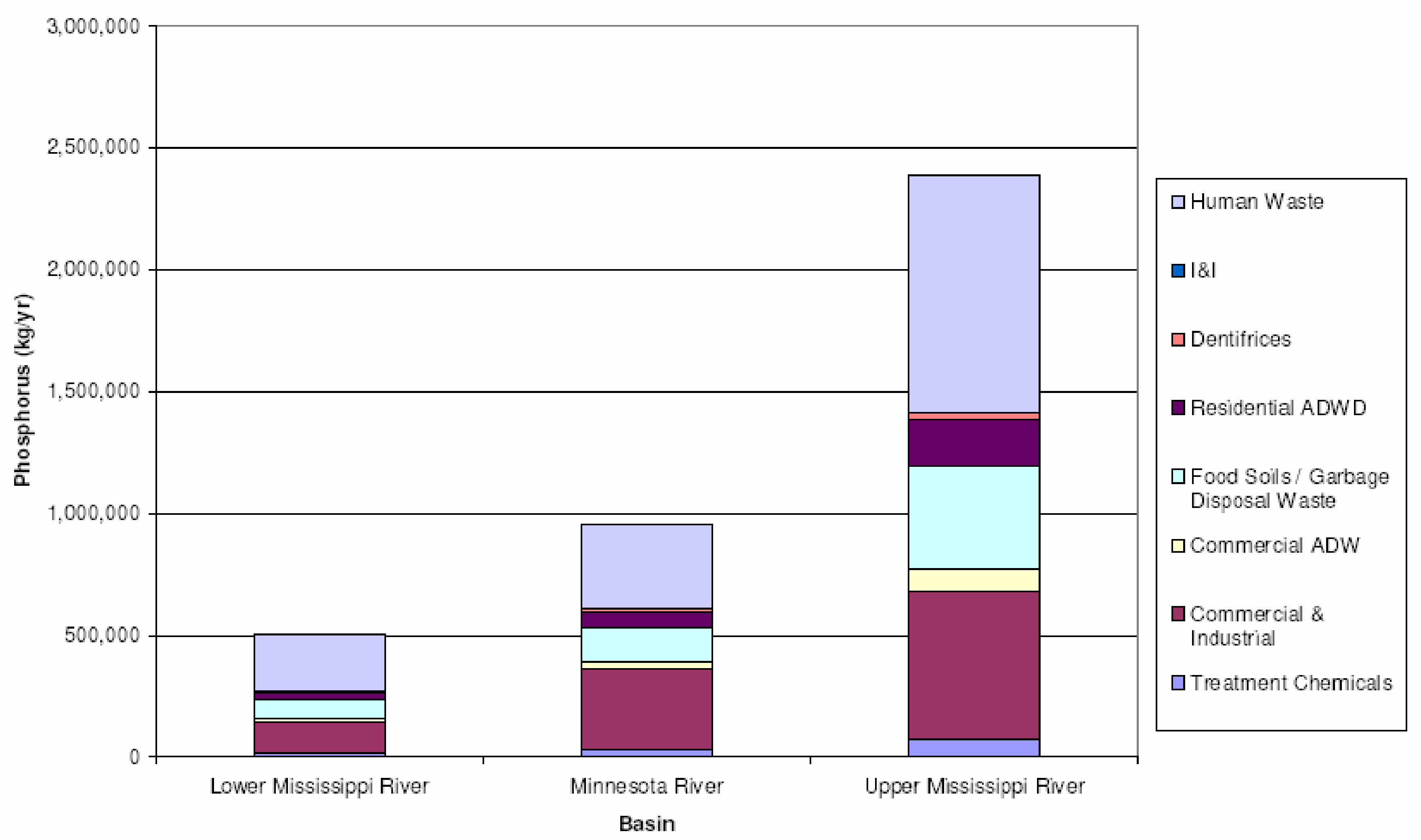


Table 3-3 Estimated Statewide Phosphorus Loadings to POTWs

		Phosphorus Load (kg/yr)		% of Total
INFLUENT				
Domestic Wastewater		2,986,392		66.8%
Residential Automatic Dishwasher Detergents	324,431		7.3%	
Food Soils / Garbage Disposal Waste	722,873		16.2%	
Dentifrices	43,894		1.0%	
Human Waste	1,895,195		42.4%	
Commercial & Industrial Process Wastewater		1,186,229		26.5%
Commercial & Institutional Automatic Dishwasher Detergent		151,815		3.4%
Water Treatment Chemicals		140,188		3.1%
Inflow & Infiltration		3,333		0.1%
Total		4,467,958		100.0%
EFFLUENT				
Total		1,735,869		100.0%

Table 3-4 Estimated Statewide Phosphorus Loadings to Private WWTP

		Phosphorus Load (kg/yr)		% of Total
INFLUENT				
Domestic Wastewater		7,804		97.6%
Residential Automatic Dishwasher Detergents	855		10.7%	
Food Soils / Garbage Disposal Waste	2,019		25.2%	
Dentifrices	118		1.5%	
Human Waste	4,813		60.2%	
Water Treatment Chemicals		193		2.4%
Total		7,997		100.0%
EFFLUENT				
Total		3,456		100.0%

The commercial and industrial process wastewater dischargers to POTWs were grouped by four digit NAICS code for each of the basins. The industries that contributed less than 1 percent of the industrial/commercial process wastewater phosphorus load were grouped in the "Other" category. The data suggests that food product processing is the largest contributor of commercial/industrial phosphorus discharged to POTWs. Animal slaughtering and processing (NAICS #3116) was the largest phosphorus contributor, estimated to discharge 168,000 kg/yr. Fruit and vegetable preserving and specialty food manufacturing (NAICS #3114) contributes 132,000 kg/yr, followed by grain and oilseed manufacturing (NAICS #3112) and dairy product manufacturing (NAICS # 3115), at 127,000 kg/yr and 45,000 kg/yr, respectively.

The information obtained regarding food soils and garbage disposal wastes suggests that this source category contributes a moderate amount of phosphorus to untreated wastewater. For the ten Minnesota basins, these amounts range from 8.8 percent to 18.4 percent and averages approximately 16 percent statewide of influent phosphorus totals. The total phosphorus load to POTWs and privately owned treatment facilities from food soils and garbage disposal wastes was estimated to be 725,000 kg/yr.

The residential use of ADWD detergents contributes a relatively smaller amount of phosphorus. For the Minnesota basins, these amounts range from 4.0 to 8.2 percent, and averaged 7.3 percent statewide, of influent total phosphorus discharging into POTWs and privately owned treatment facilities.

Dentifrices contribute a relatively small amount of phosphorus to the influent wastewater stream for each of the basins. These amounts range from 0.5 percent to 1.1 percent (1.0 percent statewide average) of the total influent phosphorus discharged into POTWs and privately owned treatment facilities.

The commercial and institutional use of ADWD detergents contributes a relatively small amount of phosphorus to untreated wastewater. For the ten Minnesota basins, these amounts ranged from 1.9 percent to 3.7 percent, while it was 3.4 percent of all sources for the statewide total influent phosphorus.

A variety of phosphorus-based chemicals are added to municipal water supplies to inhibit and control scale and corrosion, soften water and control pH. The municipal water treatment chemicals phosphorus contribution to POTWs ranged from 1.7 percent to 5.7 percent in each of the basins, and 3.1 percent statewide, of the total influent phosphorus.

The results of this study indicate that inflow and infiltration contribute a negligible amount of phosphorus to POTW influent. The inflow and infiltration contribution was approximately 0.1 percent of the total influent phosphorus load discharged into POTWs.

Subtracting the human waste component from the total POTW phosphorus influent yields the estimated total non-ingested phosphorus load discharged to POTWs. Table 3-5 presents the non-ingested phosphorus loadings to POTWs, by source category, for each basin and throughout the state. The total non-ingested phosphorus load to POTWs is approximately 2,572,900 kg/yr, which is approximately 58 percent of the total influent phosphorus load to POTWs. Commercial and industrial process wastewater represents approximately 46 percent of the total non-ingested phosphorus load. At 28 percent, food soils represent the next largest category of non-ingested phosphorus loading to POTWs. The combined residential ADWD detergent and commercial and institutional ADWD detergent categories represent approximately 18.5 percent of the non-ingested phosphorus loading to POTWs.

3.2.1.2 Phosphorus Loading to Surface Waters

The point source effluent phosphorus loads to each of the ten Minnesota basins and the state were computed using the methods described in Section 2.2.1.3. The estimated point source phosphorus loads to each of the ten Minnesota basins, along with the corresponding flow weighted mean concentrations on an average annual basis, are presented in Table 3-6. The estimated annual phosphorus load to waters of the state is 2,124,000 kg/yr, with a flow weighted mean effluent concentration of 0.6 mg/L. Fifty-six percent of the total point source effluent phosphorus load for the state is being discharged in the Upper Mississippi River basin. Table 3-6 also shows that the flow-weighted mean effluent phosphorus concentrations vary between 0.04 and 5.4 mg/L for the basins.

Table 3-5 Non-Ingested Phosphorus Loadings to POTWs

	Residential ADWD (kg/yr)	Food Soils / Garbage Disposal Waste (kg/yr)	Dentifrices (kg/yr)	Commercial and Industrial Process Wastewater (kg/yr)	Commercial and Institutional ADWD (kg/yr)	Water Treatment Chemicals (kg/yr)	Inflow and Infiltration (kg/yr)	Total (kg/yr)
Basin								
Cedar River	4,200	9,300	600	18,000	2,000	3,800	70	38,000
Des Moines River	2,400	5,300	300	6,600	1,100	2,600	30	18,300
Lake Superior	15,400	34,300	2,100	38,200	7,200	3,900	310	101,400
Lower Mississippi River	32,000	71,452	4,300	132,900	15,000	13,900	320	269,900
Minnesota River	63,100	140,700	8,500	333,200	29,500	31,500	610	607,100
Missouri River	1,400	3,200	200	7,500	700	1,000	20	14,000
Rainy River	1,300	2,500	200	1,000	600	700	20	6,300
Red River	11,200	24,900	1,500	28,000	5,200	7,800	120	78,700
St. Croix River	4,300	9,600	600	8,800	2,000	3,100	50	28,500
Upper Mississippi River	189,200	421,700	25,600	612,000	88,600	71,800	1,790	1,410,700
Total	324,500	723,000	43,900	1,186,200	151,900	140,100	3,300	2,572,900
Percent of Non-Ingested Phosphorus Load to POTWs	12.6%	28.1%	1.7%	46.1%	5.9%	5.4%	0.1%	

Table 3-6 Total Point Source Phosphorus Loads to Surface Waters for Each Basin and the State

Basin	Point Source Effluent Phosphorus Load (kg/yr)	Flow Weighted Mean Effluent Phosphorus Concentration (mg/L)
Cedar River	56,800	2.5
Des Moines River	55,500	5.4
Lake Superior	34,800	0.04
Lower Mississippi River	267,400	0.5
Minnesota River	371,700	0.6
Missouri River	13,200	3.3
Rainy River	44,300	0.6
Red River	78,100	0.8
St. Croix River	22,100	1.3
Upper Mississippi River*	1,180,100	0.9
State Total	2,124,000	0.6

Table 3-7 summarizes the estimated point source phosphorus loads for the three categories of treatment facilities; POTWs, privately owned wastewater treatment systems for domestic sources, and industrial wastewater treatment systems for each basin and the state. POTWs discharge an estimated 1,735,800 kg/yr of phosphorus or approximately 82 percent of the total point source phosphorus load statewide. In the Rainy River and Des Moines River basins, POTWs accounted for only an estimated 9.3 percent and 27 percent of the respective total point source phosphorus loading to each basin. Whereas, POTWs in the Lake Superior, St. Croix River, Missouri River, Upper Mississippi River, and Cedar River Basins accounted for between 91 and 99 percent of the total point source phosphorus loads.

Table 3-7 Point Source Phosphorus Loads by Facility Type

Basin	Publicly Owned Treatment Works (kg/yr)	POTW Flow Weighted Mean Effluent Phosphorus Concentration (mg/L)	Private WWT Systems for Domestic Use (kg/yr)	Private WWT Systems Flow Weighted Mean Effluent Phosphorus Concentration (mg/L)	Commercial and Industrial WWT Systems (kg/yr)	Commercial and Industrial Flow Weighted Mean Effluent Phosphorus Concentration (mg/L)
Cedar River	56,400	3.95	0	NA	390	0.25
Des Moines River	15,100	2.04	0	NA	40,440	10.61
Lake Superior	31,800	0.48	40	0.41	2,970	0.004
Lower Mississippi River	184,000	2.71	270	2.50	83,120	0.34
Minnesota River	237,800	1.84	840	3.73	133,060	0.30
Missouri River	12,400	3.49	20	1.18	750	2.03
Rainy River	4,100	1.06	10	1.06	40,160	0.57
Red River	64,300	2.62	30	3.00	13,810	0.37
St. Croix River	20,400	2.04	300	1.95	1,360	0.21
Upper Mississippi River	1,109,500	2.94	1,960	3.50	68,650	0.35
State Total	1,735,800	2.47	3,470	2.96	384,710	0.29

NA - Not Applicable

The data used for this study is from the years 2001, 2002 and the first half of 2003. During that time period some POTWs have implemented phosphorus removal and others will begin to implement removal in the future. The largest impact is probably phosphorus removal at the MCES' Metro plant, which is required to implement phosphorus removal to meet a 1 mg/L permit limit, which becomes effective December 31, 2005. MCES intends to be meeting the 1 mg/L limit during 2004 (as an annual average), since treatment facilities improvements have been completed. The Metro plant discharges to the Upper Mississippi River basin and had an average phosphorus effluent concentration for the study period of 3.0 mg/L at an average annual phosphorus load to the basin of approximately 870,000 kg/y. A reduction in the phosphorus concentration to 1 mg/L would result in a reduction of an estimated 581,044 kg of phosphorus per year. Because this one facility accounts for approximately 74 percent of the phosphorus load to the Upper Mississippi River basin and an estimated 40 percent statewide, phosphorus removal at this one facility will have a significant impact on the relative phosphorus loads in this basin and the state. Additional but smaller load reductions should be expected as more phosphorus effluent limits are implemented.

The phosphorus removal efficiency in POTWs and privately owned treatment facilities was estimated based on the estimated influent and effluent loads. Table 3-8 shows that the estimated average phosphorus removal is 61 percent in POTWs, and 57 percent for the private facilities, throughout the state. The phosphorus removal efficiencies for all of the POTWs in each basin range from 46 to 86 percent, while the efficiencies for private facilities in each basin are between 47 and 92 percent. By state rule all NPDES permitted discharges in the Lake Superior basin have 1 mg/L effluent limits.

Table 3-8 Phosphorus Removal in POTWs and Privately Owned Treatment Facilities

	POTW			Private		
Basin	Influent Load	Effluent Load	Percent Removal	Influent Load	Effluent Load	Percent Removal
	(kg/yr)	(kg/yr)	(%)	(kg/yr)	(kg/yr)	(%)
Cedar River Basin	105,200	56,400	46%	0	0	
Des Moines River	46,200	15,100	67%	0	0	
Lake Superior	227,000	31,800	86%	500	40	92%
Lower Mississippi River	501,900	184,000	63%	800	300	63%
Minnesota River	952,200	237,800	75%	1,500	800	47%
Missouri River	26,400	12,400	53%	100	20	80%
Rainy River	20,100	4,100	80%	30	10	67%
Red River	150,600	64,300	57%	0	0	
St. Croix River	53,500	20,400	62%	800	300	63%
Upper Mississippi River	2,384,900	1,109,500	53%	4,300	2,000	53%
State-wide	**4,468,000**	**1,735,800**	**61%**	**8,030**	**3,470**	**57%**

The estimated point source effluent phosphorus load to each basin was categorized by POTW size and category, for each of the influent phosphorus source components. The number of facilities is given in parentheses for each of the following sizes and categories:

1. Size (based on Average Wet Weather Design flow)
   a. Small – less than 0.2 mgd (316 facilities)
   b. Medium – from 0.2 mgd to 1.0 mgd (149 facilities)
   c. Large – greater than 1.0 mgd (68 facilities)

2. Waste Treated (% by flow volume treated)
   a. POTWs that serve mainly households and residences - less than 20 % industrial or commercial contributions (128 facilities)
   b. POTWs that have some commercial or industrial contribution – between 20% and 50% industrial or commercial contributions (207 facilities)
   c. POTWs that are dominated by a variety of commercial and industrial contributions – greater than 50% industrial or commercial contributions (198 facilities)

Approximately 88 percent of the phosphorus load discharged statewide from POTWs is from large POTWs (i.e., >1.0 mgd), while 8.5 percent of the point source phosphorus load is from POTWs categorized as medium (i.e., 0.2 to 1.0 mgd) and only 3.5 percent is from small POTWs (i.e., <0.2 mgd). Within the large category, POTWs that have some commercial or industrial contribution (between 20% and 50% industrial or commercial contributions) contribute the majority (72 percent) of the phosphorus load from this category to the basins. The following size categories of POTWs were ranked from high to low, based on their phosphorus load discharged statewide:

1. Large POTWs that have some commercial or industrial contribution – between 20% and 50% industrial or commercial contributions (1,100,000 kg/yr)
2. Large POTWs that are dominated by a variety of commercial and industrial contributions – greater than 50% industrial or commercial contributions (347,000 kg/yr)
3. Large POTWs that serve mainly households and residences - less than 20 % industrial or commercial contributions (83,000 kg/yr)
4. Medium POTWs that are dominated by a variety of commercial and industrial contributions – greater than 50% industrial or commercial contributions (68,000 kg/yr)
5. Medium POTWs that have some commercial or industrial contribution – between 20% and 50% industrial or commercial contributions (65,000 kg/yr)
6. Small POTWs that are dominated by a variety of commercial and industrial contributions – greater than 50% industrial or commercial contributions (23,000 kg/yr)
7. Small POTWs that have some commercial or industrial contribution – between 20% and 50% industrial or commercial contributions (22,000 kg/yr)
8. Small POTWs that serve mainly households and residences - less than 20 % industrial or commercial contributions (14,000 kg/yr)
9. Medium POTWs that serve mainly households and residences - less than 20 % industrial or commercial contributions (14,000 kg/yr)

Privately owned treatment facilities, for domestic use, account for less than half of a percent of the total point source phosphorus load to Minnesota surface waters. This amounts to approximately 10,000 kg/yr of phosphorus to all surface waters in the state.

Commercial and industrial wastewater systems, discharging directly to surface waters, make up the remaining point source phosphorus percentage of approximately 18 percent. They discharge an estimated 385,000 kg/yr to Minnesota surface waters. This study did not attempt to determine each of the major commercial and industrial phosphorus contributors. Noncontact cooling water is a subcategory of point source commercial and industrial wastewater. It is estimated that noncontact cooling water contributes approximately 14,000 kg/yr, or approximately 0.7 percent, of the total phosphorus load to surface waters in the state. In eight of the ten basins, noncontact cooling water accounted for less than one-half of a percent of the total phosphorus load. In the Red River basin, it accounted for 4.5 percent (3,500 kg/yr), and in the Minnesota River basin, it accounted for approximately 1.2 percent (4,500 kg/yr), of the total phosphorus load to the basin.

For this study, it was assumed that the influent components of the POTW's and privately owned treatment facility's phosphorus loads were represented in the treatment plant effluent in the same proportions as in the influent. It is understood that that this may not be the case, that phosphorus from the various sources may not have the same treatability. However, due to the various types of treatment and their variable removal rates, it was not in the scope of this study to estimate the individual removal rates for each type of treatment system, for each source of phosphorus. The commercial and industrial wastewater contributions were separated into those facilities discharging directly to surface waters under their own NPDES permit (Commercial & Industrial Wastewater Systems) and those discharging their wastewater to a POTW for treatment (described in Section 3.3.1.1 as Commercial and Industrial Process Wastewater).

3.2.2 Agricultural Runoff

3.2.2.1 Cropland and Pasture Runoff

As discussed in Section 2.2.2.1.1, phosphorus index values were calculated and compared with field data on phosphorus loss from four sites over five years to estimate phosphorus export conditions for each flow condition, by basin and for the entire state. The following discussion presents the results of the scenarios completed for this analysis to evaluate the impacts of rainfall/runoff conditions, crop residue cover and management practices on the estimated phosphorus risk indices:

- Average Hydrologic Runoff Volume, Average Rainfall Runoff Erosivity, Poor Crop Residue Cover Management Conditions—This scenario was based on long-term average stream flows, average rainfall erosivity, and no crop residue cover due to moldboard plow tillage methods. It is a worst case scenario for tillage methods, but the effects of supporting conservation practices such as contour strip cropping, terracing, and filter strips are here considered. From a practical standpoint, most areas of Minnesota use tillage systems that leave more crop residue than assumed in this scenario, so the phosphorus risks are overestimated in this scenario. As a rough guideline to identify impaired surface waters, Birr and Mulla (2001) suggested that values of the phosphorus index should not exceed 32 in Minnesota watersheds, except in the Red River of the North Basin, where a critical level of 25 should not be exceeded. There are seventeen watersheds in south central Minnesota with a phosphorus index value greater than 32, these include the

Lower Minnesota, Winnebago, Upper Cedar, Hawk Creek-Yellow Medicine, Blue Earth, Lac Qui Parle, Cannon, Rush-Vermillion, Middle Minnesota, South Fork of the Crow, Cottonwood, and Watonwan watersheds. Watersheds such as the Le Sueur, Redwood, Chippewa, Watonwan and South Fork of the Crow also have high phosphorus index scores (ranging from 30-31). It is well known that the Minnesota River basin generates the largest phosphorus losses of any major river basin in Minnesota. Thus, it is not surprising that nine of the twelve major watersheds in the Minnesota River basin have a phosphorus index value that exceeds 30. Watersheds in the northern half of Minnesota generally have phosphorus index values less than 21.

- Average Hydrologic Runoff Volume, Average Rainfall Runoff Erosivity, Average Crop Residue Cover Management Conditions—This scenario is similar to the previous one, except that erosion and phosphorus index values are based on the average crop residue levels as reported in tillage transect surveys. Thirteen watersheds have phosphorus index values that exceed 32, including the Lower Minnesota, Blue Earth, Shell-Rock, Cannon, Rush-Vermillion, Middle Minnesota, South Fork of the Crow, and Watonwan watersheds. These are primarily in the Minnesota River basin and Lower Mississippi River basin. Not as many watersheds have phosphorus index values exceeding 32 in this scenario as in the previous scenario, due to greater crop residue cover in this scenario.

- Average Hydrologic Runoff Volume, Average Rainfall Runoff Erosivity, Best Crop Residue Cover Management Conditions—This scenario was the same as the previous scenario, except that we assumed that conservation tillage leaving 50% of the soil covered by crop residue was practiced on row cropland. From a practical standpoint, most areas of Minnesota use tillage systems that leave less crop residue than assumed in this scenario, so the phosphorus risks are underestimated in this scenario. In general, the increase in crop residue cover produces lower phosphorus index scores in this scenario in comparison with the previous scenario involving average residue cover. Phosphorus index values exceed a score of 32 with this scenario for the Lower Minnesota, Winnebago, Cannon, Rush-Vermillion, and La Crosse-Pine watersheds. Then next highest scores occur primarily in the Minnesota River basin and in southeastern Minnesota, including the Coon-Yellow, Buffalo-Whitewater, Shell-Rock, Root, Hawk Creek-Yellow Medicine, Zumbro, Blue Earth, and Lac Qui Parle watersheds. Most of the northern half of Minnesota shows low risks for phosphorus transport in this scenario.

- Dry Hydrologic Runoff Volume, Dry Rainfall Runoff Erosivity, Best Crop Residue Cover Management Conditions, Cropland Contributing Corridor Based on Perennial Streams and

Ditches—In this scenario, the hydrologic runoff and rainfall runoff erosivity values were typical of dry years. Crop residue cover was based on widespread adoption of conservation tillage. One caveat is that the percent of cropland within 91.4 m of perennial streams and ditches may be unrealistic for this scenario. In dry years the cropland that contributes eroded sediment and runoff to surface waters may be considerably less in area than the cropland that contributes in average years. Thus, the phosphorus index values in this scenario may be overestimated. Phosphorus index values for this scenario are always smaller than those for the scenario based on an average climatic year. The maximum phosphorus index value for watersheds in the dry year scenario is about 29, whereas the maximum value for an average year is about 41. No watersheds exceed the critical phosphorus index value of 32 in this scenario, and none are in the next highest category ranging from 31 to 34 either. Only one watershed, the Lower Minnesota watershed has a phosphorus index score between 27 and 30. Only a handful of watersheds have phosphorus index scores ranging from 22-26, while a majority have scores below 21.

- Dry Hydrologic Runoff Volume, Dry Rainfall Runoff Erosivity, Best Crop Residue Cover Management Conditions, Cropland Contributing Corridor Based on Perennial Streams Only—This scenario is the same as the previous, except that the cropland contributing corridor is reduced in area by assuming that only croplands near perennial streams contribute to phosphorus losses in dry years. This is reasonable, since most ditches flow only sporadically during dry years. No watersheds or agroecoregions have phosphorus index values that exceed 25 or 27, respectively, in this scenario. Only two small watersheds have phosphorus index scores greater than 21, the La Crosse-Pine and Rush-Vermillion watersheds of southeastern Minnesota. This scenario is probably a more accurate representation of the risks of phosphorus transport to surface waters in dry years than the scenario that was based on a contributing corridor around both perennial streams and ditches.

- Wet Hydrologic Runoff Volume, Wet Rainfall Runoff Erosivity, Best Crop Residue Cover Management Conditions, Cropland Contributing Corridor Based on Perennial Streams and Ditches—This scenario indicates the risk of phosphorus transport to surface waters from agricultural land during wet years. It is based on runoff volumes and rainfall runoff erosivity values for wet years, on widespread adoption of conservation tillage, and on a cropland contributing corridor 91.4 m wide around perennial streams and ditches. Comparing this scenario with that for an average climatic year, it is evident that the risks of phosphorus loss have increased by a large amount (phosphorus index scores as high as 43) in a significant number of watersheds and agroecoregions. In the wet year scenario there are 24 watersheds with a phosphorus index score exceeding 32, whereas there were only 5 in the average year scenario. The watersheds exceeding the critical score in wet years are spread across south central and central Minnesota, as well as the Red River of the North basin. It is interesting to note that many of the watersheds in southeastern Minnesota are still below this critical threshold in wet years. This is primarily because of their relatively smaller percent area of cropland within 91.4 m of perennial streams and ditches. As will be shown in the next scenario, if the effects of intermittent streams are considered, the risk of phosphorus transport is considerably increased in southeastern Minnesota.

- Wet Hydrologic Runoff Volume, Wet Rainfall Runoff Erosivity, Best Crop Residue Cover Management Conditions, Cropland Contributing Corridor Based on All Streams and Ditches—This scenario differs from the previous one in that the effects on phosphorus transport of cropland near intermittent streams, which flow during wet years, was considered. The risks of phosphorus transport to surface waters are considerably increased all across Minnesota in comparison to the scenario for wet years which does not consider intermittent streams. Most of the southern two thirds of Minnesota watersheds and agroecoregions exceed the critical phosphorus index score of 32 in this scenario. Only the watersheds and agroecoregions in the far northeastern portion of Minnesota are relatively unaffected by including the effects of intermittent streams on phosphorus transport. This scenario is probably a more accurate representation of the risks of phosphorus transport to surface waters in wet years than the scenario based on a contributing corridor around only perennial streams and ditches.

- Average Hydrologic Runoff Volume, Average Rainfall Runoff Erosivity, Average Crop Residue Cover Management Conditions, Reduced Phosphorus Fertilizer, Cropland Contributing Corridor Around Perennial Streams and Ditches—This scenario illustrates the reductions in risk of phosphorus transport to surface waters (based on a contributing corridor around perennial streams and ditches only) due to reductions in rate of application of phosphorus fertilizer. These reductions were only made in watersheds or agroecoregions that had both high soil test phosphorus levels and high rates of phosphorus fertilizer application. More specifically the reductions were made where STP was greater than 32 ppm and fertilizer P application rates exceeded 27 kg/ha or where STP was greater than 39 ppm regardless of fertilizer P application rates. In both these cases, the rate of phosphorus fertilizer application was reduced to 5 kg/ha. These reductions reduce the risk of phosphorus transport in about one third of watersheds and agroecoregions, namely those units where the soil is generally capable of supplying P for crop production with little or no phosphorus fertilizer application. The phosphorus index values in the

Middle Minnesota, Cottonwood, Lower Minnesota, Rush-Vermillion and Cannon watersheds are reduced significantly in this scenario in comparison to their phosphorus index values for the scenario (scores decrease from generally above 32 to generally below 27), thus bringing them below the critical threshold. Large reductions in phosphorus index values also occur in the Le Sueur watershed.

- Average Hydrologic Runoff Volume, Average Rainfall Runoff Erosivity, Average Crop Residue Cover Management Conditions, Variable Manure Application Method—This scenario involves consideration of the variations in manure application method arising from differences in animal species and manure storage facilities. The baseline scenario assumes that manure is applied and incorporated immediately just before planting a crop. This is most likely an overly optimistic scenario for most manure applications in the state. The phosphorus index values are more realistic for Minnesota watersheds and agroecoregions based on consideration of differences across regions in manure application methods. Phosphorus index scores increase in this scenario relative to the baseline scenario that assumes relatively good methods of manure application. The increases are particularly noteworthy in northern Minnesota, where beef cattle operations are relatively abundant relative to other types of animal production. Beef cattle operations tend to be small, and many lack adequate manure storage facilities. This results in frequent hauling and land application of manure, generally without incorporation, including application of manure during the winter to frozen or snow covered cropland. Small increases in phosphorus index scores also occur in portions of the Red River of the North basin, in areas with relatively abundant beef cattle. These small increases bring the phosphorus index scores close to the critical threshold value of 25 in that region. Phosphorus index scores are relatively unaffected in southern Minnesota in regions where hog production dominates, because hog producers tend to have adequate manure storage and inject their manure rather than spreading it on the soil surface where it is very susceptible to losses by erosion and runoff.

Agricultural phosphorus export coefficients show considerable variation across basins and across climatic conditions (Figure 3-5). Export coefficients (kg/ha) during average climatic conditions vary from 0.54 kg/ha for the Minnesota River basin, 0.4 kg/ha for the Red River basin, 0.39 kg/ha for the Upper Mississippi River basin, and 0.66 kg/ha for the Lower Mississippi River basin. During wet years, the export coefficients are increased to 0.81 kg/ha for the Minnesota River, to 0.54 kg/ha for the Red River, to 0.69 kg/ha for the Upper Mississippi River, and to 0.80 kg/ha for the Lower Mississippi River basin. The export coefficients decrease during dry years to 0.28, 0.13, 0.22, and

0.36 kg/ha for the Minnesota, Red, Upper Mississippi, and Lower Mississippi River basins, respectively.

Phosphorus export coefficients for river basins with relatively sparse agricultural cropland are smaller than the coefficients for river basins with intensive agricultural land use. For example, during average climatic years, the phosphorus export coefficients for the Lake Superior, Rainy, and St. Croix River basins are only 0.24, 0.23 and 0.38 kg/ha, respectively.

Phosphorus loads exported to surface waters from agricultural lands under dry, average and wet climatic conditions are shown in Table 3-9 and Figure 3-6 (based on an analysis of phosphorus index values and export coefficients for major watersheds). Under average climatic conditions, the phosphorus loads are greatest for the Minnesota River basin (517,862 kg/yr), followed by the Red River (384,695 kg/yr), the Upper Mississippi (359,681 kg/yr) and the Lower Mississippi (232,581 kg/yr) River basins. All of the other basins have phosphorus loads that are considerably smaller than the loads in these four basins.

As expected, phosphorus loads exported from agricultural lands to surface waters are considerably greater during wet years than average years. Under wet climatic conditions, the phosphorus loads exported in the Minnesota, Red, Upper Mississippi, and Lower Mississippi River basins are 759,749, 545,247, 652,266, and 282,780 kg/yr, respectively. In dry years the phosphorus loads exported are 262,851, 131,311, 200,865, and 116,810 kg/yr, respectively, for these same basins.

Phosphorus loads from agricultural lands are much smaller for the Rainy, Lake Superior and St. Croix River basins than the basins with larger proportions of agricultural cropland (the Minnesota, Red, Upper and Lower Mississippi River basins). For example, during years with average climatic conditions, phosphorus loads exported from agricultural land to surface waters are only 13,112, 20,713, 59,931 kg/yr for the Lake Superior, Rainy and St. Croix River basins, respectively. Similar comparisons can be made for wet and dry climatic years.

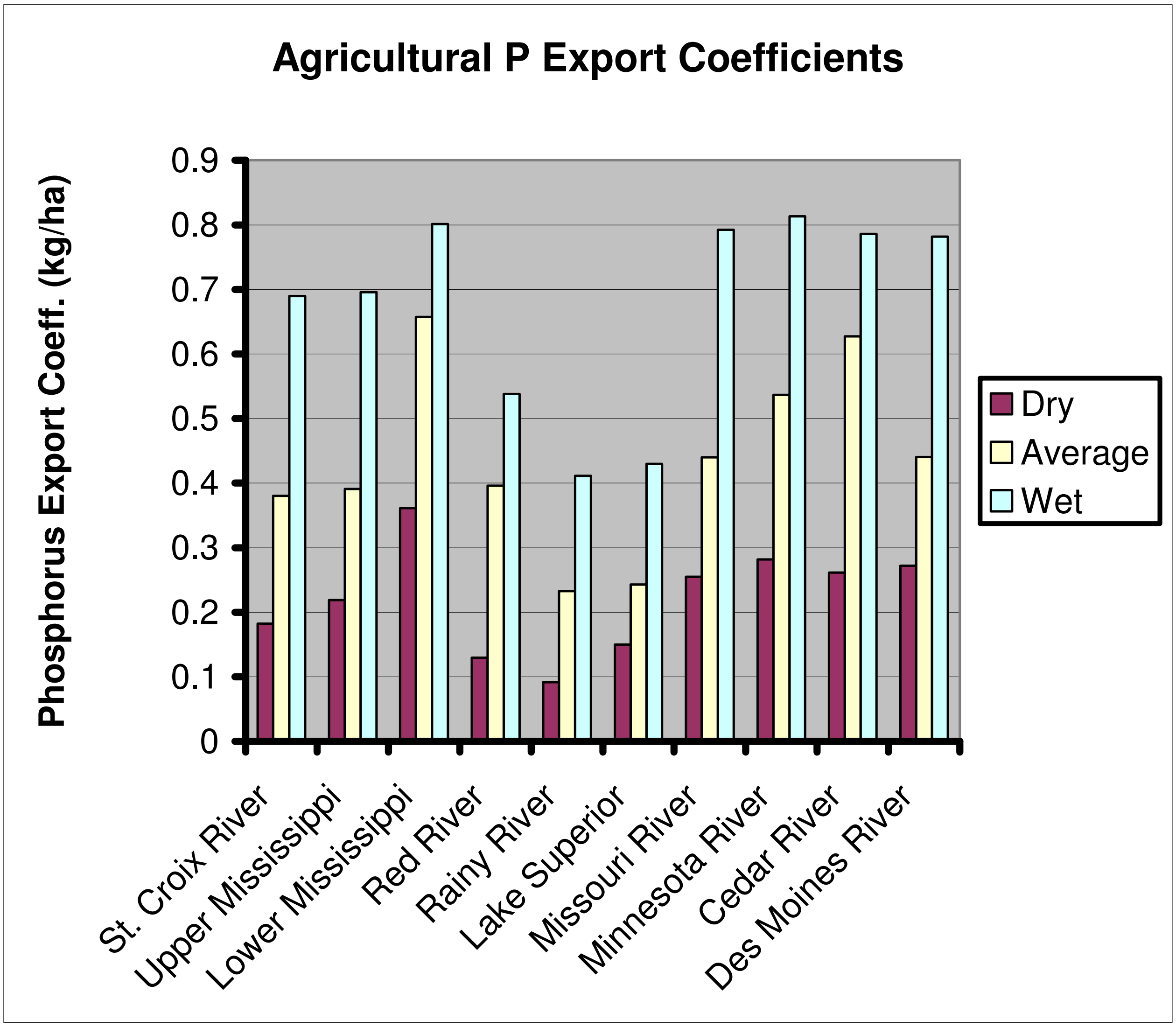


Figure 3-5 Cropland and pasture runoff P export coefficients (kg/ha) for major drainage basins in dry, average, and wet climatic years.

Export coefficients are derived from major watershed based phosphorus index values. These do not include contributions from surface tile inlets or subsurface tile drains.

Table 3-9 Phosphorus Loadings (kg/yr) to Minnesota Surface Waters from Agricultural Cropland by Major Drainage Basin Based on an Analysis of Phosphorus Index Values in Major Watersheds.

	Phosphorus Loads* Exported from Agricultural Land (kg/yr)		
Basin	Dry Year	Average Year	Wet Year
St. Croix River	27857	59931	110046
Upper Mississippi	200865	359681	652266
Lower Mississippi	116810	232581	282780
Red River	131311	384695	545247
Rainy River	8988	20713	36072
Lake Superior	7617	13112	22528
Minnesota River	262851	517862	759749
Missouri River	36055	58758	109222
Cedar River	13722	33270	42444
Des Moines River	24670	37743	73149

*These loads are computed by multiplying the phosphorus export coefficients for each major watershed by the area of cropland within the contributing corridor for the same major watershed, and then summing over all major watersheds with the river basin. An additional 11.1% load is then added to account for phosphorus contributions by overland flow from outside the contributing corridor, excluding the contributions from surface tile inlets and subsurface tile drains.

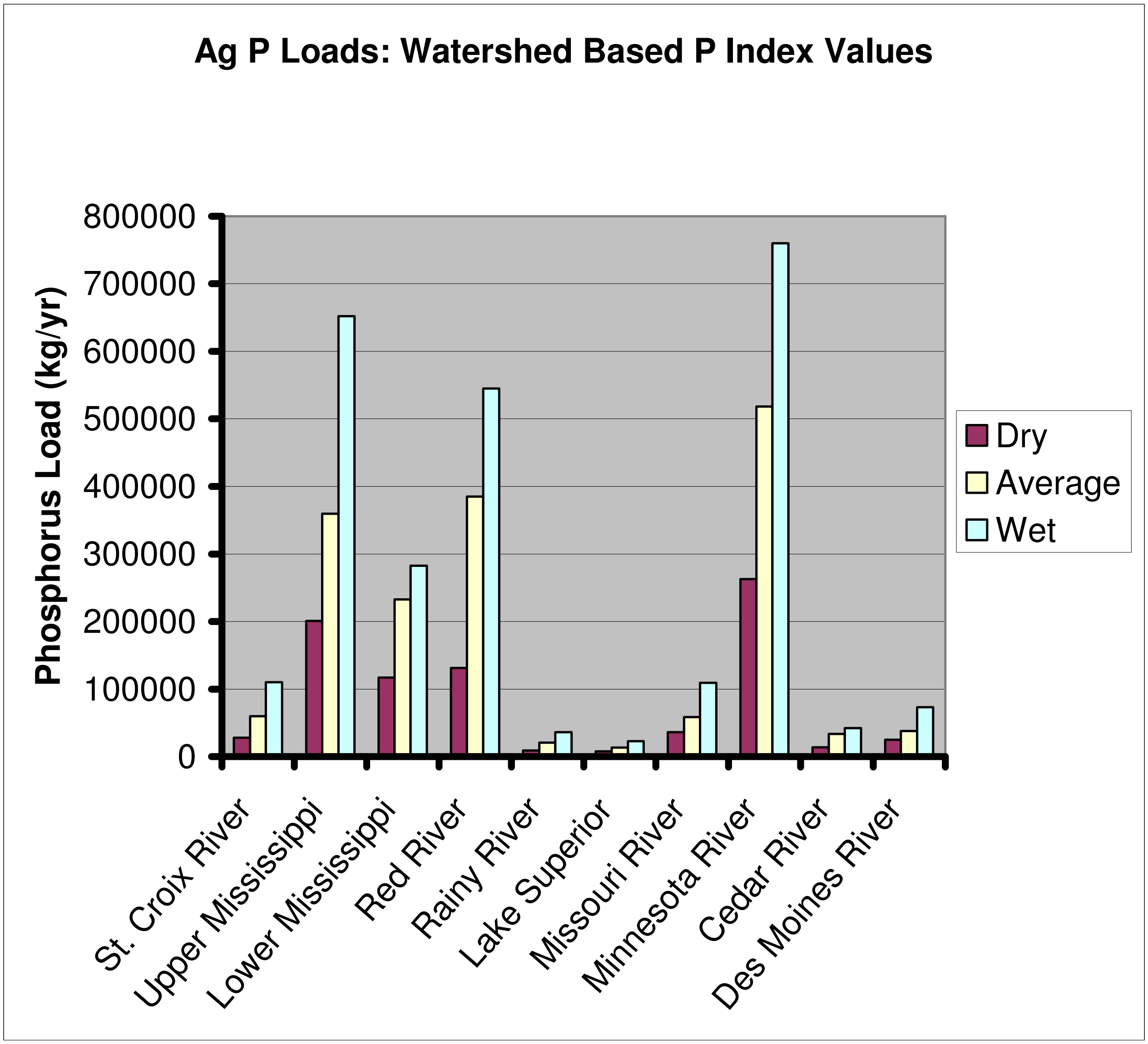


Figure 3-6 Cropland and pasture runoff phosphorus loads (kg/yr) exported to surface waters in major drainage basins of Minnesota under dry, average and wet climatic conditions

These results are based on phosphorus export coefficients derived from major watershed based phosphorus index values. These do not include contributions from surface tile inlets or subsurface tile drains.

The method of estimation used here does not consider the influence that subsurface tile drains and surface tile intakes farther than 100 m may have on phosphorus loadings. As discussed in Section 2.2.2.1.1, the total phosphorus loading from surface tile intakes to surface water bodies in the Minnesota River basin would result in 94,000 kg per year, while the phosphorus loading from subsurface tile drainage is estimated to be 30,000 kg/yr. The combined loading of 124,000 kg/yr is approximately 24 percent of the Minnesota River basin phosphorus loading from cropland within 100 m of surface waters during an average year (517,862 kg/yr). As previously discussed, not enough research data are available to reliably estimate the phosphorus loadings from surface tile intakes or subsurface tile drains to surface waters in the Minnesota River basin during dry or wet climatic years. As a first approximation, scaling the phosphorus loadings from tile drains so that they have the same relative ratio as the phosphorus index based loadings for the Minnesota River basin in dry, average and wet years (262,851; 517,862; and 759,749 kg/yr, respectively) results in estimated phosphorus loadings from subsurface tile drains of 15,227 kg/yr during dry years and 44,013 kg/yr during wet years. Using the same approach, phosphorus loadings from surface tile inlets in the Minnesota River basin during dry and wet years would be 47,711 and 137,906 kg/yr, respectively. As mentioned previously, the phosphorus loadings in dry years are expected to be overestimates.

In summary, the risk of phosphorus transport to surface waters depends on many factors. These include factors affecting soil erosion by water (conservation tillage, landscape steepness, climate), soil test phosphorus levels, rate of application of phosphorus from fertilizer or manure, and method of application of manure. Extensive databases for Minnesota watersheds and agroecoregions were developed to explore the variation in risks of phosphorus transport to surface waters in response to these factors. The results show that phosphorus losses are more sensitive to climatic variability than any other factor. The fraction of cropland near streams and ditches also has a large impact on phosphorus losses, during both wet and dry years. Watersheds and agroecoregions in Minnesota exhibit a considerable amount of variation in the risks of phosphorus loss. In general, the watersheds and agroecoregions with the greatest potential for phosphorus loss are located in the Lower Mississippi and Minnesota River basins. This is because of a combination of high rates of erosion, high rates of phosphorus application from fertilizer or manure, and a high percentage of cropland near streams and ditches. From a basin wide perspective, however, the greatest phosphorus loads are exported from agricultural lands to surface waters in the Minnesota River basin, followed by the Red River, Upper Mississippi, and Lower Mississippi River basins. Basins with relatively small areas of agricultural land use, such as the Lake Superior, Rainy and St. Croix River basins have significantly smaller phosphorus loads exported from agricultural lands to surface waters than basins with significant amounts of agricultural land use. Analysis shows that farmers have made progress in controlling phosphorus losses from agricultural cropland over the last twenty years or more due to accelerated adoption of conservation tillage. Additional progress can be made through continued adoption of best management practices, including reductions in the amount of phosphorus fertilizer applied to cropland when soil phosphorus levels are sufficient for crop production. Improved methods of manure application are also important in northern drainage basins for reductions in phosphorus loads to surface waters. Land retirement programs can be effective at reducing phosphorus loads to surface waters if cropland near surface waters is targeted for retirement.

3.2.2.2 Feedlot Runoff

The results of each of the four steps (discussed in Section 2.2.2.1.2) taken to estimate the phosphorus loadings from noncompliant open feedlots are presented in Table 3-10, along with the results of the phosphorus loading computations for runoff from noncompliant open feedlots during low, average and high flow conditions within each of the major basins of the state. Table 3-10 shows that the Lower Mississippi River produces the most phosphorus in feedlot runoff, with similar loadings estimated for the Upper Mississippi and Minnesota River basins. These three basins combined account for 88, 81, and 78 percent of the total statewide phosphorus loadings from feedlot runoff under low, average and high flow conditions, respectively. On a statewide basis, the total phosphorus loading during an average year is twice as high as the loading during a low flow year, while the high flow loading estimate is approximately 1.7 times higher than the estimate for average flow conditions. Table 3-10 shows that dairy in the Upper Mississippi River produces the largest amount of manure phosphorus generated from all open lots, followed by beef in the Minnesota River basin.

Due to uncertainties, variability and unaccounted sources (further described in Appendix D), the feedlot runoff loading results could be significantly higher or lower in some basins than the results show. It should be noted that even though feedlots are a small fraction of total P loading from a basin-wide perspective, some feedlots have been shown to contribute relatively high percentages of P loading to individual lakes and localized water resources.

Table 3-10 Estimated Annual Phosphorus Loadings for Outdoor Open Lot Feedlot Runoff to Surface Waters

Major Basin	Animal	P Produced per Animal Unit	Open Lot Animal Units	Manure P Produced from All Open Lots	Assumed Open Lots Contributing P to Waters	Manure P Produced from P Contributing Feedlots	Fraction of P Generated Entering Surface Waters from Non-Compliant Lots by Flow Condition (from FLEVAL)			Estimated TP from Feedlot Runoff by Flow Condition		
		lbs/yr	AU	lbs	fraction	lbs P/yr	fraction Low	fraction Average	fraction High	kg P/yr Low	kg P/yr Average	kg P/yr High
Cedar	Beef	33.5	6,809	228,102	0.35	79,836	0.0036	0.0062	0.0112	130	225	406
	Dairy	47.8	2,529	120,886	0.35	42,310	0.0033	0.0057	0.0102	63	109	196
	Hogs	26.6	9,759	259,589	0.35	90,856	0.0033	0.0057	0.0102	136	235	420
									Basin Total	**330**	**569**	**1,022**
Des Moines	Beef	33.5	48,639	1,629,407	0.35	570,292	0.0009	0.0036	0.0085	233	931	2,199
	Dairy	47.8	3,945	188,571	0.35	66,000	0.0008	0.0033	0.0077	24	99	231
	Hogs	26.6	48,122	1,280,045	0.35	448,016	0.0008	0.0033	0.0077	163	671	1,565
									Basin Total	**419**	**1,701**	**3,994**
Lake Superior	Beef	33.5	3,074	102,979	0.35	36,043	0.005	0.008	0.0107	82	131	175
	Dairy	47.8	3,203	153,103	0.35	53,586	0.0045	0.0073	0.0097	109	177	236
	Hogs	26.6	92	2,447	0.35	857	0.0045	0.0073	0.0097	2	3	4
									Basin Total	**193**	**311**	**414**
Lower	Beef	33.5	238,216	7,980,236	0.35	2,793,083	0.0045	0.0065	0.0099	5,701	8,235	12,543
	Dairy	47.8	200,040	9,561,912	0.35	3,346,669	0.0041	0.0059	0.009	6,224	8,956	13,662
	Hogs	26.6	79,301	2,109,407	0.35	738,292	0.0041	0.0059	0.009	1,373	1,976	3,014
									Basin Total	**13,298**	**19,167**	**29,219**
Minnesota	Beef	33.5	358,579	12,012,397	0.35	4,204,339	0.0012	0.0036	0.0071	2,288	6,865	13,540
	Dairy	47.8	158,480	7,575,344	0.35	2,651,370	0.0011	0.0033	0.0064	1,323	3,969	7,697
	Hogs	26.6	271,561	7,223,523	0.35	2,528,233	0.0011	0.0033	0.0064	1,261	3,784	7,339
									Basin Total	**4,873**	**14,619**	**28,576**
Missouri	Beef	33.5	132,679	4,444,747	0.35	1,555,661	0.0006	0.0033	0.008	423	2,329	5,645
	Dairy	47.8	27,219	1,301,068	0.35	455,374	0.0005	0.003	0.0072	103	620	1,487
	Hogs	26.6	81,589	2,170,267	0.35	759,594	0.0005	0.003	0.0072	172	1,034	2,481
									Basin Total	**699**	**3,982**	**9,613**
Rainy	Beef	33.5	8,993	301,266	0.35	105,443	0.003	0.005	0.0075	143	239	359
	Dairy	47.8	1,668	79,730	0.35	27,906	0.0027	0.0045	0.0068	34	57	86
	Hogs	26.6	116	3,086	0.35	1,080	0.0027	0.0045	0.0068	1	2	3
									Basin Total	**179**	**298**	**448**
Red	Beef	33.5	142,375	4,769,563	0.35	1,669,347	0.0006	0.0022	0.0039	454	1,666	2,953
	Dairy	47.8	54,886	2,623,551	0.35	918,243	0.0005	0.002	0.0036	208	833	1,499
	Hogs	26.6	9,740	259,084	0.35	90,679	0.0005	0.002	0.0036	21	82	148
									Basin Total	**683**	**2,581**	**4,601**
St. Croix	Beef	33.5	28,985	970,998	0.35	339,849	0.0036	0.0062	0.0091	555	956	1,403
	Dairy	47.8	36,362	1,738,104	0.35	608,336	0.0033	0.0056	0.0082	911	1,545	2,263
	Hogs	26.6	1,744	46,390	0.35	16,237	0.0033	0.0056	0.0082	24	41	60
									Basin Total	**1,490**	**2,542**	**3,726**
Upper	Beef	33.5	256,585	8,595,598	0.35	3,008,459	0.0023	0.0044	0.0066	3,139	6,004	9,006
	Dairy	47.8	391,607	18,718,815	0.35	6,551,585	0.0021	0.004	0.006	6,241	11,887	17,830
	Hogs	26.6	53,454	1,421,876	0.35	497,657	0.0021	0.004	0.006	474	903	1,354
									Basin Total	**9,853**	**18,794**	**28,191**
									Statewide Total	**32,017**	**64,564**	**109,804**

3.2.3 Atmospheric Deposition

As identified in Table 3-11, the estimate of atmospheric phosphorus deposition for each basin is based on the area identified as "water" or "wetland" in the GIS database. Estimates of average wet phosphorus deposition (average precipitation) range from ~ 0.069 kg ha^{-1} yr^{-1} in the Rainy River to 0.212 kg ha^{-1} yr^{-1} in the Cedar River basin (see Table 3-11). When factoring in dry/wet years, Table 3-11 shows that the range in potential wet phosphorus deposition is from approximately 0.059 kg ha^{-1} yr^{-1} in the Rainy River basin (dry year) to 0.273 kg ha^{-1} yr^{-1} in the Cedar River basin (wet year). The estimates of average phosphorus wet deposition (average precipitation) for the respective basins, ranges from approximately 2,100 kg/yr for the Cedar River to approximately 155,850 kg/yr for the Upper Mississippi.

Estimates of average dry phosphorus deposition (assuming average precipitation year) range from approximately 0.028 kg ha^{-1} yr^{-1} in the St. Croix River basin to approximately 0.241 kg ha^{-1} yr^{-1} in the Cedar River basin (Table 3-11). Estimates of average "total" (wet + dry) phosphorus deposition range from ~ 0.102 kg ha^{-1} yr^{-1} in the Rainy River basin (dry year) to 0.513 kg ha^{-1} yr^{-1} in the Cedar River basin (wet year) (Table 3-11). The largest phosphorus loading of approximately 299,044 kg/yr is found in the Upper Mississippi basin. As noted in Table 3-11, dry deposition could only be estimated for an "average" year due to the lack of available data for estimating deposition during a wet or dry year. Therefore, total (wet + dry) estimates for the dry, average, and wet years for each basin in Table 3-11 use the same dry deposition value, which adds some uncertainty to the deposition estimates (further discussed in Appendix E).

Table 3-11 Estimated Total Phosphorus Deposition to Minnesota Basins

Basin	Low Precipitation Phosphorus Deposition [1] (kg ha^{-1} yr^{-1})	Average Precipitation Phosphorus Deposition [1] (kg ha^{-1} yr^{-1})	High Precipitation Phosphorus Deposition [1] (kg ha^{-1} yr^{-1})	Dry Phosphorus Deposition [2] (kg ha^{-1} yr^{-1})	Dry Year Total (wet+dry) Phosphorus Deposition [3a] (kg ha^{-1} yr^{-1})	Average Year Total (wet+dry) Phosphorus Deposition [3b] (kg ha^{-1} yr^{-1})	Wet Year Total (wet+dry) Phosphorus Deposition 3[c] (kg ha^{-1} yr^{-1})	Basin Waters and Wetland Area [4] (hectares)	% of Total Basin Land Area [5]	Waters and Wetland Basin Loading Estimate: Dry Year Total (wet+dry) Phosphorus Deposition [6a] (kg/yr)	Average Year Total (wet+dry) Phosphorus Deposition [6b] (kg/yr)	Wet Year Total (wet+dry) Phosphorus Deposition [6c] (kg/yr)
Cedar River	0.1815	0.2118	0.2725	0.2408	0.4223	0.4526	0.5133	9,924	3.7	4,191	4,492	5,095
Des Moines River	0.1452	0.1848	0.2428	0.0686	0.2138	0.2534	0.3114	21,761	5.5	4,652	5,514	6,777
Lake Superior	0.0765	0.0873	0.1053	0.0447	0.1212	0.1320	0.1501	531,000	33.3	64,382	70,118	79,677
Minnesota River	0.1458	0.1854	0.2296	0.0761	0.2219	0.2615	0.3057	300,462	7.8	66,672	78,567	91,850
Mississippi, Lower [7]	0.1253	0.1545	0.1847	0.0925	0.2177	0.2470	0.2771	82,740	5.1	18,016	20,435	22,930
Mississippi, Upper [8]	0.0809	0.1006	0.1228	0.0703	0.1512	0.1709	0.1931	1,548,735	29.7	234,154	264,658	299,044
Missouri River	0.1392	0.1795	0.2349	0.0686	0.2079	0.2481	0.3035	12,016	2.6	2,497	2,981	3,647
Rainy River	0.0590	0.0690	0.0846	0.0431	0.1021	0.1121	0.1277	1,525,718	52.4	155,792	171,065	194,778
Red River	0.0778	0.0975	0.1209	0.1102	0.1880	0.2077	0.2311	1,092,132	23.8	205,367	226,843	252,432
St. Croix River	0.0938	0.1211	0.1488	0.0280	0.1218	0.1491	0.1768	275,251	30.1	33,518	41,032	48,655
State Wide Totals								5,399,738		789,241	885,704	1,004,885

Note:
[1] The phosphorus deposition rates from dry, average and wet precipitation volumes. Dry, average and wet year precipitation volume data based on the 1979-2002 period (using water years 10/1-9/30). The dry period is defined as the 10th percentile frequency value, the average is the 50th percentile and the wet is the 90th percentile. Derived by the MDNR (2003).
[2] Includes coarse and fine dry deposition. Calculations assumed to be for an "average" precipitation year. There is insufficient information to estimate deposition for a dry or wet year; therefore, dry deposition is only estimated for what is assumed to be an "average" year.
[3a] Total deposition = low precipitation phosphorus deposition + dry deposition
[3b] Total deposition = average precipitation deposition + dry deposition
[3c] Total deposition = high precipitation phosphorus deposition + dry deposition
[4] Basin area is that part of the basin within the state's borders designated as "Water" or "Wetland" in the GIS database. Surface water included open water, woody wetlands and emergent herbaceous wetlands as defined by the USGS National Landcover database (~1992). This is a landsat based raster data set developed by the USGS with a minimum mapping unit of 30 meters.
[5] The percentage of the total land area within a river basin that is designated as water or wetland surface water.
[6a] The total phosphorus deposition rate to the basin water or wetland surface waters. The low precipitation deposition rate + dry depositon rate was used to calculate this total.
[6b] The total phosphorus deposition rate to the basin water or wetland surface waters. The average precipitation deposition rate + dry depositon rate was used to calculate this total.
[6c] The total phosphorus deposition rate to the basin water or wetland surface waters. The high precipitation deposition rate + dry depositon rate was used to calculate this total.
[7] Lower Mississippi is that part of the Mississippi downstream of where the St.Croix River merges with the Mississippi.
[8] Upper Mississippi is that part of the Mississippi upstream of where the St.Croix River merges with the Mississippi.

3.2.4 Deicing Agents

The phosphorus loadings for each basin were computed using the deicing agents application rates and concentrations for the lane miles in each basin, as discussed in Section 2.2.2.3. Each basin calculation was completed using the application rates for the respective MnDOT Districts that encompass the basin; whenever the basin includes TCMA counties, those state highway lane miles were calculated using the higher Metro District rates for each county. Table 3-12 presents the phosphorus loading results for each of the basins under the three loading scenarios and a summary for the state-wide total phosphorus loading to surface waters from deicing agents under the same three scenarios.

Table 3-12 Major Basin and Statewide Total Phosphorus Loadings from Deicers for Each Snowfall Scenario

Basin	Snowfall Scenario	Tons of Salt	Tons of Sand	Gallons of Brine	P from Salt, kg	P from Sand, kg	P from Brine, kg	Total P, kg
St. Croix River	Dry Year	37,525	55,343	59,431	170	1893	0.03	2,063
	Avg Year	47,143	88,364	59,431	213	3022	0.03	3,236
	Wet Year	57,862	124,331	59,431	262	4252	0.03	4,514
Upper Mississippi River	Dry Year	214,976	376,477	521,969	973	12876	0.26	13,849
	Avg Year	279,640	600,253	521,969	1266	20529	0.26	21,795
	Wet Year	350,167	835,955	521,969	1585	28590	0.26	30,176
Lower Mississippi River	Dry Year	88,034	132,454	268,117	399	4530	0.13	4,929
	Avg Year	110,716	213,189	268,117	501	7291	0.13	7,793
	Wet Year	136,270	302,924	268,117	617	10360	0.13	10,977
Red River	Dry Year	112,554	240,506	135,874	510	8226	0.07	8,735
	Avg Year	156,495	374,579	135,874	708	12811	0.07	13,519
	Wet Year	204,893	546,846	135,874	928	18703	0.07	19,630
Rainy River	Dry Year	32,576	57,318	160,864	147	1960	0.08	2,108
	Avg Year	41,389	95,993	160,864	187	3283	0.08	3,470
	Wet Year	51,190	138,824	160,864	232	4748	0.08	4,980
Lake Superior	Dry Year	37,625	60,767	91,289	170	2078	0.04	2,249

Basin	Snowfall Scenario	Tons of Salt	Tons of Sand	Gallons of Brine	P from Salt, kg	P from Sand, kg	P from Brine, kg	Total P, kg
	Avg Year	47,755	98,765	91,289	216	3378	0.04	3,594
	Wet Year	59,068	140,577	91,289	267	4808	0.04	5,075
Missouri River	Dry Year	16,903	32,231	25,586	77	1102	0.01	1,179
	Avg Year	23,002	49,589	25,586	104	1696	0.01	1,800
	Wet Year	29,845	68,392	25,586	135	2339	0.01	2,474
Minnesota River	Dry Year	141,111	285,517	251,770	639	9765	0.12	10,404
	Avg Year	193,267	446,062	251,770	875	15256	0.12	16,131
	Wet Year	251,497	589,445	251,770	1138	20160	0.12	21,298
Cedar River	Dry Year	15,504	21,514	43,379	70	736	0.02	806
	Avg Year	19,503	33,493	43,379	88	1145	0.02	1,234
	Wet Year	24,042	46,803	43,379	109	1601	0.02	1,710
Des Moines River	Dry Year	13,370	27,606	18,403	61	944	0.01	1,005
	Avg Year	18,573	42,620	18,403	84	1458	0.01	1,542
	Wet Year	24,447	59,097	18,403	111	2021	0.01	2,132
Statewide Totals	Dry Year	710,178	1,289,734	1,576,683	3,215	44,110	0.77	47,326
	Avg Year	937,483	2,042,906	1,576,683	4,244	69,869	0.77	74,114
	Wet Year	1,189,280	2,853,194	1,576,683	5,384	97,582	0.77	102,966

Table 3-12 shows that the estimated phosphorus loadings associated with heavy snowfall years are approximately twice as high as the loadings associated with low snowfall years, in each basin, with the average years generally falling directly between each of the other snowfall scenarios. In descending order, the three basins experiencing the largest total phosphorus loadings to surface waters, in each snowfall scenario, are the Upper Mississippi, Minnesota and Red River basins. The Upper Mississippi River basin accounts for nearly 30% of the total phosphorus loadings, statewide.

3.2.5 Streambank Erosion

The phosphorus loadings for each basin were computed using the approach and methodology discussed in Section 2.2.2.4. Table 3-13 presents the results of the phosphorus loading computations and assessments for each flow condition, by basin and for the entire state. Table 3-14 compares the phosphorus yield associated with streambank erosion for each flow condition, by basin and the entire state. Table 3-13 shows that the estimated streambank erosion total phosphorus loadings under low flow conditions are approximately an order of magnitude lower than average flow conditions, while the streambank erosion estimates under high flow conditions are about a half an order of magnitude higher than average flow conditions.

Table 3-13 Summary of Total Phosphorus Loading Estimates (kg/yr) for Streambank Erosion

Basin	Low Flow Conditions	Average Flow Conditions	High Flow Conditions
Cedar River	140	12,200	59,600
Des Moines River	130	7,350	47,900
Lake Superior	4,730	35,100	207,000
Lower Mississippi	45,500	322,000	1,280,000
Minnesota River	9,910	200,000	900,000
Missouri River	1,440	16,100	71,600
Rainy River	0	52,700	318,000
Red River of the North	0	8,840	146,000
St. Croix River	20	15,500	98,000
Upper Mississippi	430	79,900	477,800
Statewide Totals	62,300	750,000	3,606,000

Table 3-14 Summary of Estimated Total Phosphorus Yield (kg/km^2/yr) from Streambank Erosion for Average Flow Conditions

Basin	Average Flow Conditions
Cedar River	4.6
Des Moines River	1.9
Lake Superior	2.2
Lower Mississippi	19.7
Minnesota River	5.2
Missouri River	3.5
Rainy River	1.8
Red River of the North	0.2
St. Croix River	1.7
Upper Mississippi	1.5
Statewide Totals	3.4

The relative difference between the estimated phosphorus loadings for each basin (from Table 3-14) corresponds well with the variation of observed sediment yields throughout the State, although sediment yield and streambank erosion loadings would not necessarily be expected to vary the same if other sources of phosphorus and sediment measured in the yield vary significantly. Based on the estimated yield from each basin, the Lower Mississippi River basin loadings are significantly higher than any other basin, followed by the Minnesota and Cedar River basins. This corresponds well with the portion of the State with significant loess deposits, and corresponds with the findings of other researchers (Tornes, 1986; Simon and Rinaldi, 2000; Simon et al., 2003). For each flow condition, the Lower Mississippi River basin streambank erosion estimates from Table 3-13 account for more than a third of the total loading estimated for the State. Under the low flow condition, the Lower Mississippi River basin streambank erosion estimates accounts for more than 70 percent of the total loading estimated for the State.

3.2.6 Individual Sewage Treatment Systems/Unsewered Communities

As discussed in Section 2.2.2.5, population served by Individual Sewage Treatment System (ISTS) or undersewered communities, compliance of treatment systems with performance standards, groundwater conditions, and characteristics of soil absorption field and proximity to surface waters are important factors in determining phosphorus export. The MPCA ISTS LUG spreadsheet provided estimates of the number of full time and seasonal residences served by ISTS, along with the number of failing systems and an estimate for the number of systems which are an ITPHS (Imminent Threat to Public Health and Safety). The population data used for both ISTS and undersewered communities are included in Table 3-15. Table 3-15 also shows the number of residential systems in each basin. The Upper Mississippi River basin accounts for almost one-quarter of the population served by ISTS and more than 60 percent of the unsewered areas population. The Minnesota, Lower Mississippi, Red and St. Croix River basins serve ISTS populations of between 110,000 and 160,000, while the Minnesota and St. Croix River basins have unsewered area populations between 25,000 and 33,000. The remaining basins represent small fractions of the statewide populations served by ISTS and undersewered communities.

Table 3-15 shows the percentages of failing systems and systems which discharge partially treated sewage (or are considered an ITPHS), estimated for each of the basins and the state. These estimates show that the Des Moines River basin has the highest percentage (41%) of ISTS systems considered an ITPHS, followed by the Minnesota and Missouri River basins with 29 and 22 percent, respectively. The St. Croix, Lake Superior, Rainy and Upper Mississippi River basin estimates for percentages of ISTS considered an ITPHS were all less than 8 percent. Table 3-15 shows that the Rainy River basin had the highest (43%), while the St. Croix basin had the lowest (11%), percentages of failing ISTS systems. All of the other basins had estimated percentages of failing ISTS systems between 24 and 35 percent. The high percentage for the Rainy River basin may be partially due to the presence of high water tables relative to the other basins.

Table 3-15 presents the results of the phosphorus loading computations done for the assessment of ISTS and undersewered communities. The last five columns of Table 3-15 show the estimated total phosphorus loadings to surface waters from undersewered communities, direct-to-tile ISTS, all seasonal ISTS, the remaining ISTS, and the total load in each basin (and the state) from all four source categories. On a statewide basis, Table 3-15 shows that more than half of the phosphorus load from undersewered communities/ISTS is coming from permanent ISTS, while approximately 35 percent of the total load originates from undersewered communities. Undersewered communities represent a large percentage of the total load to the St. Croix and Upper Mississippi River basins (56 and 53 percent, respectively). Undersewered communities represent less than 27 percent of the total phosphorus load for the remaining basins. Direct-to-tile ISTS represents 20, 16 and 11 percent of the total phosphorus load in the Cedar Minnesota, and Des Moines River basins, respectively; but less than 8 percent for the remaining basins. The estimated seasonal ISTS contributions are 16 and 18 percent of the total phosphorus loads in the Rainy River and Lake Superior basins, respectively, and less than 7 percent for the remaining basins. The remaining ISTS contributions (from both conforming and nonconforming systems) accounts for more than 40 percent of the total phosphorus load from ISTS/undersewered communities in all of the basins. The highest total phosphorus contribution from the remaining ISTS category is 87 percent in the Missouri River basin.

Table 3-15 Estimated Annual Phosphorus Loadings for ISTS and Unsewered Communities

											Estimated P Load Produced (kg)				Estimated P Load Discharged to Surface Waters (kg)				
Major Basin	ISTS Population by Difference	Total Residential Systems	Percent Partially Treated	Percent Failing	Unsewered Areas Population	Avg. Pop. per Household	Direct-to-Tile Systems	Direct-to-Tile Pop.	Remaining ISTS Pop.	Seasonal Pop.	Unsewered Areas	Direct-to-Tile Systems	Seasonal ISTS	Remaining ISTS	Unsewered Areas	Direct-to-Tile Systems	Seasonal ISTS	Remaining ISTS	Total
Cedar River	17,654	4,500	15.7%	34.6%	299	3.92	514	2,016	15,339	0	264	1,784	0	13,568	114	767	0	2,999	3,880
Des Moines River	6,818	5,420	41.1%	23.8%	1,028	1.28	419	536	5,254	191	909	474	56	4,647	391	204	20	1,316	1,930
Lake Superior	39,419	16,000	5.5%	35.0%	342	4.80	0	0	39,077	16,363	303	0	4,825	34,565	130	0	1,415	6,507	8,051
Lower Mississippi	143,466	31,002	10.6%	26.8%	11,272	4.75	450	2,137	130,057	1,676	9,971	1,891	494	115,041	4,287	813	141	21,707	26,949
Minnesota River	158,257	67,100	29.4%	32.8%	25,872	2.55	7,399	18,847	113,538	10,437	22,885	16,671	3,077	100,430	9,841	7,168	1,056	26,377	44,442
Missouri	16,697	5,233	22.1%	33.4%	509	3.27	227	743	15,445	281	450	658	83	13,662	194	283	27	3,275	3,778
Rainy River	33,533	23,928	7.0%	43.1%	6,216	2.02	0	0	27,317	15,395	5,498	0	4,539	24,163	2,364	0	1,431	5,056	8,851
Red River	112,474	46,447	13.1%	27.0%	8,966	2.92	0	0	103,508	16,655	7,931	0	4,911	91,558	3,410	0	1,434	18,038	22,882
St. Croix River	110,520	45,249	2.3%	11.4%	32,612	2.76	0	0	77,908	10,857	28,847	0	3,201	68,913	12,404	0	741	8,987	22,132
Upper Mississippi	453,857	227,515	7.8%	24.7%	154,696	2.32	436	1,014	298,147	67,809	136,836	897	19,993	263,725	58,839	386	5,497	46,250	110,972
TOTAL	1,092,695	472,394	11.6%	26.4%	241,812	2.69	9,445	25,294	825,589	139,665	213,894	22,373	41,180	730,271	91,974	9,621	11,762	140,510	253,867

3.2.7 Non-Agricultural Rural Runoff

As described in Section 2.2.2.6, the ecoregion-based phosphorus export rates and contributory areas for each land cover type within each basin were utilized, along with the basin runoff factors, to calculate the results of the phosphorus loadings for each basin and the state. The phosphorus loading results are shown in Table 3-16. The highest total phosphorus loadings are estimated for the Rainy River, Upper Mississippi River and Lake Superior basins, which combined, represent approximately 75 percent of the non-agricultural rural total phosphorus loadings for each flow condition. For each land cover type the estimated total phosphorus loadings for the high flow condition are typically one-and-one-half to two-and-one-half times as high as the low flow loadings for each basin, with the average flow condition loadings typically mid-way between the high and low flow condition loadings. Table 3-16 shows that deciduous forest represents approximately 45, 50 and 55 percent of the statewide non-agricultural rural total phosphorus loadings under low, average and high flow conditions, respectively. The evergreen forest and commercial/industrial/transportation land cover types each represent approximately 13 percent of the statewide non-agricultural rural total phosphorus loadings under average flow conditions with the commercial/industrial/transportation percentage being higher (19%) under low flow and lower (10%) under high flow conditions.

Table 3-16 Estimated Annual Phosphorus Loadings for Non-Agricultural Rural Land Cover Types

Basin	Hydrology Scenario	Low Intensity Residential	High Intensity Residential	Commercial/ Industrial/ Transportation	Bare Rock/Sand/ Clay	Transitional	Deciduous Forest	Evergreen Forest	Mixed Forest	Shrubland	Grasslands/ Herbaceous	Urban/ Recreational Grasses	Total Kg P
Cedar River	Dry Year	69.8	8.2	1263.7	2.7	0.0	291.1	0.0	1.9	0.0	0.0	28.3	1,666
	Avg Year	73.9	8.7	1338.2	2.9	0.0	510.7	0.0	3.3	0.0	0.0	30.0	1,968
	Wet Year	75.7	8.9	1369.6	2.9	0.0	914.2	0.0	5.9	0.0	0.0	30.7	2,408
Des Moines River	Dry Year	35.8	1.1	1020.1	0.0	0.0	117.5	2.7	3.0	0.1	0.0	98.3	1,279
	Avg Year	41.5	1.3	1183.0	0.0	0.1	469.9	10.6	12.0	0.4	0.0	114.0	1,833
	Wet Year	46.7	1.5	1332.3	0.0	0.3	1108.9	25.1	28.4	0.8	0.0	128.4	2,673
Lake Superior	Dry Year	178.4	93.3	4546.1	92.9	559.1	23219.3	7883.2	10799.0	264.2	177.0	181.0	47,993
	Avg Year	190.7	99.7	4859.4	99.3	887.4	36856.1	12513.1	17141.2	419.4	281.0	193.5	73,541
	Wet Year	204.1	106.7	5201.1	106.3	1198.0	49755.7	16892.7	23140.7	566.2	379.3	207.1	97,758
Lower Mississippi River	Dry Year	214.9	53.6	4496.0	16.3	1.2	4944.9	63.7	348.5	0.3	35.7	313.9	10,489
	Avg Year	238.6	59.6	4991.9	18.1	1.8	7064.2	91.1	497.8	0.4	51.0	348.6	13,363
	Wet Year	252.5	63.0	5284.0	19.2	2.7	10667.0	137.5	751.7	0.6	77.0	369.0	17,624
Minnesota River	Dry Year	539.2	61.4	5962.3	0.3	2.3	3772.9	93.5	197.0	64.2	0.0	1603.9	12,297
	Avg Year	627.1	71.4	6934.2	0.4	6.7	11096.9	274.9	579.3	188.8	0.0	1865.3	21,645
	Wet Year	695.7	79.2	7693.0	0.4	13.4	22193.8	549.9	1158.6	377.6	0.0	2069.5	34,831
Missouri River	Dry Year	39.6	0.7	1412.6	0.0	0.0	48.7	0.2	0.9	0.0	0.1	51.2	1,554
	Avg Year	46.6	0.9	1662.6	0.0	0.0	270.5	0.9	5.1	0.1	0.6	60.3	2,047
	Wet Year	53.0	1.0	1890.4	0.0	0.1	659.9	2.3	12.5	0.2	1.4	68.5	2,689
Rainy River	Dry Year	226.2	42.2	6770.8	189.7	1394.9	27232.8	15260.7	17633.1	2445.7	25.1	199.9	71,421
	Avg Year	248.5	46.4	7436.2	208.3	2324.8	45388.0	25434.5	29388.4	4076.2	41.8	219.6	114,813
	Wet Year	273.7	51.1	8191.5	229.5	3324.4	64904.8	36371.4	42025.4	5829.0	59.8	241.9	161,503
Red River of the North	Dry Year	310.8	41.4	5839.0	122.5	167.6	7806.5	343.6	357.4	396.2	0.1	849.9	16,235
	Avg Year	362.5	48.2	6810.6	142.8	540.7	25182.4	1108.4	1153.0	1278.0	0.4	991.3	37,618
	Wet Year	410.0	54.6	7702.9	161.5	962.4	44824.6	1973.0	2052.4	2274.8	0.7	1121.1	61,538
St. Croix River	Dry Year	252.4	71.7	2257.9	0.0	83.9	9777.1	515.1	810.9	61.3	34.3	734.8	14,599
	Avg Year	293.4	83.3	2624.8	0.0	144.6	16857.1	888.1	1398.2	105.7	59.1	854.2	23,308
	Wet Year	320.0	90.9	2863.2	0.0	212.6	24779.9	1305.6	2055.3	155.4	86.8	931.7	32,801
Upper Mississippi River	Dry Year	2780.6	573.4	11562.3	30.5	695.5	27379.7	5221.9	5762.3	1309.9	1.3	3386.8	58,704
	Avg Year	3181.9	656.2	13231.0	34.9	1337.4	52653.3	10042.2	11081.4	2519.1	2.4	3875.6	98,615
	Wet Year	3509.1	723.6	14591.4	38.5	2032.9	80033.1	15264.1	16843.8	3829.0	3.7	4274.1	141,143

	Hydrology Scenario	Low Intensity Residential	High Intensity Residential	Commercial/ Industrial/ Transportation	Bare Rock/Sand/ Clay	Transitional	Deciduous Forest	Evergreen Forest	Mixed Forest	Shrubland	Grasslands/ Herbaceous	Urban/ Recreational Grasses	Total Kg P
Statewide Totals	Dry Year	4,648	947	45,131	455	2,904	104,591	29,385	35,914	4,542	274	7,448	236,238
	Avg Year	5,305	1,076	51,072	507	5,244	196,349	50,364	61,260	8,588	436	8,552	388,751
	Wet Year	5,840	1,181	56,120	558	7,747	299,842	72,522	88,075	13,034	609	9,442	554,968

3.2.8 Urban Runoff

As described in Section 2.2.2.7, the phosphorus concentrations, runoff coefficients and contributory areas for each urban land cover type within each basin were utilized, along with the annual rainfall amounts for each flow condition, to calculate the results of the phosphorus loadings for each basin and the state. The phosphorus loading results are shown in Table 3-17. The highest total phosphorus loadings are estimated for the Upper Mississippi River basin, which represents approximately 50 percent of the total phosphorus loadings from incorporated areas for each flow condition. The Minnesota River basin represents approximately 20 percent, while no other basin represents more than 10 percent of the total phosphorus loadings from incorporated areas for each flow condition. For each land cover type the estimated total phosphorus loadings for the high flow condition are typically one-and-one-half times as high as the low flow loadings for each basin, with the average flow condition loadings typically mid-way between the high and low flow condition loadings. Low intensity residential land cover represents between 26 and 30 percent of the statewide total phosphorus loadings from incorporated areas under the various flow conditions. The commercial/industrial/transportation and high intensity residential land cover types represent approximately 20 percent and 15 percent, respectively, of the statewide total phosphorus loadings from incorporated areas under the various flow conditions. Agricultural runoff represents approximately 12, 20 and 25 percent of the statewide total phosphorus loadings from incorporated areas under low, average and high flow conditions, respectively.

Table 3-17 Estimated Annual Phosphorus Loadings for Incorporated Urban Areas

Basin	Hydrology Scenario	Low Intensity Residential	High Intensity Residential	Commercial/ Industrial/ Transportation	Bare Rock/Sand/ Clay	Transitional	Deciduous Forest	Evergreen Forest	Mixed Forest	Shrubland	Grasslands/ Herbaceous	Urban/ Recreational Grasses	Agricultural Lands in Incorporated Areas	Total Kg P
Cedar River	Dry Year	738.7	1,251.5	1,827.8	0.0	0.0	46.2	0.0	0.2	0.0	0.0	262.1	413	4,539
	Avg Year	782.3	1,325.3	1,935.6	0.0	0.0	53.9	0.0	0.3	0.0	0.0	277.5	1,002	5,377
	Wet Year	800.6	1,356.4	1,981.0	0.0	0.0	69.4	0.0	0.3	0.0	0.0	284.0	1,278	5,770
Des Moines River	Dry Year	1,097.6	245.8	992.7	0.0	0.0	18.8	0.3	0.2	0.0	0.0	460.6	351	3,167
	Avg Year	1,272.8	285.0	1,151.1	0.0	0.0	23.9	0.4	0.3	0.0	0.0	534.1	537	3,805
	Wet Year	1,433.5	321.0	1,296.4	0.0	0.0	31.5	0.6	0.4	0.0	0.0	601.6	1,042	4,727
Lake Superior	Dry Year	3,598.6	2,472.8	5,495.7	320.0	516.4	5,794.7	896.9	1,309.8	83.7	64.3	1,355.6	1,060	22,969
	Avg Year	3,846.7	2,643.3	5,874.5	342.1	552.0	6,613.3	1,023.6	1,494.8	95.5	73.4	1,449.0	1,824	25,832
	Wet Year	4,117.2	2,829.2	6,287.6	366.1	590.8	7,966.8	1,233.2	1,800.7	115.0	88.5	1,550.9	3,134	30,080
Lower Mississippi River	Dry Year	9,032.4	4,987.8	7,823.2	0.4	181.1	983.8	21.8	83.5	0.2	50.9	4,967.4	5,291	33,423
	Avg Year	10,028.5	5,537.9	8,685.9	0.4	201.1	1,212.7	26.9	103.0	0.2	62.7	5,515.2	10,535	41,909
	Wet Year	10,615.5	5,862.0	9,194.3	0.5	212.8	1,449.9	32.2	123.1	0.2	74.9	5,838.0	12,809	46,212
Minnesota River	Dry Year	24,477.9	8,625.8	14,846.9	11.6	205.0	1,135.2	38.8	44.9	5.7	0.8	8,057.5	5,723	63,173
	Avg Year	28,467.9	10,031.9	17,267.0	13.5	238.4	1,445.1	49.4	57.2	7.2	1.1	9,371.0	11,275	78,225
	Wet Year	31,583.3	11,129.8	19,156.6	15.0	264.5	1,786.3	61.0	70.7	8.9	1.3	10,396.5	16,541	91,015
Missouri River	Dry Year	913.6	223.8	707.4	1.8	0.0	14.2	0.0	0.2	0.0	1.2	389.7	614	2,866
	Avg Year	1,075.3	263.4	832.6	2.1	0.0	18.3	0.0	0.2	0.0	1.6	458.7	1,000	3,652
	Wet Year	1,222.7	299.5	946.7	2.3	0.0	24.0	0.0	0.3	0.0	2.0	521.5	1,859	4,878
Rainy River	Dry Year	800.7	370.1	948.4	122.1	191.4	913.8	226.2	355.9	23.0	2.3	227.1	218	4,399
	Avg Year	879.4	406.5	1,041.6	134.1	210.2	1,066.6	264.1	415.4	26.8	2.7	249.5	502	5,199
	Wet Year	968.7	447.8	1,147.4	147.7	231.6	1,305.2	323.1	508.3	32.8	3.3	274.8	874	6,265
Red River of the North	Dry Year	3,978.4	2,141.3	4,231.8	0.0	13.2	177.9	8.7	5.4	0.4	0.0	1,561.0	1,229	13,347
	Avg Year	4,640.4	2,497.6	4,936.0	0.0	15.4	223.0	10.9	6.8	0.5	0.0	1,820.7	3,599	17,750
	Wet Year	5,248.4	2,824.8	5,582.7	0.0	17.5	277.1	13.5	8.5	0.7	0.0	2,059.3	5,101	21,133
St. Croix River	Dry Year	2,888.4	718.1	2,076.0	0.0	22.8	735.7	109.4	117.1	0.3	16.4	1,631.9	3,397	11,713
	Avg Year	3,357.8	834.7	2,413.3	0.0	26.6	951.3	141.5	151.4	0.3	21.2	1,897.1	7,309	17,104
	Wet Year	3,662.7	910.5	2,632.5	0.0	29.0	1,168.2	173.7	185.9	0.4	26.1	2,069.3	13,421	24,279
Upper Mississippi River	Dry Year	53,550.4	32,497.7	31,620.6	38.9	1,173.4	4,982.4	628.5	814.1	104.1	47.3	17,099.9	21,243	163,800
	Avg Year	61,278.5	37,187.6	36,183.9	44.5	1,342.7	6,190.1	780.9	1,011.4	129.3	58.8	19,567.7	38,038	201,813
	Wet Year	67,579.4	41,011.4	39,904.5	49.1	1,480.8	7,560.0	953.7	1,235.2	157.9	71.8	21,579.7	68,981	250,565

	Hydrology Scenario	Low Intensity Residential	High Intensity Residential	Commercial/ Industrial/ Transportation	Bare Rock/Sand/ Clay	Transitional	Deciduous Forest	Evergreen Forest	Mixed Forest	Shrubland	Grasslands/ Herbaceous	Urban/ Recreational Grasses	Agricultural Lands in Incorporated Areas	Total Kg P
Statewide Totals	Dry Year	101,077	53,535	70,570	495	2,303	14,803	1,931	2,731	217	183	36,013	39,539	323,397
	Avg Year	115,630	61,013	80,321	537	2,586	17,798	2,298	3,241	260	221	41,140	75,621	400,667
	Wet Year	127,232	66,992	88,130	581	2,827	21,638	2,791	3,933	316	268	45,176	125,040	484,924

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3.3 Summary of Phosphorus Loadings by Basin

3.3.1 Phosphorus Loadings by Source Category

This assessment found that, under average flow conditions, the point source total phosphorus contribution represents 31 percent, while nonpoint sources of total phosphorus represent 69 percent of the loadings to surface waters, statewide (see Figure 3-7). The point source phosphorus loadings to surface waters are broken down in proportion to the influent phosphorus loadings (inflows) to wastewater treatment plants (WWTPs) in the state from each wastewater source category. This assumes that the proportion of the phosphorus load from each source category in the wastewater influent remains the same in the wastewater effluent (or treated discharge) from each treatment facility. Figure 3-7 shows for average flow conditions the major phosphorus nonpoint sources to surface waters are as follows:

- cropland and pasture runoff (26%)
- atmospheric deposition (13%)
- commercial/industrial process water (12%)
- streambank erosion (11%)
- human waste products (11%)

All of the remaining source category contributions are below 6 percent. The combination of residential and commercial automatic dishwasher detergent (ADWD) represents approximately 3 percent of the total phosphorus contributions to surface waters in the state, during an average year.

Under average flow conditions, the relative magnitude of the total phosphorus loadings from the sum of all source categories in the Upper Mississippi River basin is significantly higher than the remaining basins, with the second highest phosphorus loadings occurring in the Minnesota River basin (see Figure 3-8a). The Lower Mississippi and Red River basin total phosphorus loadings are approximately one-third less than the Minnesota River basin loadings.

Figure 3-8a illustrates the relative magnitudes of each of the phosphorus source category loadings estimated for each basin under average flow conditions, while Figure 3-8b shows the same information normalized to the basin area, as another way to compare the phosphorus loadings from basin to basin. Figures 3-8a and 3-8b show that, relative to the other phosphorus source categories in each basin, agricultural runoff is a significant source of phosphorus in all but the Lake Superior and Rainy River basins. Human waste products are a significant source of phosphorus in the Upper Mississippi River basin, along with commercial/industrial process water and food soils.

Figure 3-7
Estimated Total Phosphorus Contributions to Minnesota Surface Waters
Statewide
Average Flow Water Year

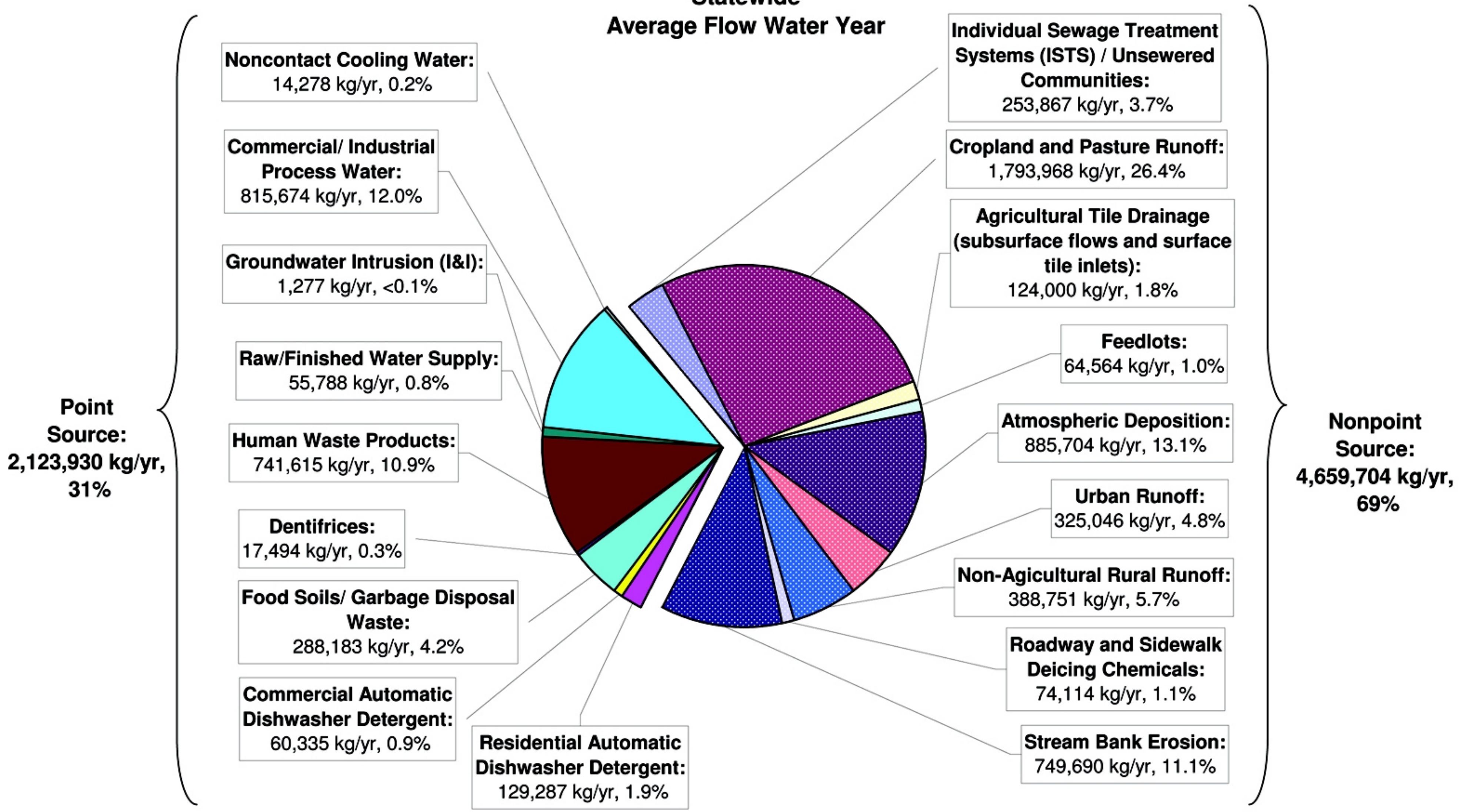

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Figure 3-8a Total Phosphorus Loads to Minnesota Surface Waters - By Major Drainage Basin: Average Flow Conditions

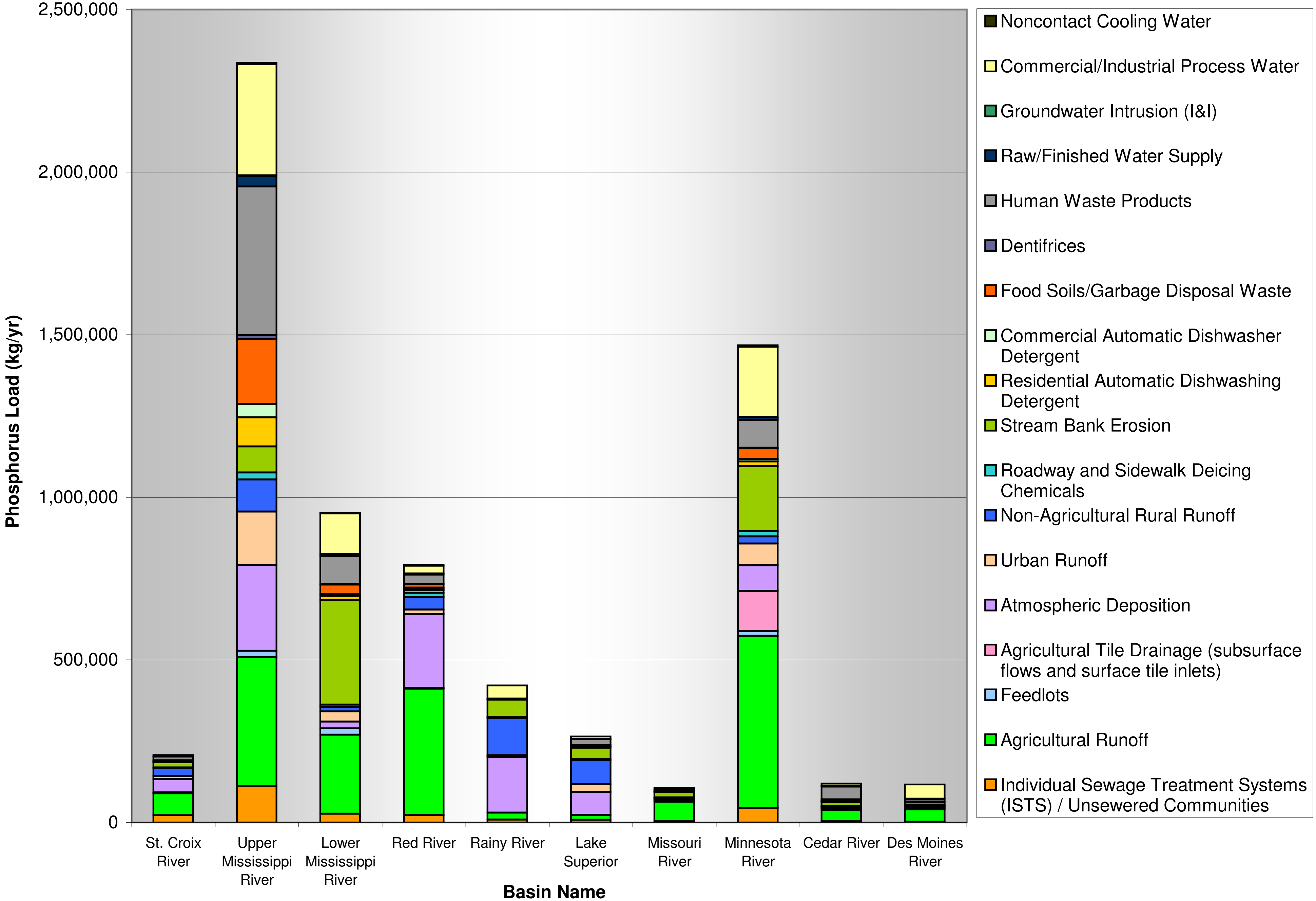
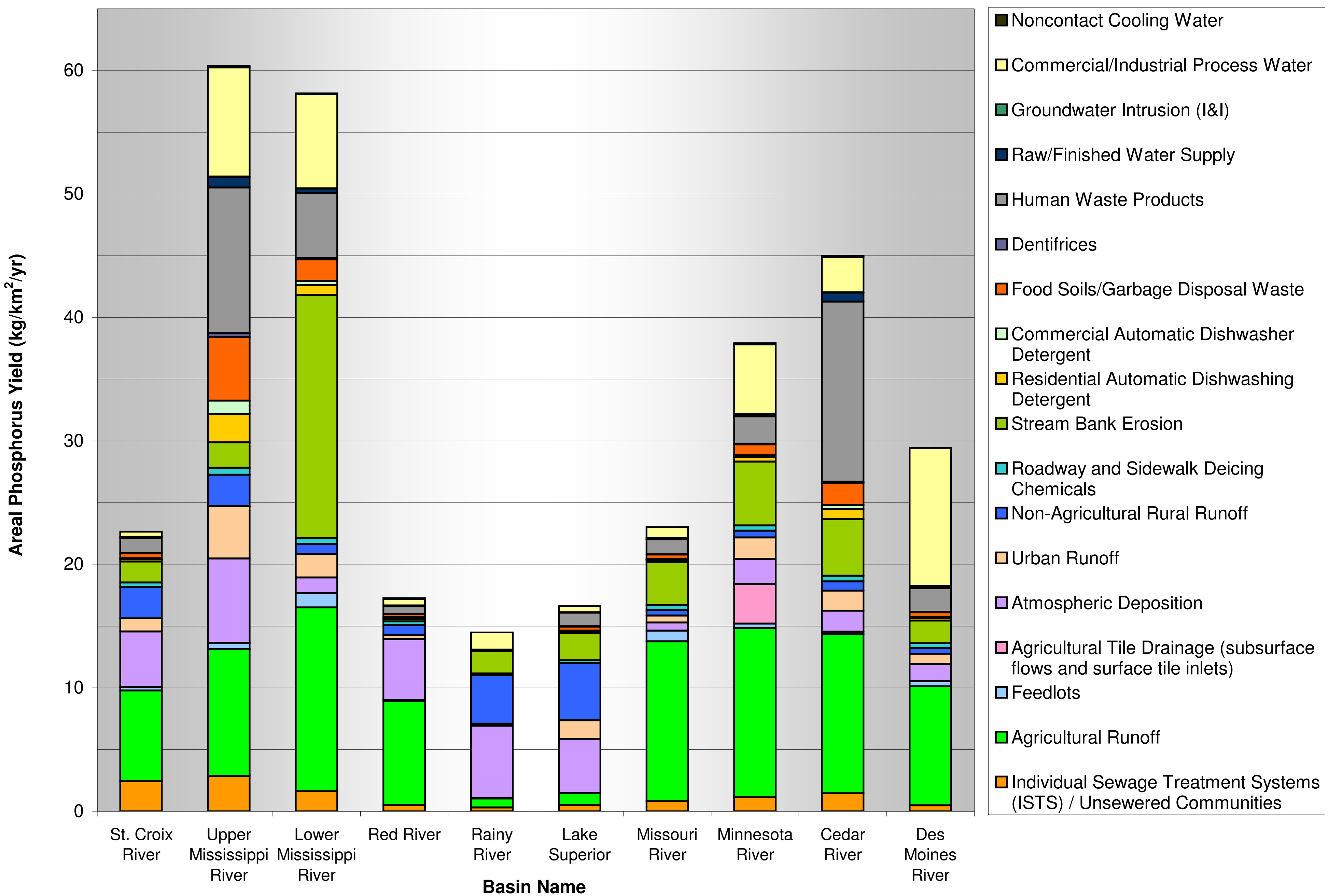


Figure 3-8b Watershed Total Phosphorus Yields to Minnesota Surface Waters - By Major Drainage Basin: Average Flow Conditions



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It should be noted that the data used for this study to assess point source loadings are from the years 2001, 2002 and the first half of 2003. Since that time period, phosphorus removal was implemented at the MCES' Metro WWTP. Because this one facility accounted for approximately 74 percent of the point source phosphorus load to the Upper Mississippi River basin and an estimated 40 percent statewide, continued phosphorus removal at this one facility will have a significant impact on the future relative phosphorus loads in this basin and the state.

Figures 3-8a and 3-8b also show that atmospheric deposition comprises significant percentages of the annual phosphorus loads as follows:

- Upper Mississippi River basin (11%)
- Red River basin (29%)
- St. Croix River basin (20%)
- Rainy River basin (34%)

This reflects the large amount of surface water and the relatively low amounts of other sources in these basins.

Streambank erosion is a significant source of phosphorus in the Lower Mississippi River basin (34%) and, to a lesser degree, in the Minnesota River basin (14%). Commercial/industrial process water is an important source of phosphorus in the Lower Mississippi (13%), Minnesota (15%), Des Moines (38%), and the Rainy River (10%) basins. Non-agricultural rural runoff sources of phosphorus are important in the Rainy River (27%) and Lake Superior (28%) basins. Finally, human waste products are a significant source of phosphorus in the Upper Mississippi (20%) and Cedar River (32%) basins.

3.3.2 Phosphorus Source Category Loadings by Flow Condition

Both total and bioavailable phosphorus source estimates vary significantly under each flow condition. This is the result of changes in the nonpoint source loading from different flow conditions. Point source loads remain constant for the three flow conditions. Total amount and relative source contributions are summarized in Table 3-18 which indicates that point sources of phosphorus are more bioavailable than nonpoint sources.

Table 3-18 Statewide phosphorus contributions of point and nonpoint sources by flow condition

	Flow Condition		
	Low (Dry)	Average	High (Wet)
Total Phosphorus			
Point Source (kg/yr)	2,123,930 (45%)	2,123,930 (31%)	2,123,930 (19%)
Nonpoint Source (kg/yr)	2,638,067 (55%)	4,659,704 (69%)	8,932,735 (81%)
Total	4,761,997	6,783,634	11,056,665
Bioavailable Phosphorus			
Point Source (kg/yr)	1,975,757 (57%)	1,975,757 (44%)	1,975,757 (30%)
Nonpoint Source (kg/yr)	1,472,784 (43%)	2,559,026 (56%)	4,648,570 (70%)
Total	3,448,542	4,534,783	6,624,327

Under low flow conditions, the total point source phosphorus contribution represents 45 percent, while nonpoint sources of phosphorus represent 55 percent of the statewide loadings to surface waters. The expected load reduction of approximately 581,000 kg/yr associated with a 1 mg/L permit limit at the MCES Metro WWTP would shift the point source contribution to approximately 37 percent of the total load and the nonpoint source contribution to 63 percent. Under low flow conditions, the bioavailable point source phosphorus contribution represents 57 percent of the statewide loadings to surface waters (see Table 3-18). The expected load reduction of approximately 496,800 kg/yr associated with a 1 mg/L permit limit at the MCES Metro WWTP would shift the point source contribution to approximately 50 percent of the total bioavailable phosphorus load.

Under average flow conditions (see Table 3-18), the total point source phosphorus contribution drops to 31 percent, compared to 45 percent for the statewide loadings to surface waters under low flow conditions. The nonpoint source phosphorus loadings nearly double from low to average flow conditions.

Under high flow conditions (see Table 3-18), the total point source phosphorus contribution drops to 19 percent, compared to 31 and 45 percent for the statewide loadings to surface waters under average and low flow conditions, respectively. Table 3-18 shows a 3.3-fold increase in nonpoint source phosphorus loadings from low to high flow conditions and a near two-fold increase from average to high flow conditions.

Table 3-19 presents the contributions of each source category to the total and bioavailable phosphorus loadings to surface waters in each basin and the state, by flow condition. The importance of the total and bioavailable phosphorus contributions from each source category varies significantly by basin, and somewhat by flow condition. Human waste products represent a significant portion of the total and bioavailable phosphorus loadings in the Upper Mississippi and Cedar River basins under each flow condition, and on a statewide basis, for the low and to a lesser extent average flow conditions. During low flow conditions, human waste products contribute between 10 and 20 percent of the bioavailable phosphorus loadings in the Lake Superior and St. Croix, Lower Mississippi, Red, Missouri, and Minnesota River basins. Commercial/industrial process water represents a significant portion of the total and bioavailable phosphorus loadings in the Upper Mississippi, Lower Mississippi, Minnesota, and Des Moines River basins under each flow condition, and on a statewide basis, for the low and to a lesser extent average flow conditions. Phosphorus contributions from ISTS/unsewered communities are of relative importance in the St. Croix River basin.

Cropland and pasture runoff represents significant total and bioavailable phosphorus loadings in the St. Croix, Lower Mississippi, Red, Missouri, Minnesota, Cedar and Des Moines River basins, and on a statewide basis, under all flow conditions. The phosphorus contribution from cropland and pasture runoff is also significant in the Upper Mississippi River basin for the average and high flow conditions. Atmospheric deposition represents a significant portion of the phosphorus loadings in the Lake Superior, St. Croix, Red, and Rainy River basins for each flow condition. Non-agricultural rural runoff contributes a significant portion of the phosphorus loadings in the Lake Superior and Rainy River basins for each flow condition. It should be noted, based on the analyses used in this study, that the typical rate of total phosphorus export from each acre of non-agricultural land is approximately four times lower than the corresponding load from each acre of contributing agricultural land (cropland and pasture). Finally, Table 3-19 shows that streambank erosion is an important source of phosphorus under high flow conditions for all of the basins, and is fairly significant in the Lake Superior, Lower Mississippi, Rainy and Missouri River basins under average flow conditions. Streambank erosion can also contribute somewhat significant amounts of total phosphorus statewide and to the Minnesota and Cedar River basins under average flow conditions.

Table 3-19 Major Source Category Contributions of Total and Bioavailable Phosphorus to Each Basin and the State, by Flow Condition

Basin	St. Croix River						Upper Mississippi River						Lower Mississippi River					
Flow Condition	Low		Average		High		Low		Average		High		Low		Average		High	
Source Category	TP	BP	TP	BP	TP	BP	TP	BP	TP	BP	TP	BP	TP	BP	TP	BP	TP	BP
Point Sources																		
Residential ADWD																		
Commercial ADWD																		
Food Soils/ Garbage Disposal Waste							◆	◆										
Dentifrices																		
Human Waste Products		◆					■	■	◆	■	◆	◆	◆	◆		◆		
Raw/Finished Water Supply																		
Groundwater Intrusion (I&I)																		
Commercial/Industrial Process Water							◆	■	◆	◆	◆	◆	■	■	◆	◆		◆
Noncontact Cooling Water																		
NonPoint Sources																		
ISTS/Unsewered Communities	◆	■	◆	◆		◆												
Cropland and Pasture Runoff	■	■	■	■	■	■	◆		◆	◆	■	◆	■	◆	■	■	◆	◆
Agricultural Tile Drainage																		
Feedlots																		
Atmospheric Deposition	■	◆	◆	◆	◆	◆	◆		◆									
Urban Runoff																		
Non-Agicultural Rural Runoff	◆		◆	◆														
Roadway and Sidewalk Deicers																		
Stream Bank Erosion					■	■					◆				■	■	■	■

Basin	Red River						Rainy River						Lake Superior					
Flow Condition	Low		Average		High		Low		Average		High		Low		Average		High	
Source Category	TP	BP	TP	BP	TP	BP	TP	BP	TP	BP	TP	BP	TP	BP	TP	BP	TP	BP
Point Sources																		
Residential ADWD																		
Commercial ADWD																		
Food Soils/ Garbage Disposal Waste																		
Dentifrices																		
Human Waste Products		◆												◆		◆		
Raw/Finished Water Supply																		
Groundwater Intrusion (I&I)																		
Commercial/Industrial Process Water							◆	■		◆								
Noncontact Cooling Water																		
NonPoint Sources																		
ISTS/Unsewered Communities																		
Cropland and Pasture Runoff	■	■	■	■	■	■												
Agricultural Tile Drainage																		
Feedlots																		
Atmospheric Deposition	■	■	■	◆	■	◆	■	■	■	■	■	◆	■	■	■	◆	◆	◆
Urban Runoff													◆	◆				
Non-Agicultural Rural Runoff							■	■	■	■	■	■	■	■	■	■	■	■
Roadway and Sidewalk Deicers																		
Stream Bank Erosion					◆	◆			◆	◆	■	■			◆	◆	■	■

Basin	Missouri River						Minnesota River						Cedar River					
Flow Condition	Low		Average		High		Low		Average		High		Low		Average		High	
Source Category	TP	BP	TP	BP	TP	BP	TP	BP	TP	BP	TP	BP	TP	BP	TP	BP	TP	BP
Point Sources																		
Residential ADWD																		
Commercial ADWD																		
Food Soils/ Garbage Disposal Waste																		
Dentifrices																		
Human Waste Products		◆						◆					■	■	■	■	■	■
Raw/Finished Water Supply																		
Groundwater Intrusion (I&I)																		
Commercial/Industrial Process Water							■	■	◆	■		◆		◆				
Noncontact Cooling Water																		
NonPoint Sources																		
ISTS/Unsewered Communities																		
Cropland and Pasture Runoff	■	■	■	■	■	■	■	■	■	■	■	■	◆	◆	■	■	■	■
Agricultural Tile Drainage																		
Feedlots																		
Atmospheric Deposition																		
Urban Runoff																		
Non-Agicultural Rural Runoff																		
Roadway and Sidewalk Deicers																		
Stream Bank Erosion			◆	◆	■	■			◆		■	■			◆		■	■

Basin	Des Moines River						Statewide					
Flow Condition	Low		Average		High		Low		Average		High	
Source Category	TP	BP	TP	BP	TP	BP	TP	BP	TP	BP	TP	BP
Point Sources												
Residential ADWD												
Commercial ADWD												
Food Soils/ Garbage Disposal Waste												
Dentifrices												
Human Waste Products							◆	■	◆	◆		◆
Raw/Finished Water Supply												
Groundwater Intrusion (I&I)												
Commercial/Industrial Process Water	■	■	■	■	■	■	◆	■	◆	◆		◆
Noncontact Cooling Water												
NonPoint Sources												
ISTS/Unsewered Communities												
Cropland and Pasture Runoff	■	◆	■	■	■	■	◆	◆	■	■	■	■
Agricultural Tile Drainage												
Feedlots												
Atmospheric Deposition							◆		◆			
Urban Runoff												
Non-Agicultural Rural Runoff												
Roadway and Sidewalk Deicers												
Stream Bank Erosion					■	◆			◆		■	■

KEY: TP -- Total Phosphorus

BP -- Bioavailable Phosphorus

ADWD -- Automatic Dishwashing Detergent

■ -- Source category represents more than 20% of the total basin phosphorus loading.

◆ -- Source category represents between 10% and 20% of the total basin phosphorus loading.

☐ -- Source category represents less than 10% of the total basin phosphorus loading.

3.4 Phosphorus Sources and Estimated Amounts Contributed to Surface Waters (by Basin, Total and Bioavailable)

This section is intended to present the results of the total and bioavailable phosphorus loading estimates to surface waters from each source category, by basin. The following sections provide a detailed discussion of the results of the phosphorus loading estimates for each major basin and the state, including assessments of which phosphorus source categories are important at varying flow conditions.

3.4.1 Statewide Inventory

This section discusses the results of all of the combined phosphorus source estimates for all of the basins in the state under each flow condition for total and bioavailable phosphorus.

3.4.1.1 Dry Conditions (Low Flow)

3.4.1.1.1 Total Phosphorus

Figure 3-9 shows that, under low flow conditions, the total point source phosphorus contribution represents 45 percent, while nonpoint sources of phosphorus represent 55 percent of the statewide loadings to surface waters. The expected load reduction of approximately 581,000 kg/yr associated with a 1 mg/L permit limit at the MCES Metro WWTF would shift the point source contribution to approximately 37 percent of the total load and nonpoint source to 63 percent. Figure 3-9 shows that commercial/industrial process water and human waste products represent 38 and 35 percent, respectively, of the point source total phosphorus contributions. The remaining point source categories contribute less than 14 percent of the statewide point source loadings. The combination of residential and commercial automatic dishwasher detergent represents approximately 10 percent of the point source total phosphorus contributions. As shown in Figure 3-9, cropland and pasture runoff and atmospheric deposition represent 33 and 30 percent, respectively, of the nonpoint source total phosphorus loadings, with the remaining nonpoint source contributions below 11 percent.

3.4.1.1.2 Bioavailable Phosphorus

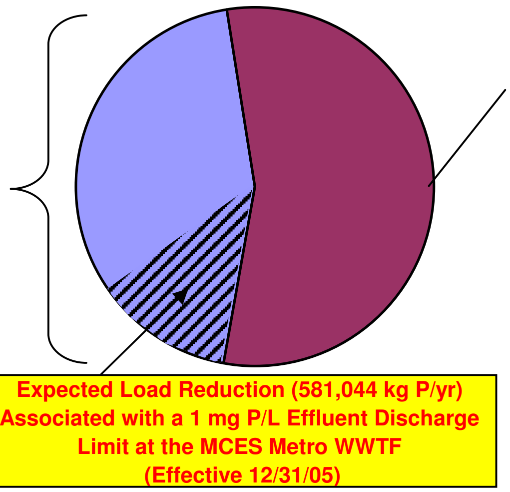
Figure 3-10 shows that, under low flow conditions, the bioavailable point source phosphorus contribution represents 57 percent of the statewide loadings to surface waters. The expected load reduction of approximately 496,800 kg/yr associated with a 1 mg/L permit limit at the MCES Metro WWTF would shift the point source contribution to approximately 50 percent of the total bioavailable phosphorus load. Figure 3-10 shows that commercial/industrial process water and human waste products represent 40 and 35 percent, respectively, of the point source bioavailable phosphorus contributions. The remaining point source categories contribute less than 12 percent of the statewide point source loadings. The combination of residential and commercial automatic dishwasher detergent represents approximately 10 percent of the point source bioavailable

Figure 3-9

Estimated Total Phosphorus Contributions to Minnesota Surface Waters Statewide Dry, Low Flow Water Year

Point Source:
2,123,930 kg/yr,
45%

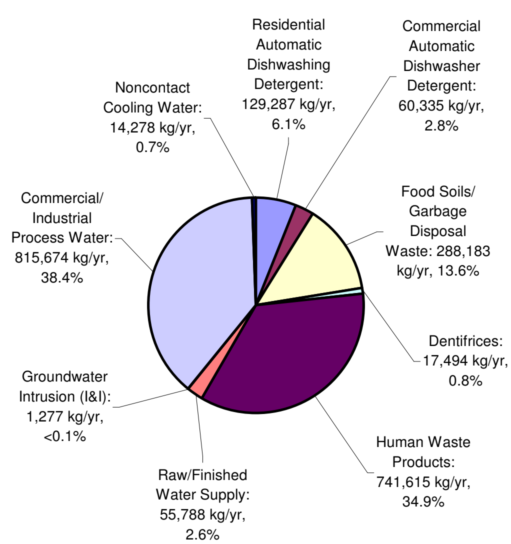
- Commercial Automatic Dishwasher Detergent
- Commercial/Industrial Process Water
- Dentifrices
- Food Soils/Garbage Disposal Waste
- Groundwater Intrusion (I&I)
- Residential Automatic Dishwasher Detergent
- Human Waste Products
- Noncontact Cooling Water
- Raw/Finished Water Supply



Nonpoint Source:
2,638,067 kg/yr,
55%

- Atmospheric Deposition
- Cropland and Pasture Runoff
- Feedlots
- Individual Sewage Treatment Systems (ISTS)/Unsewered Communities
- Non-Agriculture Rural Runoff
- Roadway and Sidewalk Deicing Chemicals
- Stream Bank Erosion
- Urban Runoff

Point Source Total Phosphorus Contributions



(Based on data from NPDES/SDS Permit Discharge Monitoring Reports, 2001 through mid-2003.)

Nonpoint Source Total Phosphorus Contributions

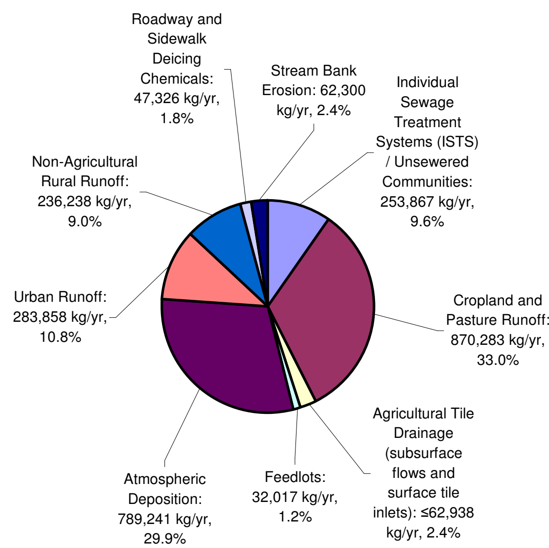
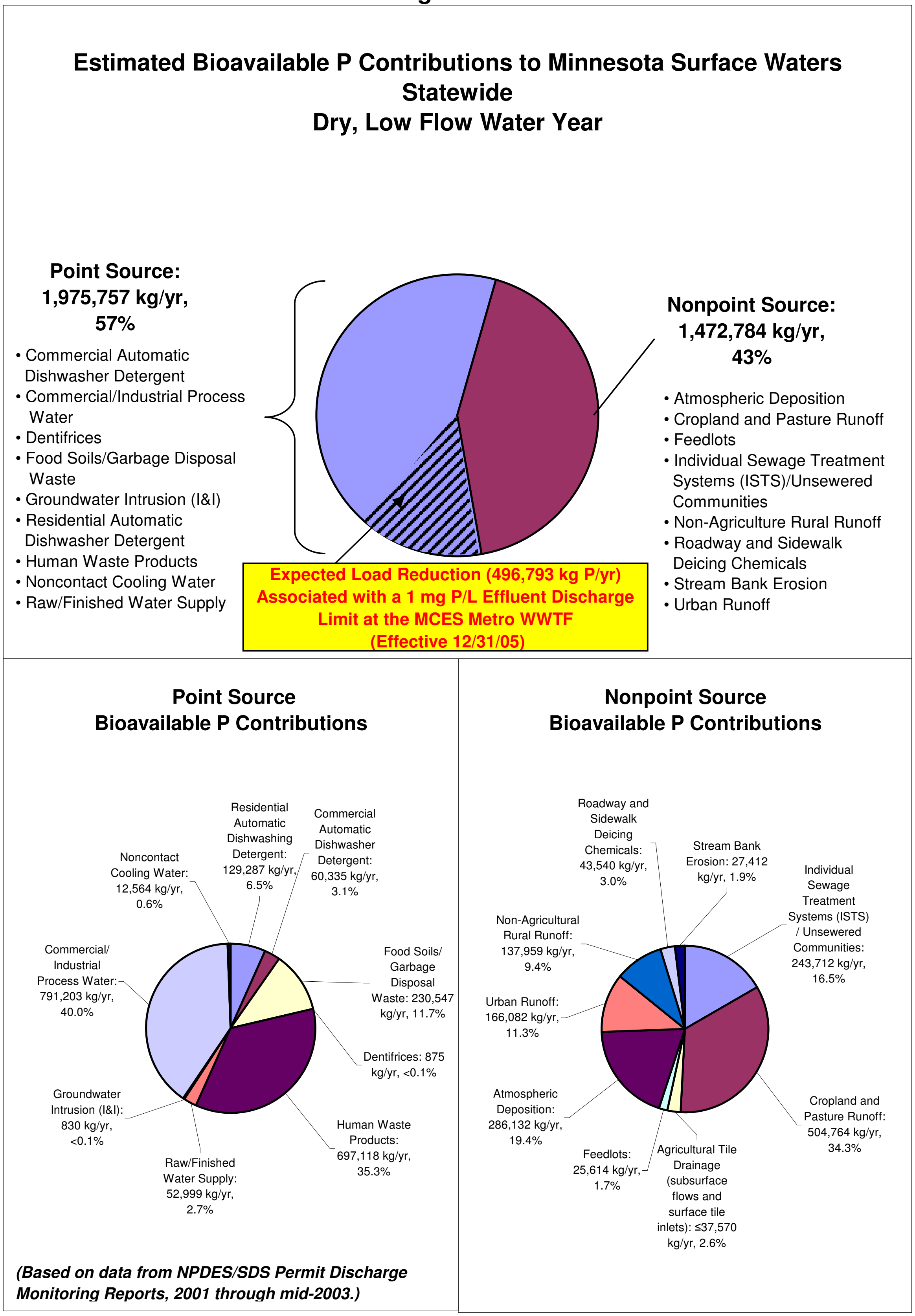


Figure 3-10



Estimated Bioavailable P Contributions to Minnesota Surface Waters
Statewide
Dry, Low Flow Water Year
Point Source:
1,975,757 kg/yr,
57%
• Commercial Automatic Dishwasher Detergent
• Commercial/Industrial Process Water
• Dentifrices
• Food Soils/Garbage Disposal Waste
• Groundwater Intrusion (I&I)
• Residential Automatic Dishwasher Detergent
• Human Waste Products
• Noncontact Cooling Water
• Raw/Finished Water Supply
Nonpoint Source:
1,472,784 kg/yr,
43%
• Atmospheric Deposition
• Cropland and Pasture Runoff
• Feedlots
• Individual Sewage Treatment Systems (ISTS)/Unsewered Communities
• Non-Agriculture Rural Runoff
• Roadway and Sidewalk Deicing Chemicals
• Stream Bank Erosion
• Urban Runoff
Expected Load Reduction (496,793 kg P/yr) Associated with a 1 mg P/L Effluent Discharge Limit at the MCES Metro WWTF (Effective 12/31/05)
Point Source
Bioavailable P Contributions
Residential Automatic Dishwashing Detergent: 129,287 kg/yr, 6.5%
Commercial Automatic Dishwasher Detergent: 60,335 kg/yr, 3.1%
Noncontact Cooling Water: 12,564 kg/yr, 0.6%
Commercial/ Industrial Process Water: 791,203 kg/yr, 40.0%
Food Soils/ Garbage Disposal Waste: 230,547 kg/yr, 11.7%
Dentifrices: 875 kg/yr, <0.1%
Groundwater Intrusion (I&I): 830 kg/yr, <0.1%
Human Waste Products: 697,118 kg/yr, 35.3%
Raw/Finished Water Supply: 52,999 kg/yr, 2.7%
(Based on data from NPDES/SDS Permit Discharge Monitoring Reports, 2001 through mid-2003.)
Nonpoint Source
Bioavailable P Contributions
Roadway and Sidewalk Deicing Chemicals: 43,540 kg/yr, 3.0%
Stream Bank Erosion: 27,412 kg/yr, 1.9%
Individual Sewage Treatment Systems (ISTS) / Unsewered Communities: 243,712 kg/yr, 16.5%
Non-Agricultural Rural Runoff: 137,959 kg/yr, 9.4%
Urban Runoff: 166,082 kg/yr, 11.3%
Atmospheric Deposition: 286,132 kg/yr, 19.4%
Cropland and Pasture Runoff: 504,764 kg/yr, 34.3%
Feedlots: 25,614 kg/yr, 1.7%
Agricultural Tile Drainage (subsurface flows and surface tile inlets): ≤37,570 kg/yr, 2.6%

phosphorus contributions. As shown in Figure 3-10, cropland and pasture runoff, atmospheric deposition and ISTS/unsewered communities represent approximately 34, 19 and 17 percent, respectively, of the nonpoint source bioavailable phosphorus loadings, with the remaining nonpoint source contributions below 12 percent. A comparison of Figures 3-9 and 3-10 generally indicates that point sources of phosphorus are more bioavailable than nonpoint sources. Looking more specifically at each source category in comparing Figures 3-9 and 3-10, indicates that ISTS/unsewered communities exhibits a significant increased contribution, while atmospheric deposition exhibits a significant decreased contribution, relative to the other sources for the bioavailable contribution of phosphorus. The relative shift for the remaining source categories is less than 2 percent in comparing the bioavailable and total phosphorus contributions in each figure.

3.4.1.2 Average Condition

3.4.1.2.1 Total Phosphorus

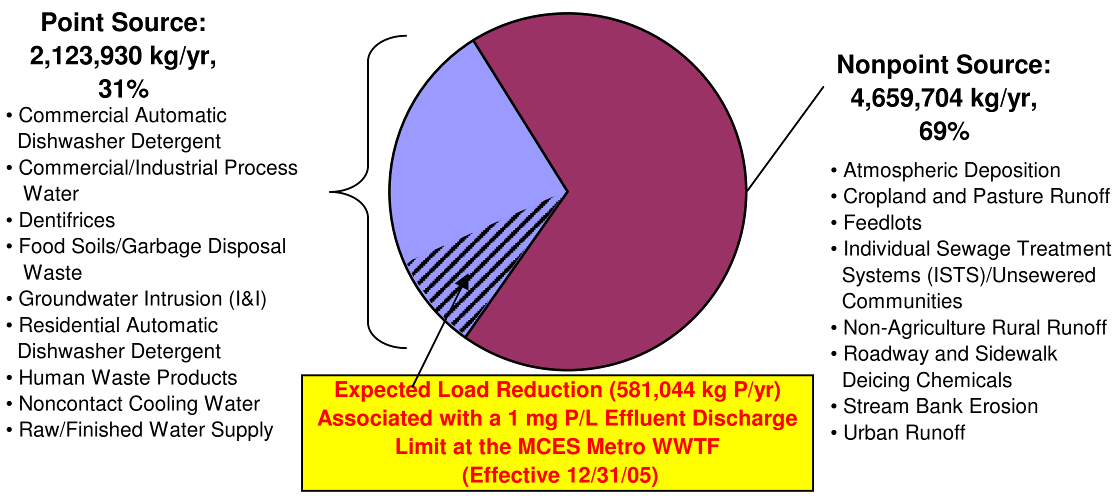
Under average flow conditions, Figure 3-11 shows that the total point source phosphorus contribution drops to 31 percent, compared to 45 percent for the statewide loadings to surface waters under low flow conditions. The expected load reduction of approximately 581,000 kg/yr associated with a 1 mg/L permit limit at the MCES Metro WWTF would shift the point source contribution to approximately 25 percent of the total load. As presented in Figure 3-11, cropland and pasture runoff, atmospheric deposition, and streambank erosion represent 39, 19 and 16 percent, respectively, of the nonpoint source total phosphorus loadings, with the remaining nonpoint source contributions below 9 percent. Compared to low flow conditions (Figure 3-9), Figure 3-11 shows that the relative statewide nonpoint source contributions of total phosphorus increased significantly for streambank erosion, increased slightly for cropland and pasture runoff, decreased somewhat for urban runoff, and decreased significantly for atmospheric deposition and ISTS/unsewered communities.

3.4.1.2.2 Bioavailable Phosphorus

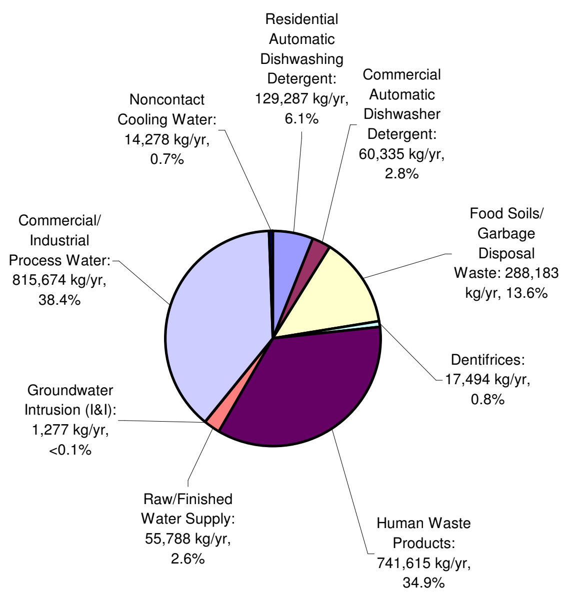
Under average flow conditions, Figure 3-12 shows that the bioavailable point source phosphorus contribution drops to 44 percent, compared to 57 percent for the statewide loadings to surface waters under low flow conditions. The expected load reduction of approximately 496,800 kg/yr associated with a 1 mg/L permit limit at the MCES Metro WWTF would shift the point source contribution to approximately 37 percent of the total bioavailable phosphorus load. As presented in Figure 3-12, cropland and pasture runoff, atmospheric deposition, and streambank erosion represent 40, 13 and 13 percent, respectively, of the nonpoint source bioavailable phosphorus loadings, with the remaining nonpoint source contributions below 10 percent. Compared to low flow conditions (Figure 3-10), Figure 3-12 shows that the relative statewide nonpoint source contributions of bioavailable phosphorus increased significantly for streambank erosion, increased slightly for cropland and

Figure 3-11

Estimated Total Phosphorus Contributions to Minnesota Surface Waters
Statewide
Average Flow Water Year



Point Source
Total Phosphorus Contributions



(Based on data from NPDES/SDS Permit Discharge Monitoring Reports, 2001 through mid-2003.)

Nonpoint Source
Total Phosphorus Contributions

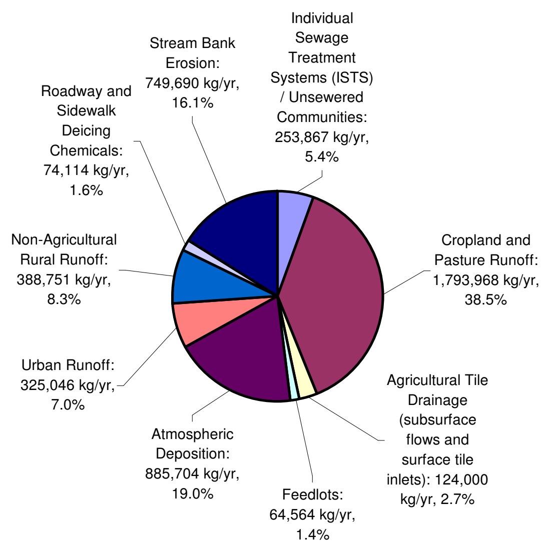
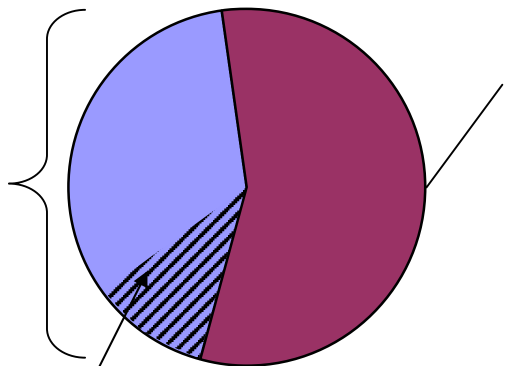


Figure 3-12

Estimated Bioavailable P Contributions to Minnesota Surface Waters Statewide
Average Flow Water Year

Point Source:
1,975,757 kg/yr,
44%

- Commercial Automatic Dishwasher Detergent
- Commercial/Industrial Process Water
- Dentifrices
- Food Soils/Garbage Disposal Waste
- Groundwater Intrusion (I&I)
- Residential Automatic Dishwasher Detergent
- Human Waste Products
- Noncontact Cooling Water
- Raw/Finished Water Supply

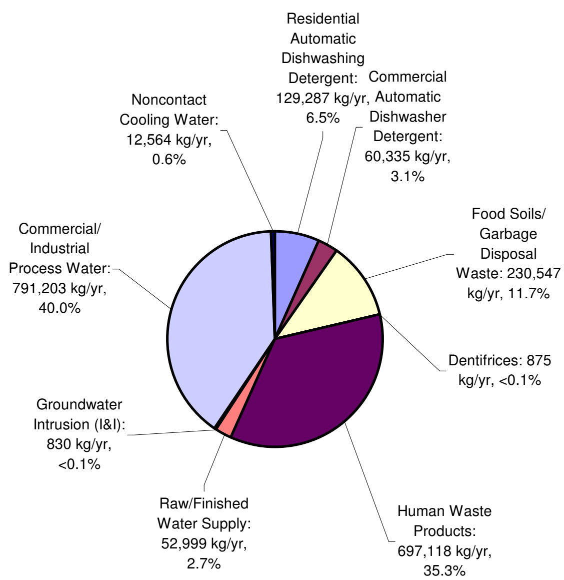


Expected Load Reduction (496,793 kg P/yr) Associated with a 1 mg P/L Effluent Discharge Limit at the MCES Metro WWTF (Effective 12/31/05)

Nonpoint Source:
2,559,026 kg/yr,
56%

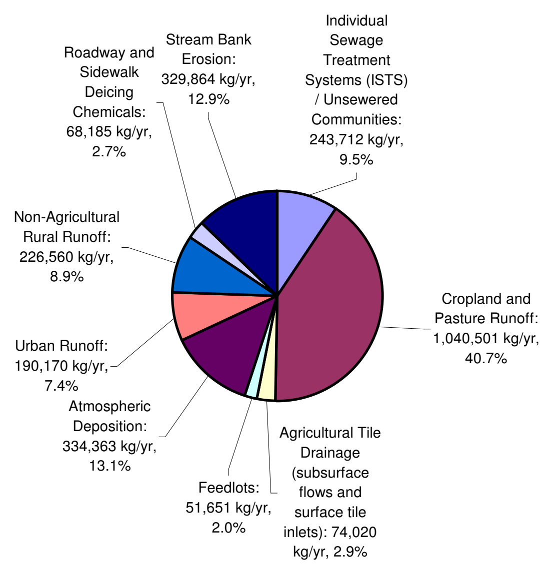
- Atmospheric Deposition
- Cropland and Pasture Runoff
- Feedlots
- Individual Sewage Treatment Systems (ISTS)/Unsewered Communities
- Non-Agriculture Rural Runoff
- Roadway and Sidewalk Deicing Chemicals
- Stream Bank Erosion
- Urban Runoff

Point Source Bioavailable P Contributions



(Based on data from NPDES/SDS Permit Discharge Monitoring Reports, 2001 through mid-2003.)

Nonpoint Source Bioavailable P Contributions



pasture runoff, decreased somewhat for urban runoff, and decreased significantly for atmospheric deposition and ISTS/unsewered communities.

3.4.1.3 Wet Condition (High Flow)

3.4.1.3.1 Total Phosphorus

Under high flow conditions, Figure 3-13 shows that the total point source phosphorus contribution drops to 19 percent, compared to 31 and 45 percent for the statewide loadings to surface waters under average and low flow conditions, respectively. The expected load reduction of approximately 581,000 kg/yr associated with a 1 mg/L permit limit at the MCES Metro WWTF would shift the point source contribution to approximately 15 percent of the total load. As presented in Figure 3-13, streambank erosion, cropland and pasture runoff, and atmospheric deposition represent 40, 31 and 11 percent, respectively, of the nonpoint source total phosphorus loadings, with the remaining nonpoint source contributions below 7 percent. Compared to average flow conditions (Figure 3-11), Figure 3-13 shows that the relative statewide nonpoint source contributions of total phosphorus increased significantly for streambank erosion, decreased slightly for cropland and pasture and non-agricultural rural runoff, decreased somewhat for urban runoff, and decreased significantly for atmospheric deposition and ISTS/unsewered communities.

3.4.1.3.2 Bioavailable Phosphorus

Under high flow conditions, Figure 3-14 shows that the bioavailable point source phosphorus contribution drops to 30 percent, compared to 44 and 57 percent for the statewide loadings to surface waters under average and low flow conditions, respectively. The expected load reduction of approximately 496,800 kg/yr associated with a 1 mg/L permit limit at the MCES Metro WWTF would shift the point source contribution to approximately 24 percent of the total load. As presented in Figure 3-14, streambank erosion, cropland and pasture runoff, and atmospheric deposition represent 34, 34 and 9 percent, respectively, of the nonpoint source bioavailable phosphorus loadings, with the remaining nonpoint source contributions at or below 7 percent. Compared to average flow conditions (Figure 3-12), Figure 3-14 shows that the relative statewide nonpoint source contributions of bioavailable phosphorus increased significantly for streambank erosion, decreased slightly for cropland and pasture and non-agricultural rural runoff, decreased somewhat for urban runoff, and decreased significantly for atmospheric deposition and ISTS/unsewered communities.

Figure 3-13

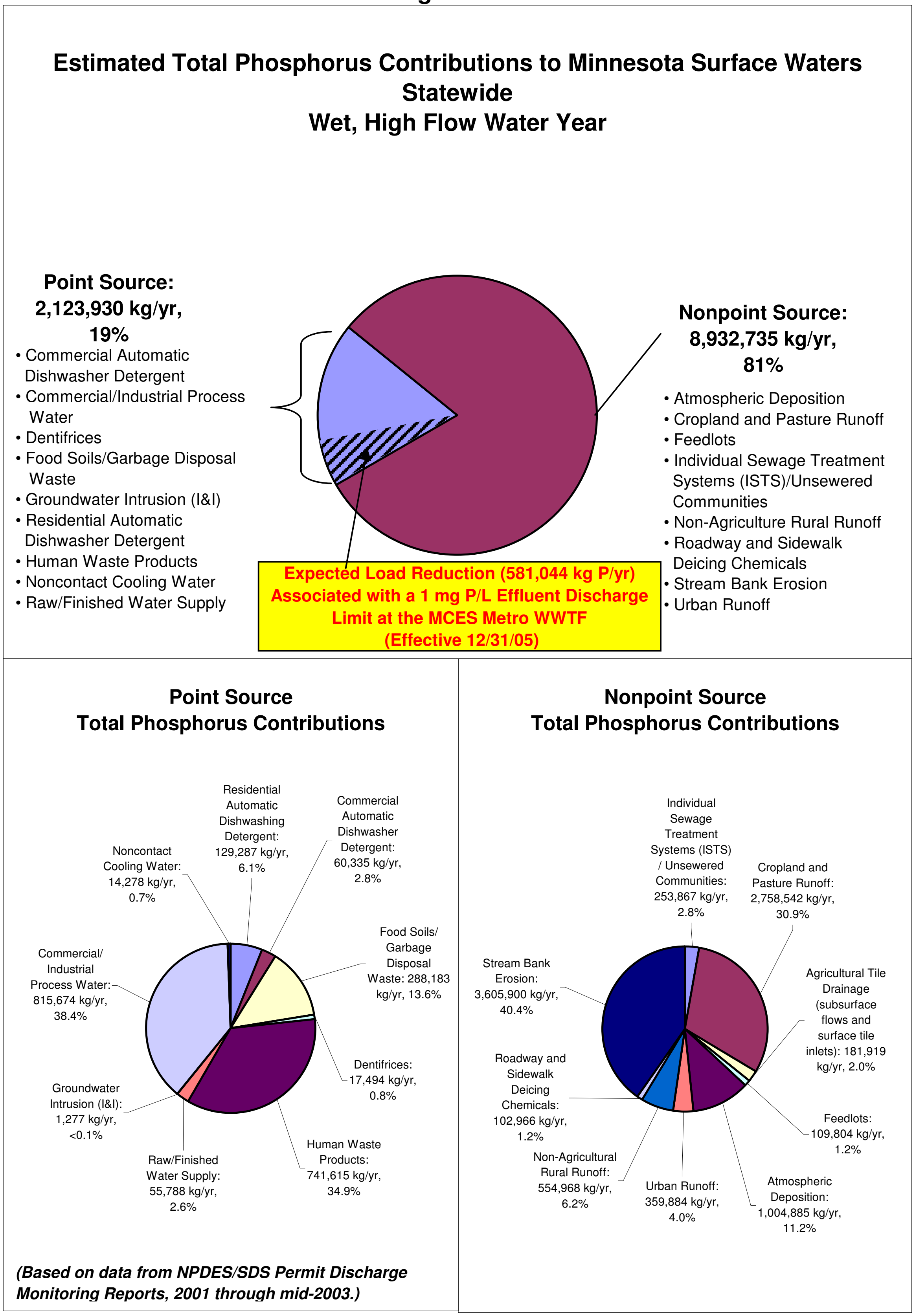
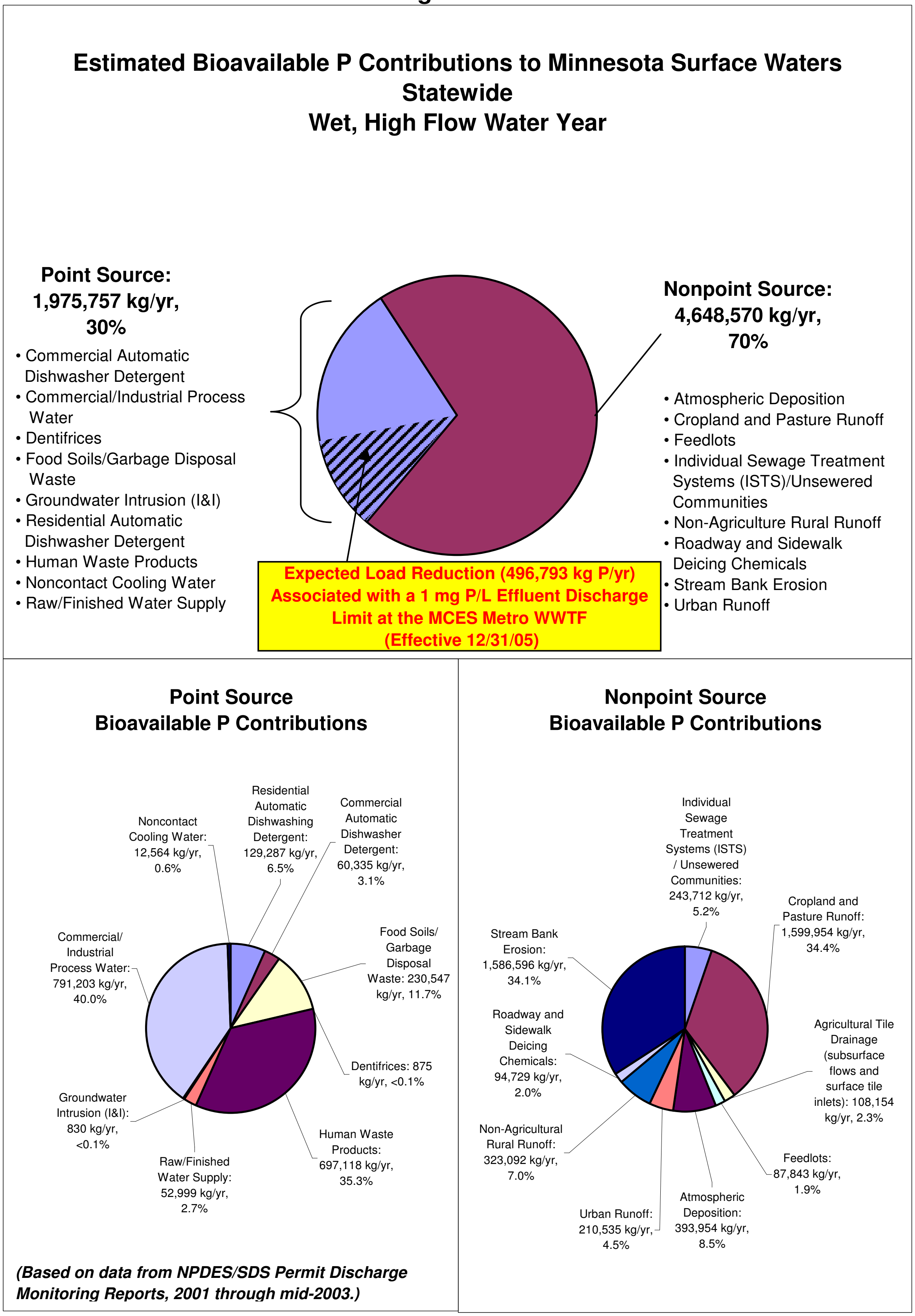

Estimated Total Phosphorus Contributions to Minnesota Surface Waters
Statewide
Wet, High Flow Water Year
Point Source:
2,123,930 kg/yr,
19%
• Commercial Automatic Dishwasher Detergent
• Commercial/Industrial Process Water
• Dentifrices
• Food Soils/Garbage Disposal Waste
• Groundwater Intrusion (I&I)
• Residential Automatic Dishwasher Detergent
• Human Waste Products
• Noncontact Cooling Water
• Raw/Finished Water Supply
Nonpoint Source:
8,932,735 kg/yr,
81%
• Atmospheric Deposition
• Cropland and Pasture Runoff
• Feedlots
• Individual Sewage Treatment Systems (ISTS)/Unsewered Communities
• Non-Agriculture Rural Runoff
• Roadway and Sidewalk Deicing Chemicals
• Stream Bank Erosion
• Urban Runoff
Expected Load Reduction (581,044 kg P/yr) Associated with a 1 mg P/L Effluent Discharge Limit at the MCES Metro WWTF (Effective 12/31/05)
Point Source
Total Phosphorus Contributions
Residential Automatic Dishwashing Detergent: 129,287 kg/yr, 6.1%
Commercial Automatic Dishwasher Detergent: 60,335 kg/yr, 2.8%
Noncontact Cooling Water: 14,278 kg/yr, 0.7%
Food Soils/ Garbage Disposal Waste: 288,183 kg/yr, 13.6%
Commercial/ Industrial Process Water: 815,674 kg/yr, 38.4%
Dentifrices: 17,494 kg/yr, 0.8%
Groundwater Intrusion (I&I): 1,277 kg/yr, <0.1%
Human Waste Products: 741,615 kg/yr, 34.9%
Raw/Finished Water Supply: 55,788 kg/yr, 2.6%
(Based on data from NPDES/SDS Permit Discharge Monitoring Reports, 2001 through mid-2003.)
Nonpoint Source
Total Phosphorus Contributions
Individual Sewage Treatment Systems (ISTS) / Unsewered Communities: 253,867 kg/yr, 2.8%
Cropland and Pasture Runoff: 2,758,542 kg/yr, 30.9%
Stream Bank Erosion: 3,605,900 kg/yr, 40.4%
Agricultural Tile Drainage (subsurface flows and surface tile inlets): 181,919 kg/yr, 2.0%
Roadway and Sidewalk Deicing Chemicals: 102,966 kg/yr, 1.2%
Feedlots: 109,804 kg/yr, 1.2%
Non-Agricultural Rural Runoff: 554,968 kg/yr, 6.2%
Urban Runoff: 359,884 kg/yr, 4.0%
Atmospheric Deposition: 1,004,885 kg/yr, 11.2%

Figure 3-14



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3.4.2 St. Croix River Basin

3.4.2.1 Dry Conditions (Low Flow)

3.4.2.1.1 Total Phosphorus

Figure 3-15 shows that, under low flow conditions, the total point source phosphorus contribution represents 16 percent, while nonpoint sources of phosphorus represent 84 percent of the loadings to surface waters in the St. Croix River basin. Figure 3-15 also shows that human waste products, commercial/industrial process water, and food soils represent 50, 17 and 17 percent, respectively, of the point source total phosphorus contributions. The remaining point source categories contribute less than 8 percent of the point source loadings. The combination of residential and commercial automatic dishwasher detergent represents approximately 11 percent of the point source total phosphorus contributions. As shown in Figure 3-15, cropland and pasture runoff, atmospheric deposition, and ISTS/unsewered communities represent 28, 30, and 20 percent, respectively, of the nonpoint source total phosphorus loadings, with the remaining nonpoint source contributions below 13 percent.

3.4.2.1.2 Bioavailable Phosphorus

Figure 3-16 shows that, under low flow conditions, the bioavailable point source phosphorus contribution represents 22 percent of the loadings to surface waters in the St. Croix River basin. Figure 3-16 also shows that human waste products, commercial/industrial process water, and food soils represent 51, 18 and 15 percent, respectively, of the point source bioavailable phosphorus contributions. The remaining point source categories contribute less than 9 percent of the point source loadings to the St. Croix River basin. The combination of residential and commercial automatic dishwasher detergent represents approximately 12 percent of the point source bioavailable phosphorus contributions. As shown in Figure 3-16, cropland and pasture runoff, atmospheric deposition and ISTS/unsewered communities represent approximately 26, 21 and 30 percent, respectively, of the nonpoint source bioavailable phosphorus loadings, with the remaining nonpoint source contributions below 13 percent.

Figure 3-15

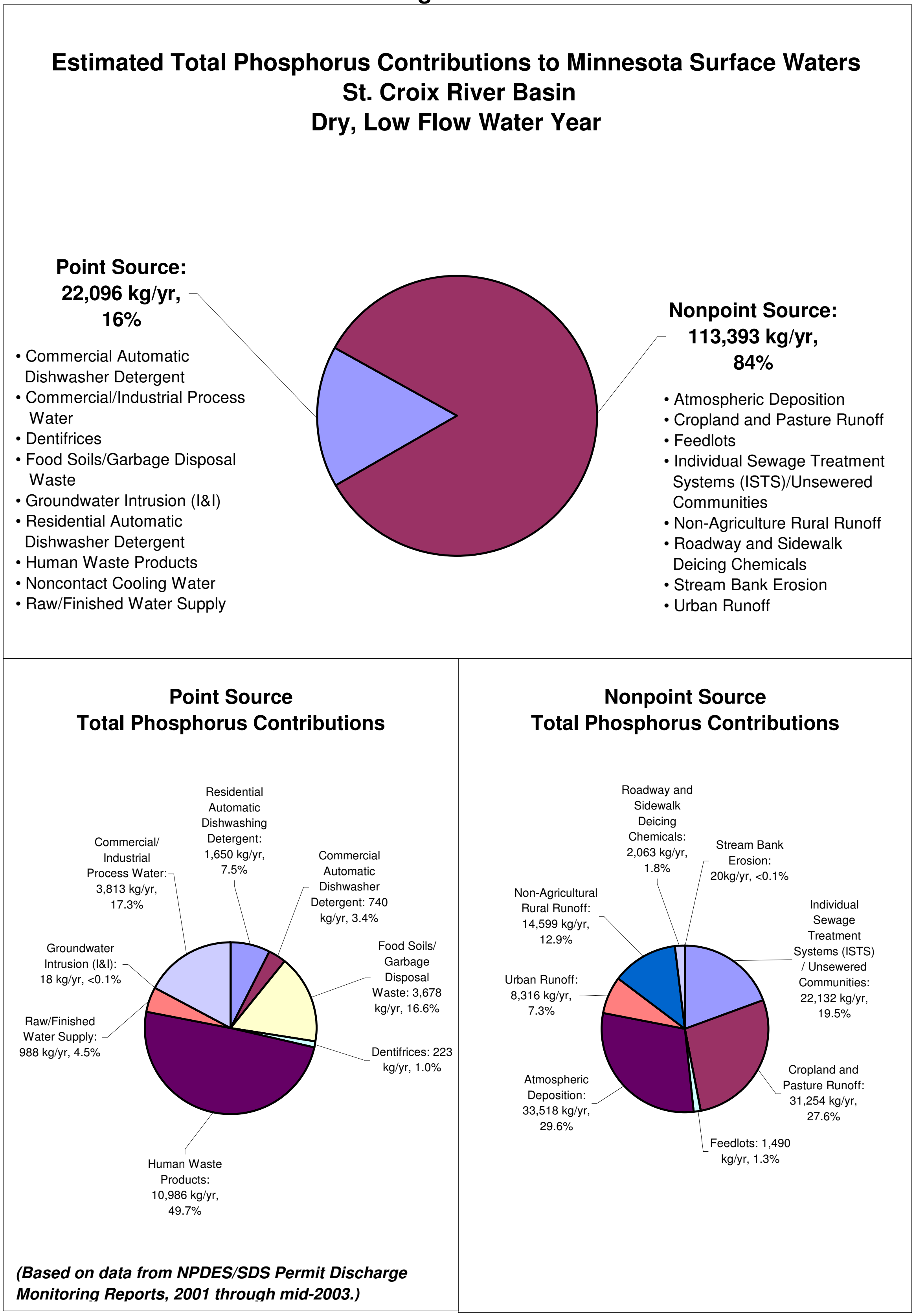
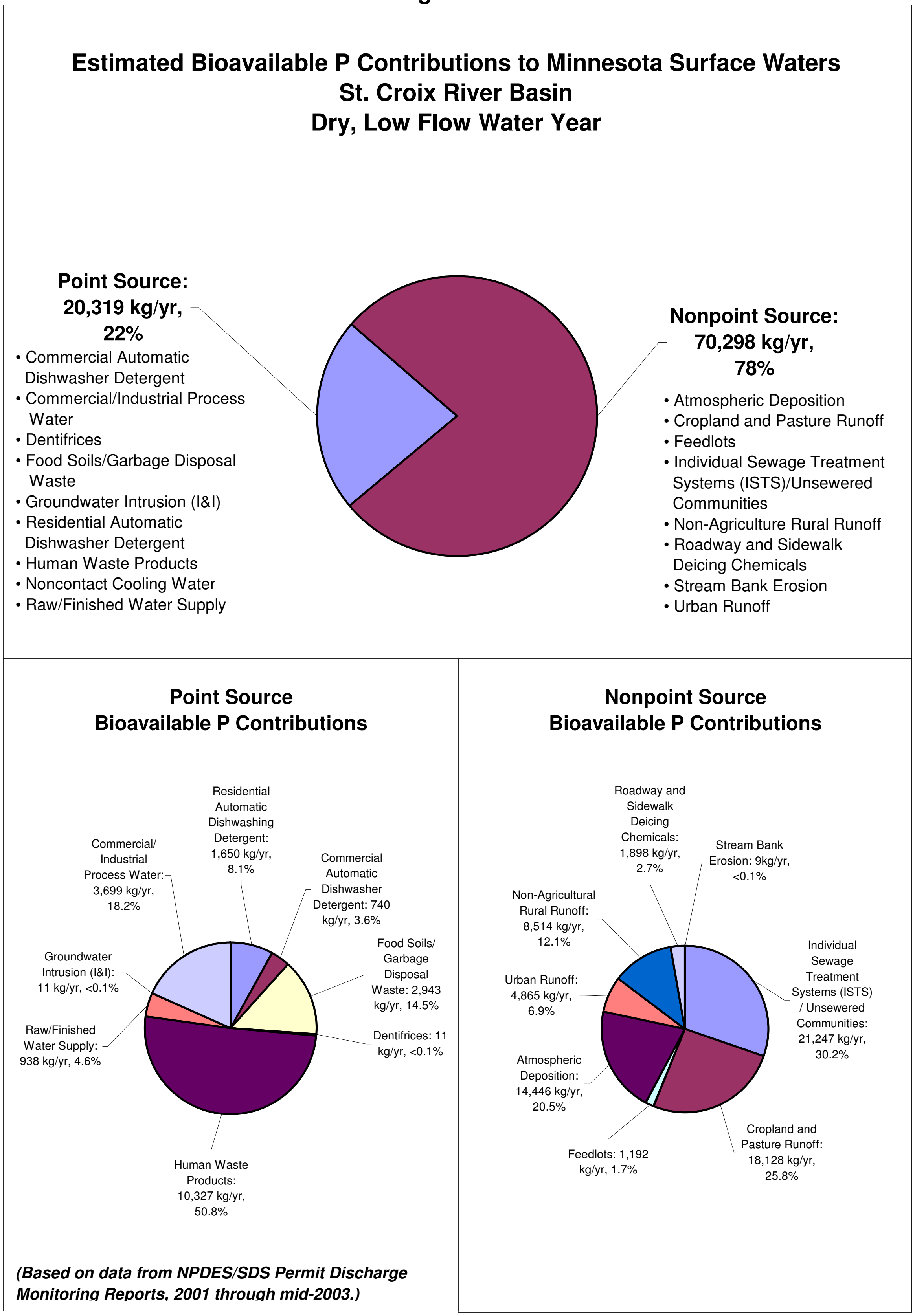

Estimated Total Phosphorus Contributions to Minnesota Surface Waters
St. Croix River Basin
Dry, Low Flow Water Year
Point Source:
22,096 kg/yr,
16%
• Commercial Automatic Dishwasher Detergent
• Commercial/Industrial Process Water
• Dentifrices
• Food Soils/Garbage Disposal Waste
• Groundwater Intrusion (I&I)
• Residential Automatic Dishwasher Detergent
• Human Waste Products
• Noncontact Cooling Water
• Raw/Finished Water Supply
Nonpoint Source:
113,393 kg/yr,
84%
• Atmospheric Deposition
• Cropland and Pasture Runoff
• Feedlots
• Individual Sewage Treatment Systems (ISTS)/Unsewered Communities
• Non-Agriculture Rural Runoff
• Roadway and Sidewalk Deicing Chemicals
• Stream Bank Erosion
• Urban Runoff
Point Source
Total Phosphorus Contributions
Residential Automatic Dishwashing Detergent: 1,650 kg/yr, 7.5%
Commercial/ Industrial Process Water: 3,813 kg/yr, 17.3%
Commercial Automatic Dishwasher Detergent: 740 kg/yr, 3.4%
Groundwater Intrusion (I&I): 18 kg/yr, <0.1%
Food Soils/ Garbage Disposal Waste: 3,678 kg/yr, 16.6%
Raw/Finished Water Supply: 988 kg/yr, 4.5%
Dentifrices: 223 kg/yr, 1.0%
Human Waste Products: 10,986 kg/yr, 49.7%
(Based on data from NPDES/SDS Permit Discharge Monitoring Reports, 2001 through mid-2003.)
Nonpoint Source
Total Phosphorus Contributions
Roadway and Sidewalk Deicing Chemicals: 2,063 kg/yr, 1.8%
Stream Bank Erosion: 20kg/yr, <0.1%
Non-Agricultural Rural Runoff: 14,599 kg/yr, 12.9%
Individual Sewage Treatment Systems (ISTS) / Unsewered Communities: 22,132 kg/yr, 19.5%
Urban Runoff: 8,316 kg/yr, 7.3%
Cropland and Pasture Runoff: 31,254 kg/yr, 27.6%
Atmospheric Deposition: 33,518 kg/yr, 29.6%
Feedlots: 1,490 kg/yr, 1.3%

Figure 3-16


Estimated Bioavailable P Contributions to Minnesota Surface Waters
St. Croix River Basin
Dry, Low Flow Water Year
Point Source:
20,319 kg/yr,
22%
• Commercial Automatic Dishwasher Detergent
• Commercial/Industrial Process Water
• Dentifrices
• Food Soils/Garbage Disposal Waste
• Groundwater Intrusion (I&I)
• Residential Automatic Dishwasher Detergent
• Human Waste Products
• Noncontact Cooling Water
• Raw/Finished Water Supply
Nonpoint Source:
70,298 kg/yr,
78%
• Atmospheric Deposition
• Cropland and Pasture Runoff
• Feedlots
• Individual Sewage Treatment Systems (ISTS)/Unsewered Communities
• Non-Agriculture Rural Runoff
• Roadway and Sidewalk Deicing Chemicals
• Stream Bank Erosion
• Urban Runoff
Point Source
Bioavailable P Contributions
Residential Automatic Dishwashing Detergent: 1,650 kg/yr, 8.1%
Commercial Automatic Dishwasher Detergent: 740 kg/yr, 3.6%
Commercial/ Industrial Process Water: 3,699 kg/yr, 18.2%
Food Soils/ Garbage Disposal Waste: 2,943 kg/yr, 14.5%
Groundwater Intrusion (I&I): 11 kg/yr, <0.1%
Raw/Finished Water Supply: 938 kg/yr, 4.6%
Dentifrices: 11 kg/yr, <0.1%
Human Waste Products: 10,327 kg/yr, 50.8%
(Based on data from NPDES/SDS Permit Discharge Monitoring Reports, 2001 through mid-2003.)
Nonpoint Source
Bioavailable P Contributions
Roadway and Sidewalk Deicing Chemicals: 1,898 kg/yr, 2.7%
Stream Bank Erosion: 9kg/yr, <0.1%
Non-Agricultural Rural Runoff: 8,514 kg/yr, 12.1%
Individual Sewage Treatment Systems (ISTS) / Unsewered Communities: 21,247 kg/yr, 30.2%
Urban Runoff: 4,865 kg/yr, 6.9%
Atmospheric Deposition: 14,446 kg/yr, 20.5%
Feedlots: 1,192 kg/yr, 1.7%
Cropland and Pasture Runoff: 18,128 kg/yr, 25.8%

3.4.2.2 Average Condition

3.4.2.2.1 Total Phosphorus

Under average flow conditions, Figure 3-17 shows that the total point source phosphorus contribution drops to 11 percent, compared to 16 percent for the loadings to surface waters in the St. Croix River basin under low flow conditions. As presented in Figure 3-17, cropland and pasture runoff, atmospheric deposition, non-agricultural rural runoff and ISTS/unsewered communities represent 36, 22, 12, and 12 percent, respectively, of the nonpoint source total phosphorus loadings, with the remaining nonpoint source contributions below 9 percent. Compared to low flow conditions (Figure 3-15), Figure 3-17 shows that the relative nonpoint source contributions of total phosphorus increased significantly for streambank erosion, as well as cropland and pasture runoff, decreased slightly for urban runoff, and decreased significantly for atmospheric deposition and ISTS/unsewered communities.

3.2.2.2.2 Bioavailable Phosphorus

Under average flow conditions, Figure 3-18 shows that the bioavailable point source phosphorus contribution drops to 16 percent, compared to 22 percent for the loadings to surface waters in the St. Croix River basin under low flow conditions. As presented in Figure 3-18, cropland and pasture runoff, atmospheric deposition, non-agricultural rural runoff and ISTS/unsewered communities represent 36, 17, 12, and 19 percent, respectively, of the nonpoint source bioavailable phosphorus loadings, with the remaining nonpoint source contributions below 7 percent. Compared to low flow conditions (Figure 3-16), Figure 3-18 shows that the relative nonpoint source contributions of bioavailable phosphorus increased significantly for streambank erosion, as well as cropland and pasture runoff, decreased slightly for urban runoff, and decreased significantly for atmospheric deposition and ISTS/unsewered communities.

3.4.2.3 Wet Condition (High Flow)

3.4.2.3.1 Total Phosphorus

Under high flow conditions, Figure 3-19 shows that the total point source phosphorus contribution drops to 6 percent, compared to 11 and 16 percent for the loadings to surface waters in the St. Croix River basin under average and low flow conditions, respectively. As presented in Figure 3-19, streambank erosion, cropland and pasture runoff, and atmospheric deposition represent 29, 36 and 14 percent, respectively, of the nonpoint source total phosphorus loadings, with the remaining nonpoint source contributions below 10 percent. Compared to average flow conditions (Figure 3-17), Figure 3-19 shows that the relative statewide nonpoint source contributions of total phosphorus increased significantly for streambank erosion, decreased slightly for cropland and pasture and non-agricultural rural runoff, decreased somewhat for urban runoff, and decreased significantly for atmospheric deposition and ISTS/unsewered communities.

Figure 3-17

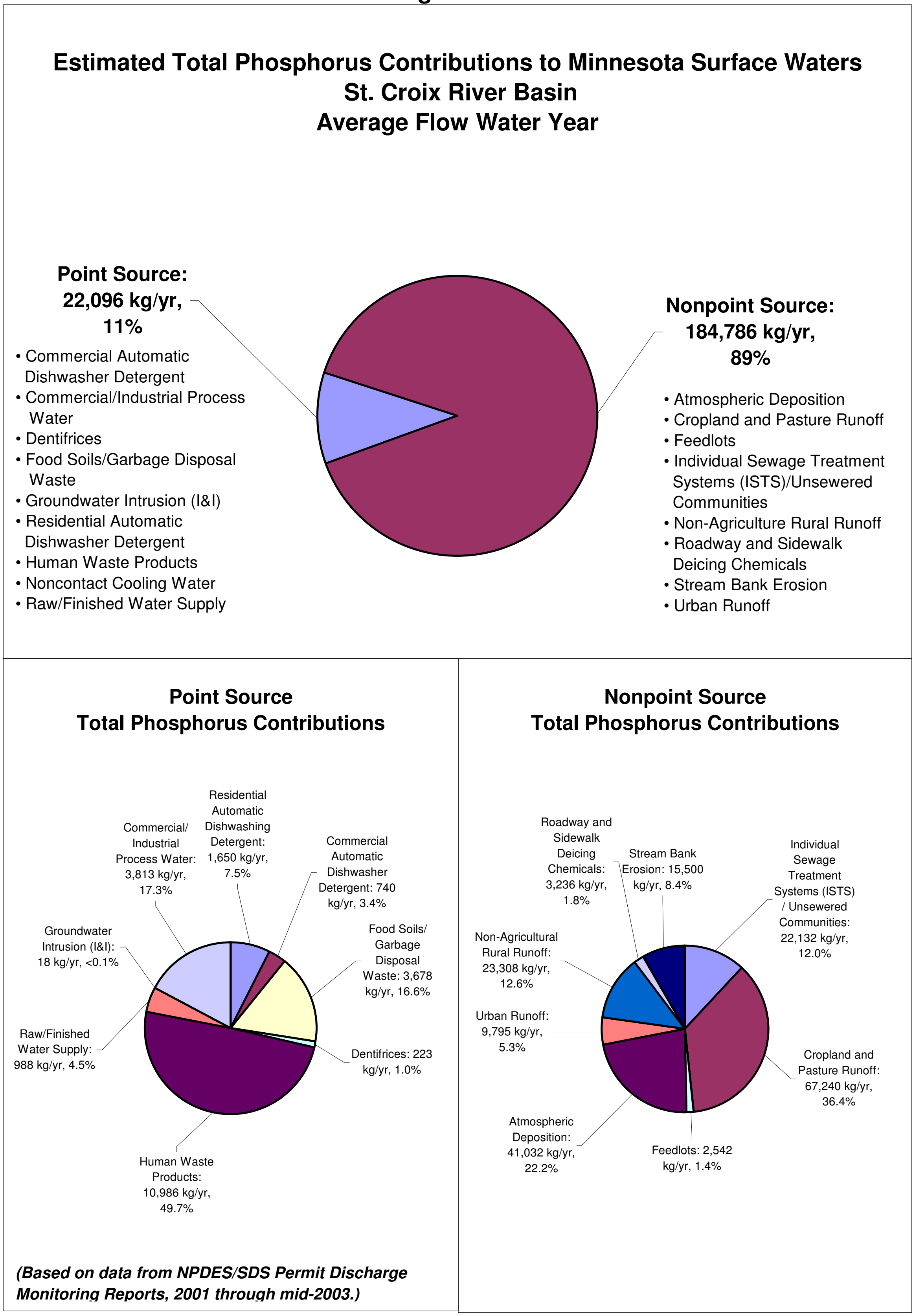
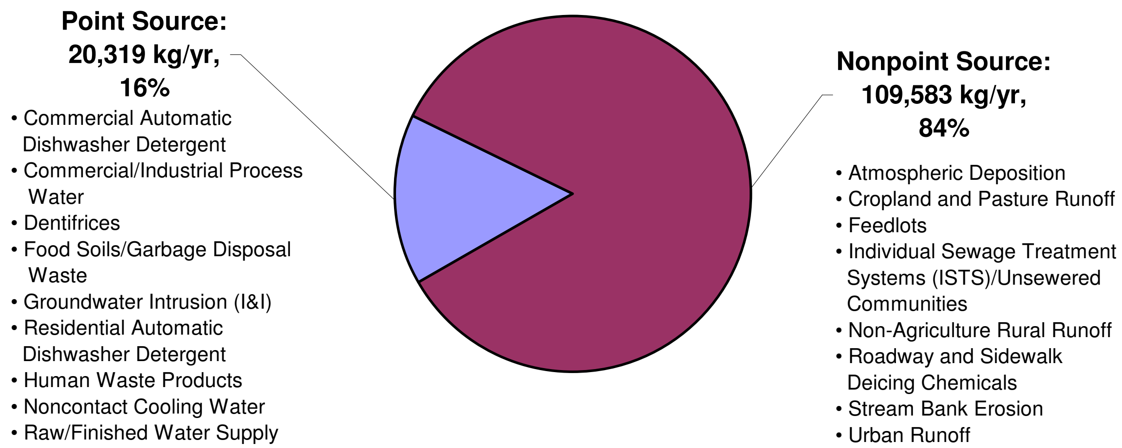
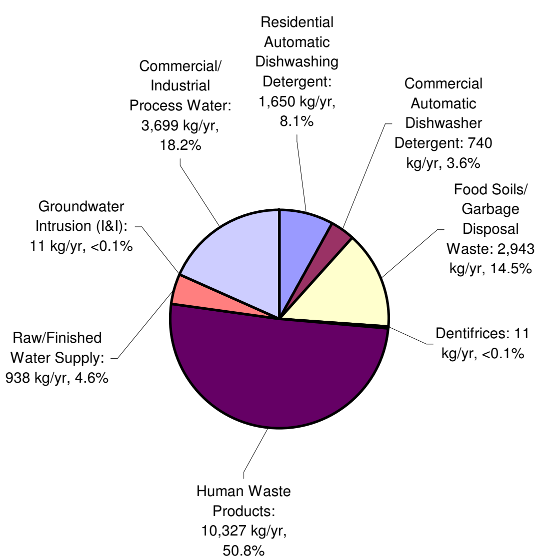

Estimated Total Phosphorus Contributions to Minnesota Surface Waters
St. Croix River Basin
Average Flow Water Year
Point Source:
22,096 kg/yr,
11%
• Commercial Automatic Dishwasher Detergent
• Commercial/Industrial Process Water
• Dentifrices
• Food Soils/Garbage Disposal Waste
• Groundwater Intrusion (I&I)
• Residential Automatic Dishwasher Detergent
• Human Waste Products
• Noncontact Cooling Water
• Raw/Finished Water Supply
Nonpoint Source:
184,786 kg/yr,
89%
• Atmospheric Deposition
• Cropland and Pasture Runoff
• Feedlots
• Individual Sewage Treatment Systems (ISTS)/Unsewered Communities
• Non-Agriculture Rural Runoff
• Roadway and Sidewalk Deicing Chemicals
• Stream Bank Erosion
• Urban Runoff
Point Source
Total Phosphorus Contributions
Residential Automatic Dishwashing Detergent: 1,650 kg/yr, 7.5%
Commercial/ Industrial Process Water: 3,813 kg/yr, 17.3%
Commercial Automatic Dishwasher Detergent: 740 kg/yr, 3.4%
Groundwater Intrusion (I&I): 18 kg/yr, <0.1%
Food Soils/ Garbage Disposal Waste: 3,678 kg/yr, 16.6%
Raw/Finished Water Supply: 988 kg/yr, 4.5%
Dentifrices: 223 kg/yr, 1.0%
Human Waste Products: 10,986 kg/yr, 49.7%
(Based on data from NPDES/SDS Permit Discharge Monitoring Reports, 2001 through mid-2003.)
Nonpoint Source
Total Phosphorus Contributions
Roadway and Sidewalk Deicing Chemicals: 3,236 kg/yr, 1.8%
Stream Bank Erosion: 15,500 kg/yr, 8.4%
Individual Sewage Treatment Systems (ISTS) / Unsewered Communities: 22,132 kg/yr, 12.0%
Non-Agricultural Rural Runoff: 23,308 kg/yr, 12.6%
Urban Runoff: 9,795 kg/yr, 5.3%
Cropland and Pasture Runoff: 67,240 kg/yr, 36.4%
Atmospheric Deposition: 41,032 kg/yr, 22.2%
Feedlots: 2,542 kg/yr, 1.4%

Figure 3-18

Estimated Bioavailable P Contributions to Minnesota Surface Waters
St. Croix River Basin
Average Flow Water Year



Point Source Bioavailable P Contributions



(Based on data from NPDES/SDS Permit Discharge Monitoring Reports, 2001 through mid-2003.)

Nonpoint Source Bioavailable P Contributions

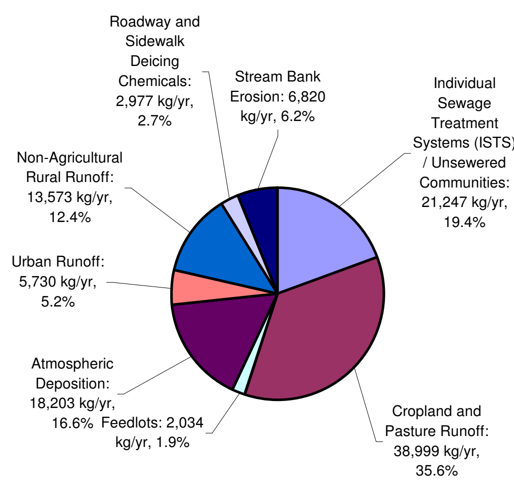
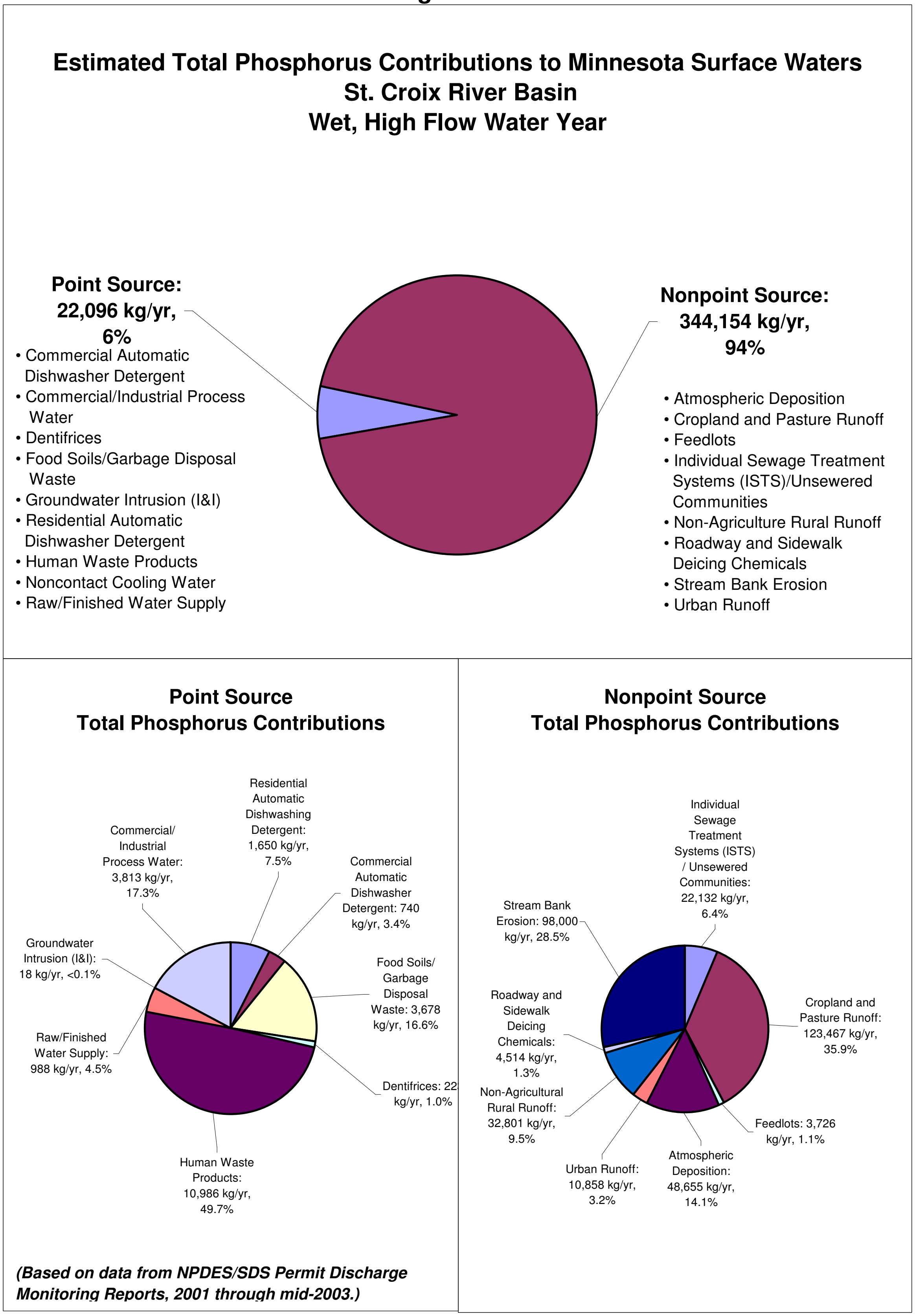


Figure 3-19



Estimated Total Phosphorus Contributions to Minnesota Surface Waters
St. Croix River Basin
Wet, High Flow Water Year
Point Source: 22,096 kg/yr, 6%
• Commercial Automatic Dishwasher Detergent
• Commercial/Industrial Process Water
• Dentifrices
• Food Soils/Garbage Disposal Waste
• Groundwater Intrusion (I&I)
• Residential Automatic Dishwasher Detergent
• Human Waste Products
• Noncontact Cooling Water
• Raw/Finished Water Supply
Nonpoint Source: 344,154 kg/yr, 94%
• Atmospheric Deposition
• Cropland and Pasture Runoff
• Feedlots
• Individual Sewage Treatment Systems (ISTS)/Unsewered Communities
• Non-Agriculture Rural Runoff
• Roadway and Sidewalk Deicing Chemicals
• Stream Bank Erosion
• Urban Runoff
Point Source
Total Phosphorus Contributions
Residential Automatic Dishwashing Detergent: 1,650 kg/yr, 7.5%
Commercial/ Industrial Process Water: 3,813 kg/yr, 17.3%
Commercial Automatic Dishwasher Detergent: 740 kg/yr, 3.4%
Groundwater Intrusion (I&I): 18 kg/yr, <0.1%
Food Soils/ Garbage Disposal Waste: 3,678 kg/yr, 16.6%
Raw/Finished Water Supply: 988 kg/yr, 4.5%
Dentifrices: 22 kg/yr, 1.0%
Human Waste Products: 10,986 kg/yr, 49.7%
(Based on data from NPDES/SDS Permit Discharge Monitoring Reports, 2001 through mid-2003.)
Nonpoint Source
Total Phosphorus Contributions
Individual Sewage Treatment Systems (ISTS) / Unsewered Communities: 22,132 kg/yr, 6.4%
Stream Bank Erosion: 98,000 kg/yr, 28.5%
Roadway and Sidewalk Deicing Chemicals: 4,514 kg/yr, 1.3%
Cropland and Pasture Runoff: 123,467 kg/yr, 35.9%
Non-Agricultural Rural Runoff: 32,801 kg/yr, 9.5%
Feedlots: 3,726 kg/yr, 1.1%
Urban Runoff: 10,858 kg/yr, 3.2%
Atmospheric Deposition: 48,655 kg/yr, 14.1%

3.4.2.3.2 Bioavailable Phosphorus

Under high flow conditions, Figure 3-20 shows that the bioavailable point source phosphorus contribution drops to 10 percent, compared to 16 and 22 percent for the loadings to surface waters in the St. Croix River basin under average and low flow conditions, respectively. As presented in Figure 3-20, cropland and pasture runoff, streambank erosion, atmospheric deposition, non-agricultural rural runoff and ISTS/unsewered communities represent 38, 23, 12, 10, and 11 percent, respectively, of the nonpoint source bioavailable phosphorus loadings, with the remaining nonpoint source contributions at or below 4 percent. Compared to average flow conditions (Figure 3-18), Figure 3-20 shows that the relative nonpoint source contributions of bioavailable phosphorus increased significantly for streambank erosion, increased slightly for cropland and pasture, decreased slightly for non-agricultural rural runoff, decreased somewhat for urban runoff, and decreased significantly for atmospheric deposition and ISTS/unsewered communities.

3.4.3 Upper Mississippi River Basin

3.4.3.1 Dry Conditions (Low Flow)

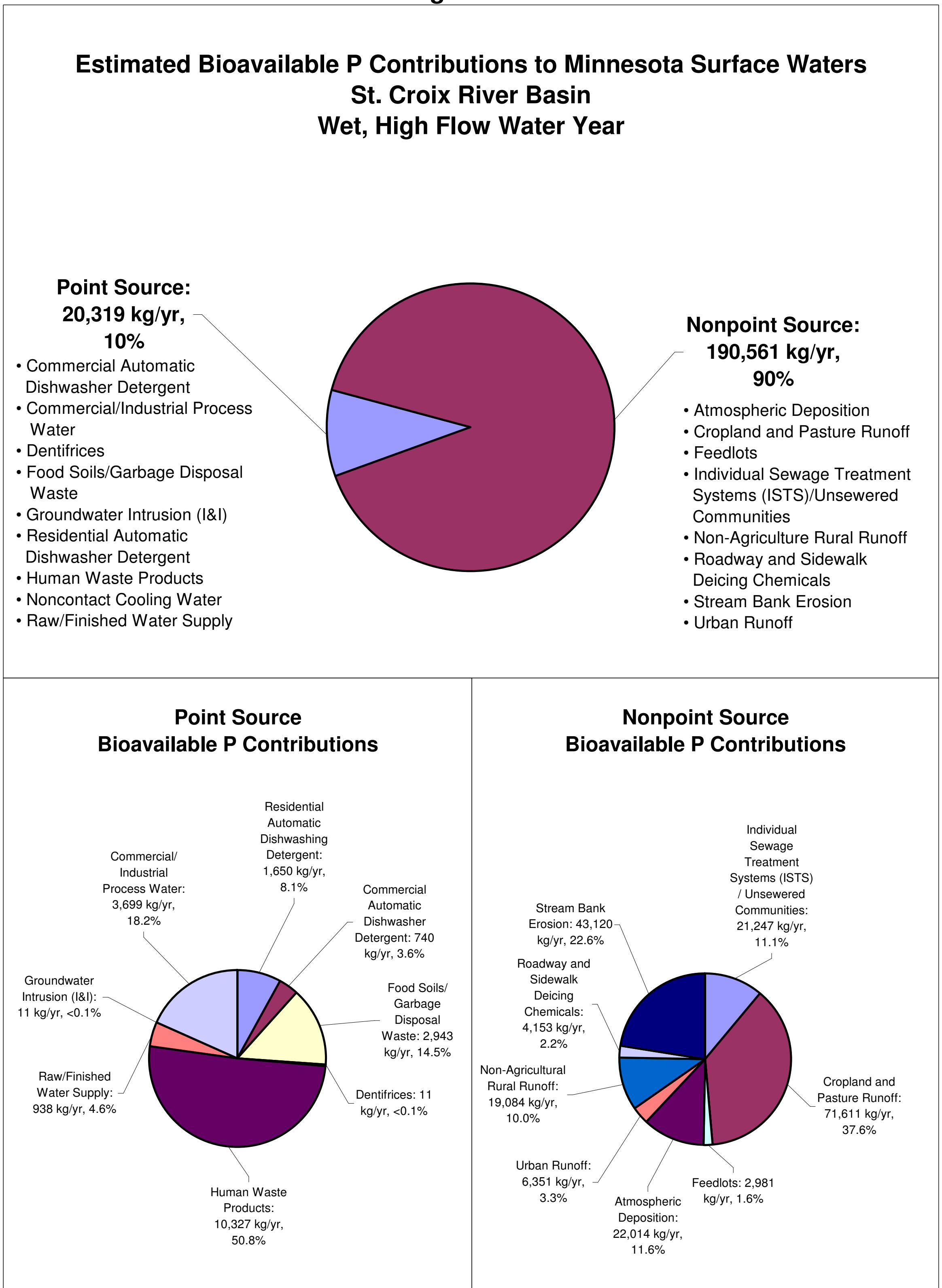
3.4.3.1.1 Total Phosphorus

Figure 3-21 shows that, under low flow conditions, the total point source phosphorus contribution represents 60 percent, while nonpoint sources of phosphorus represent 40 percent of the loadings to surface waters in the Upper Mississippi River basin. The expected load reduction of approximately 581,000 kg/yr associated with a 1 mg/L permit limit at the MCES Metro WWTF would shift the point source contribution to approximately 43 percent of the total load. Figure 3-21 shows that commercial/industrial process water and human waste products represent 29 and 39 percent, respectively, of the point source total phosphorus contributions. The remaining point source categories contribute less than 17 percent of the point source loadings in the Upper Mississippi River basin. The combination of residential and commercial automatic dishwasher detergent represents approximately 11 percent of the point source total phosphorus contributions. As shown in Figure 3-21, cropland and pasture runoff, atmospheric deposition, urban runoff and ISTS/unsewered communities represent 28, 30, 18 and 14 percent, respectively, of the nonpoint source total phosphorus loadings, with the remaining nonpoint source contributions below 8 percent.

3.4.3.1.2 Bioavailable Phosphorus

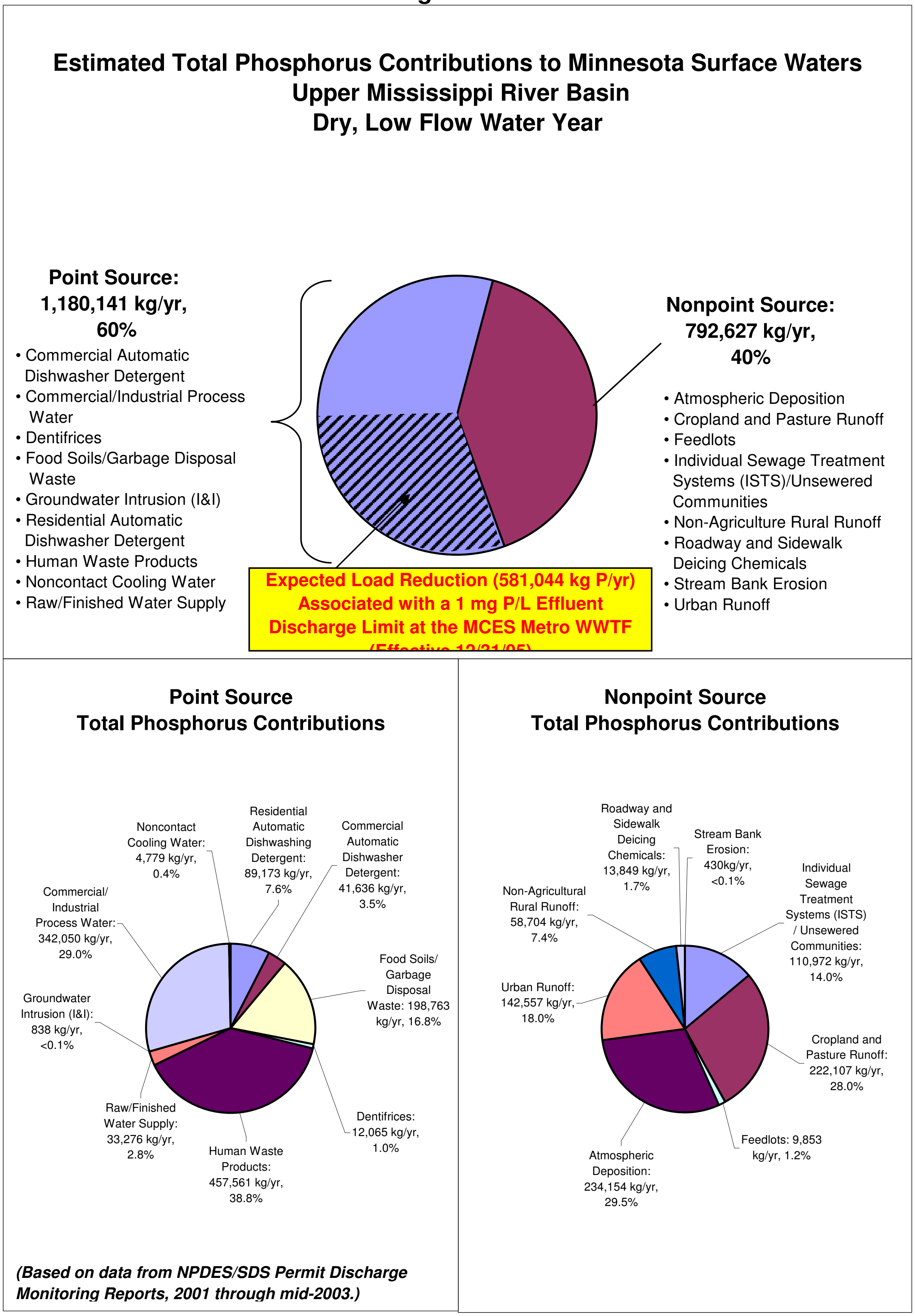
Figure 3-22 shows that, under low flow conditions, the bioavailable point source phosphorus contribution represents 70 percent of the loadings to surface waters in the Upper Mississippi River basin. The expected load reduction of approximately 496,800 kg/yr associated with a 1 mg/L permit

Figure 3-20



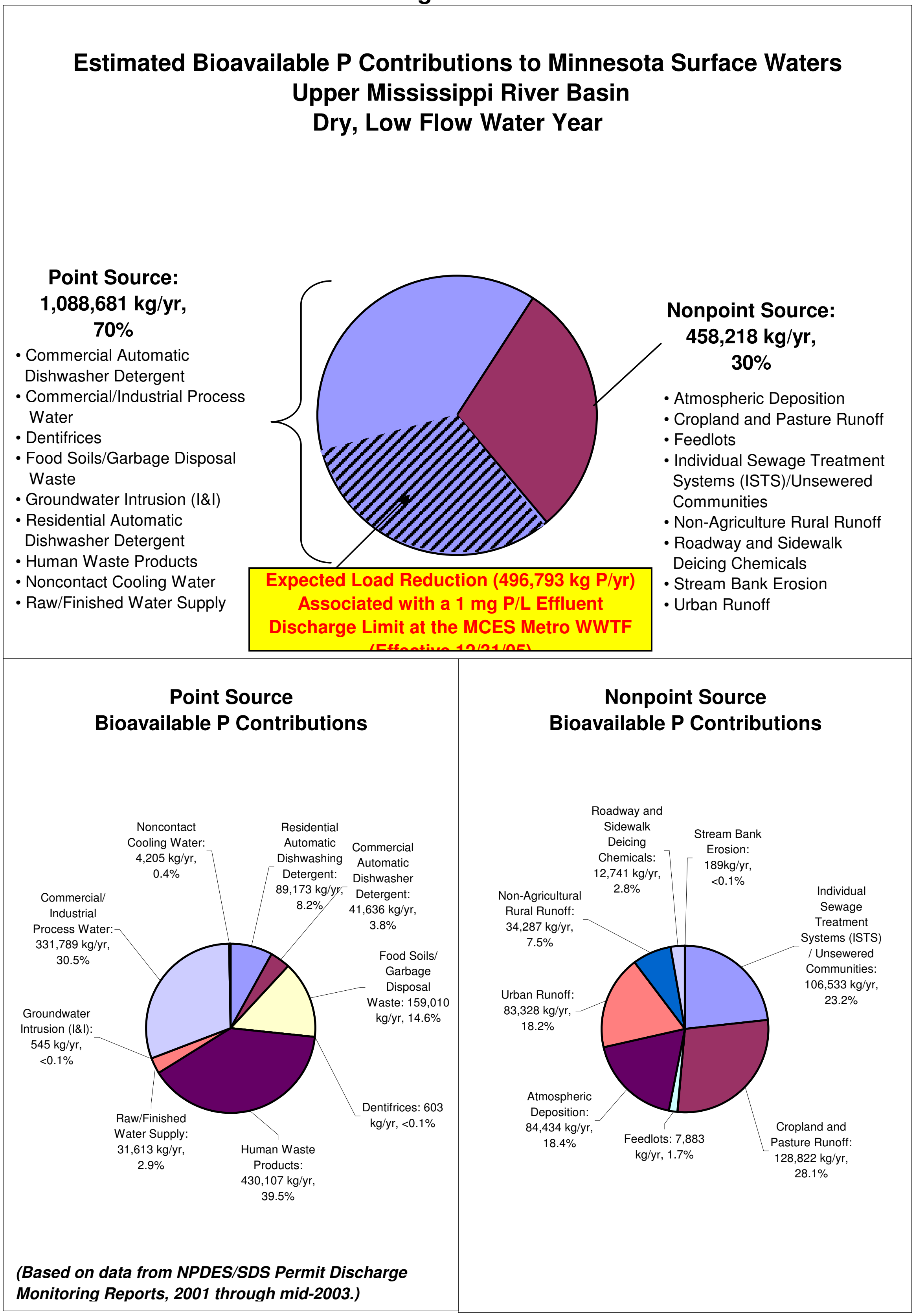
(Based on data from NPDES/SDS Permit Discharge Monitoring Reports, 2001 through mid-2003.)

Figure 3-21



Estimated Total Phosphorus Contributions to Minnesota Surface Waters
Upper Mississippi River Basin
Dry, Low Flow Water Year
Point Source:
1,180,141 kg/yr,
60%
• Commercial Automatic Dishwasher Detergent
• Commercial/Industrial Process Water
• Dentifrices
• Food Soils/Garbage Disposal Waste
• Groundwater Intrusion (I&I)
• Residential Automatic Dishwasher Detergent
• Human Waste Products
• Noncontact Cooling Water
• Raw/Finished Water Supply
Nonpoint Source:
792,627 kg/yr,
40%
• Atmospheric Deposition
• Cropland and Pasture Runoff
• Feedlots
• Individual Sewage Treatment Systems (ISTS)/Unsewered Communities
• Non-Agriculture Rural Runoff
• Roadway and Sidewalk Deicing Chemicals
• Stream Bank Erosion
• Urban Runoff
Expected Load Reduction (581,044 kg P/yr)
Associated with a 1 mg P/L Effluent
Discharge Limit at the MCES Metro WWTF
Point Source
Total Phosphorus Contributions
Noncontact Cooling Water: 4,779 kg/yr, 0.4%
Residential Automatic Dishwashing Detergent: 89,173 kg/yr, 7.6%
Commercial Automatic Dishwasher Detergent: 41,636 kg/yr, 3.5%
Commercial/ Industrial Process Water: 342,050 kg/yr, 29.0%
Food Soils/ Garbage Disposal Waste: 198,763 kg/yr, 16.8%
Groundwater Intrusion (I&I): 838 kg/yr, <0.1%
Raw/Finished Water Supply: 33,276 kg/yr, 2.8%
Human Waste Products: 457,561 kg/yr, 38.8%
Dentifrices: 12,065 kg/yr, 1.0%
(Based on data from NPDES/SDS Permit Discharge Monitoring Reports, 2001 through mid-2003.)
Nonpoint Source
Total Phosphorus Contributions
Roadway and Sidewalk Deicing Chemicals: 13,849 kg/yr, 1.7%
Stream Bank Erosion: 430kg/yr, <0.1%
Individual Sewage Treatment Systems (ISTS) / Unsewered Communities: 110,972 kg/yr, 14.0%
Non-Agricultural Rural Runoff: 58,704 kg/yr, 7.4%
Urban Runoff: 142,557 kg/yr, 18.0%
Cropland and Pasture Runoff: 222,107 kg/yr, 28.0%
Feedlots: 9,853 kg/yr, 1.2%
Atmospheric Deposition: 234,154 kg/yr, 29.5%

Figure 3-22



Estimated Bioavailable P Contributions to Minnesota Surface Waters
Upper Mississippi River Basin
Dry, Low Flow Water Year
Point Source:
1,088,681 kg/yr,
70%
• Commercial Automatic Dishwasher Detergent
• Commercial/Industrial Process Water
• Dentifrices
• Food Soils/Garbage Disposal Waste
• Groundwater Intrusion (I&I)
• Residential Automatic Dishwasher Detergent
• Human Waste Products
• Noncontact Cooling Water
• Raw/Finished Water Supply
Nonpoint Source:
458,218 kg/yr,
30%
• Atmospheric Deposition
• Cropland and Pasture Runoff
• Feedlots
• Individual Sewage Treatment Systems (ISTS)/Unsewered Communities
• Non-Agriculture Rural Runoff
• Roadway and Sidewalk Deicing Chemicals
• Stream Bank Erosion
• Urban Runoff
Expected Load Reduction (496,793 kg P/yr)
Associated with a 1 mg P/L Effluent
Discharge Limit at the MCES Metro WWTF
Point Source
Bioavailable P Contributions
Noncontact Cooling Water: 4,205 kg/yr, 0.4%
Residential Automatic Dishwashing Detergent: 89,173 kg/yr, 8.2%
Commercial Automatic Dishwasher Detergent: 41,636 kg/yr, 3.8%
Commercial/ Industrial Process Water: 331,789 kg/yr, 30.5%
Food Soils/ Garbage Disposal Waste: 159,010 kg/yr, 14.6%
Groundwater Intrusion (I&I): 545 kg/yr, <0.1%
Dentifrices: 603 kg/yr, <0.1%
Raw/Finished Water Supply: 31,613 kg/yr, 2.9%
Human Waste Products: 430,107 kg/yr, 39.5%
(Based on data from NPDES/SDS Permit Discharge Monitoring Reports, 2001 through mid-2003.)
Nonpoint Source
Bioavailable P Contributions
Roadway and Sidewalk Deicing Chemicals: 12,741 kg/yr, 2.8%
Stream Bank Erosion: 189kg/yr, <0.1%
Non-Agricultural Rural Runoff: 34,287 kg/yr, 7.5%
Individual Sewage Treatment Systems (ISTS) / Unsewered Communities: 106,533 kg/yr, 23.2%
Urban Runoff: 83,328 kg/yr, 18.2%
Atmospheric Deposition: 84,434 kg/yr, 18.4%
Feedlots: 7,883 kg/yr, 1.7%
Cropland and Pasture Runoff: 128,822 kg/yr, 28.1%

limit at the MCES Metro WWTF would shift the point source contribution to approximately 56 percent of the total bioavailable phosphorus load. Figure 3-22 shows that commercial/industrial process water and human waste products represent 31 and 40 percent, respectively, of the point source bioavailable phosphorus contributions. The remaining point source categories contribute less than 15 percent of the point source loadings. The combination of residential and commercial automatic dishwasher detergent represents approximately 12 percent of the point source bioavailable phosphorus contributions. As shown in Figure 3-22, cropland and pasture runoff, atmospheric deposition, urban runoff and ISTS/unsewered communities represent approximately 28, 18, 18 and 23 percent, respectively, of the nonpoint source bioavailable phosphorus loadings, with the remaining nonpoint source contributions below 8 percent.

3.4.3.2 Average Condition

3.4.3.2.1 Total Phosphorus

Under average flow conditions, Figure 3-23 shows that the total point source phosphorus contribution drops to 51 percent, compared to 60 percent for the loadings to surface waters in the Upper Mississippi River basin under low flow conditions. The expected load reduction of approximately 581,000 kg/yr associated with a 1 mg/L permit limit at the MCES Metro WWTF would shift the point source contribution to approximately 34 percent of the total load. As presented in Figure 3-23, cropland and pasture runoff, atmospheric deposition, and urban runoff represent 34, 23 and 14 percent, respectively, of the nonpoint source total phosphorus loadings, with the remaining nonpoint source contributions below 10 percent. Compared to low flow conditions (Figure 3-21), Figure 3-23 shows that the relative nonpoint source contributions of total phosphorus increased significantly for streambank erosion, increased slightly for cropland and pasture runoff, decreased somewhat for urban runoff, and decreased significantly for atmospheric deposition and ISTS/unsewered communities.

3.4.3.2.2 Bioavailable Phosphorus

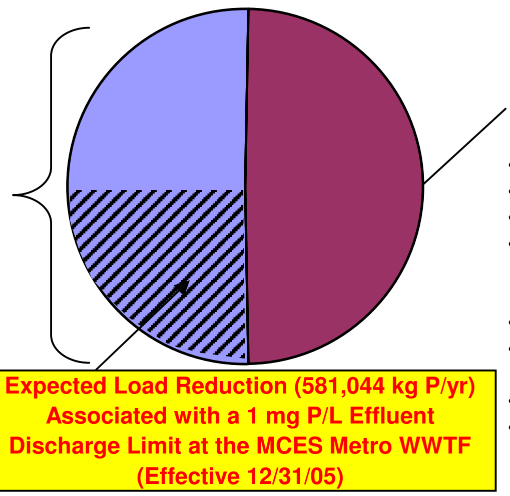
Under average flow conditions, Figure 3-24 shows that the bioavailable point source phosphorus contribution drops to 62 percent, compared to 70 percent for the loadings to surface waters in the Upper Mississippi River under low flow conditions. The expected load reduction of approximately 496,800 kg/yr associated with a 1 mg/L permit limit at the MCES Metro WWTF would shift the point source contribution to approximately 47 percent of the total bioavailable phosphorus load. As presented in Figure 3-24, cropland and pasture runoff, atmospheric deposition, urban runoff, and ISTS/unsewered communities represent 35, 15, 15 and 16 percent, respectively, of the nonpoint source total phosphorus loadings, with the remaining nonpoint source contributions below 10

Figure 3-23

Estimated Total Phosphorus Contributions to Minnesota Surface Waters
Upper Mississippi River Basin
Average Flow Water Year

Point Source:
1,180,141 kg/yr,
51%

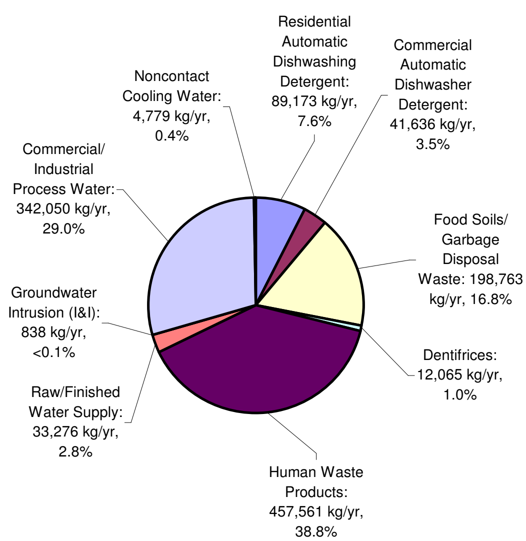
- Commercial Automatic Dishwasher Detergent
- Commercial/Industrial Process Water
- Dentifrices
- Food Soils/Garbage Disposal Waste
- Groundwater Intrusion (I&I)
- Residential Automatic Dishwasher Detergent
- Human Waste Products
- Noncontact Cooling Water
- Raw/Finished Water Supply



Nonpoint Source:
1,156,229 kg/yr,
49%

- Atmospheric Deposition
- Cropland and Pasture Runoff
- Feedlots
- Individual Sewage Treatment Systems (ISTS)/Unsewered Communities
- Non-Agriculture Rural Runoff
- Roadway and Sidewalk Deicing Chemicals
- Stream Bank Erosion
- Urban Runoff

Point Source Total Phosphorus Contributions



(Based on data from NPDES/SDS Permit Discharge Monitoring Reports, 2001 through mid-2003.)

Nonpoint Source Total Phosphorus Contributions

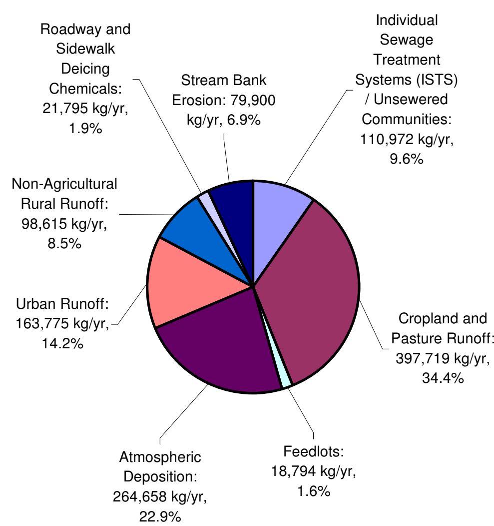
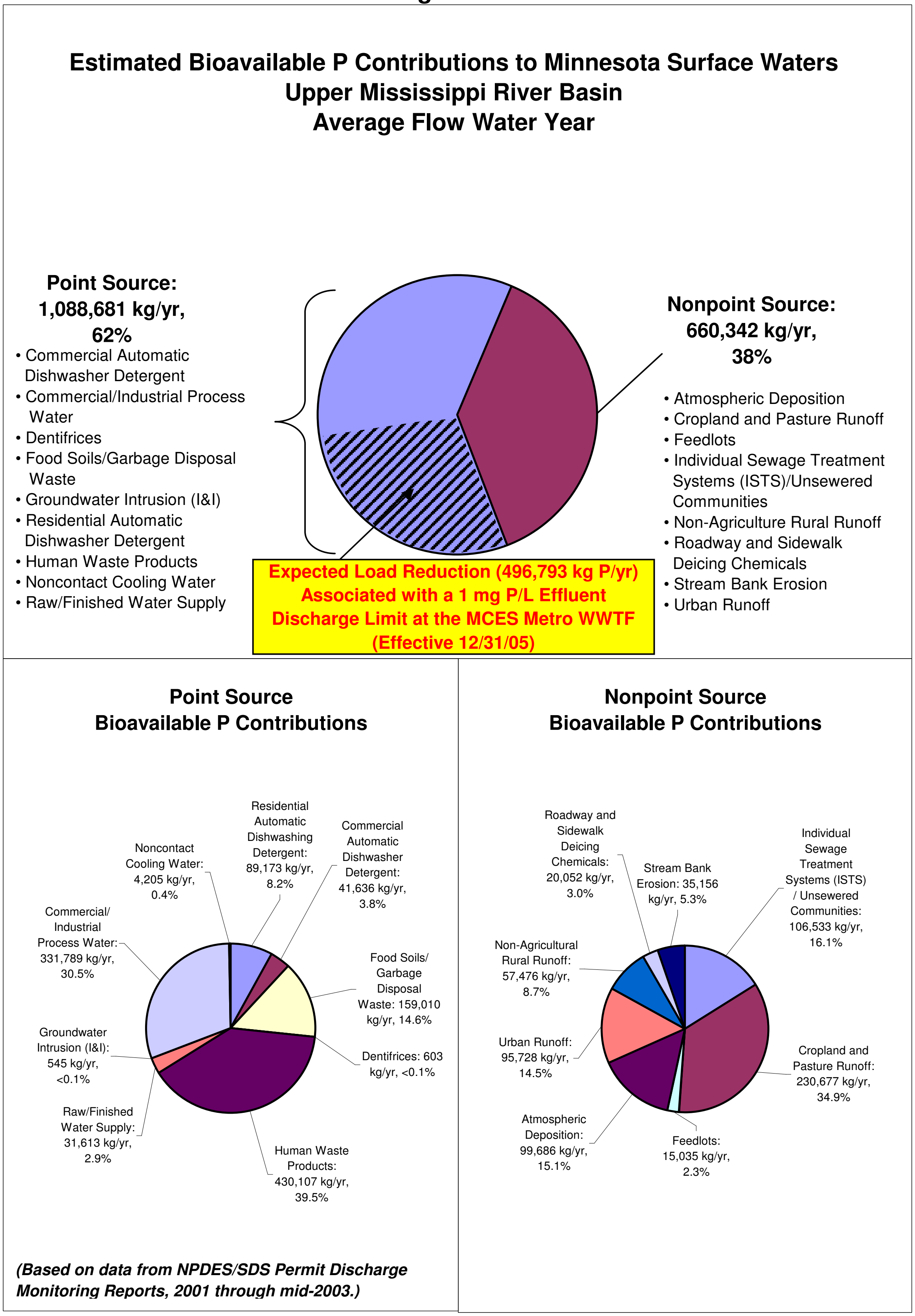


Figure 3-24



Estimated Bioavailable P Contributions to Minnesota Surface Waters
Upper Mississippi River Basin
Average Flow Water Year
Point Source: 1,088,681 kg/yr, 62%
• Commercial Automatic Dishwasher Detergent
• Commercial/Industrial Process Water
• Dentifrices
• Food Soils/Garbage Disposal Waste
• Groundwater Intrusion (I&I)
• Residential Automatic Dishwasher Detergent
• Human Waste Products
• Noncontact Cooling Water
• Raw/Finished Water Supply
Nonpoint Source: 660,342 kg/yr, 38%
• Atmospheric Deposition
• Cropland and Pasture Runoff
• Feedlots
• Individual Sewage Treatment Systems (ISTS)/Unsewered Communities
• Non-Agriculture Rural Runoff
• Roadway and Sidewalk Deicing Chemicals
• Stream Bank Erosion
• Urban Runoff
Expected Load Reduction (496,793 kg P/yr) Associated with a 1 mg P/L Effluent Discharge Limit at the MCES Metro WWTF (Effective 12/31/05)
Point Source Bioavailable P Contributions
Residential Automatic Dishwashing Detergent: 89,173 kg/yr, 8.2%
Commercial Automatic Dishwasher Detergent: 41,636 kg/yr, 3.8%
Noncontact Cooling Water: 4,205 kg/yr, 0.4%
Commercial/ Industrial Process Water: 331,789 kg/yr, 30.5%
Food Soils/ Garbage Disposal Waste: 159,010 kg/yr, 14.6%
Dentifrices: 603 kg/yr, <0.1%
Groundwater Intrusion (I&I): 545 kg/yr, <0.1%
Raw/Finished Water Supply: 31,613 kg/yr, 2.9%
Human Waste Products: 430,107 kg/yr, 39.5%
Nonpoint Source Bioavailable P Contributions
Roadway and Sidewalk Deicing Chemicals: 20,052 kg/yr, 3.0%
Stream Bank Erosion: 35,156 kg/yr, 5.3%
Individual Sewage Treatment Systems (ISTS) / Unsewered Communities: 106,533 kg/yr, 16.1%
Non-Agricultural Rural Runoff: 57,476 kg/yr, 8.7%
Urban Runoff: 95,728 kg/yr, 14.5%
Cropland and Pasture Runoff: 230,677 kg/yr, 34.9%
Atmospheric Deposition: 99,686 kg/yr, 15.1%
Feedlots: 15,035 kg/yr, 2.3%
(Based on data from NPDES/SDS Permit Discharge Monitoring Reports, 2001 through mid-2003.)

percent. Compared to low flow conditions (Figure 3-22), Figure 3-24 shows that the relative nonpoint source contributions of total phosphorus increased significantly for streambank erosion, increased slightly for cropland and pasture runoff, decreased somewhat for urban runoff and atmospheric deposition, and decreased significantly for ISTS/unsewered communities.

3.4.3.3 Wet Condition (High Flow)

3.4.3.3.1 Total Phosphorus

Under high flow conditions, Figure 3-25 shows that the total point source phosphorus contribution drops to 37 percent, compared to 51 and 60 percent for the loadings to surface waters in the Upper Mississippi River basin under average and low flow conditions, respectively. The expected load reduction of approximately 581,000 kg/yr associated with a 1 mg/L permit limit at the MCES Metro WWTF would shift the point source contribution to approximately 23 percent of the total load. As presented in Figure 3-25, streambank erosion, cropland and pasture runoff, and atmospheric deposition represent 24, 36 and 15 percent, respectively, of the nonpoint source total phosphorus loadings, with the remaining nonpoint source contributions below 10 percent. Compared to average flow conditions (Figure 3-23), Figure 3-25 shows that the relative statewide nonpoint source contributions of total phosphorus increased significantly for streambank erosion, increased slightly for cropland and pasture, decreased slightly for non-agricultural rural runoff, and decreased significantly for urban runoff, atmospheric deposition and ISTS/unsewered communities.

3.4.3.3.2 Bioavailable Phosphorus

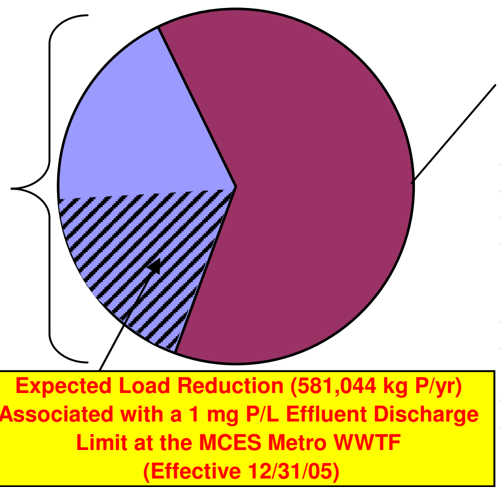
Under high flow conditions, Figure 3-26 shows that the bioavailable point source phosphorus contribution drops to 50 percent, compared to 62 and 70 percent for the loadings to surface waters in the Upper Mississippi River basin under average and low flow conditions, respectively. The expected load reduction of approximately 496,800 kg/yr associated with a 1 mg/L permit limit at the MCES Metro WWTF would shift the point source contribution to approximately 35 percent of the total load. As presented in Figure 3-26, streambank erosion and cropland and pasture runoff represent 19 and 38 percent, respectively, of the nonpoint source bioavailable phosphorus loadings, with the remaining nonpoint source contributions at or below 11 percent. Compared to average flow conditions (Figure 3-24), Figure 3-26 shows that the relative statewide nonpoint source contributions of total phosphorus increased significantly for streambank erosion, increased slightly for cropland and pasture, decreased slightly for non-agricultural rural runoff, and decreased significantly for urban runoff, atmospheric deposition and ISTS/unsewered communities.

Figure 3-25

Estimated Total Phosphorus Contributions to Minnesota Surface Waters
Upper Mississippi River Basin
Wet, High Flow Water Year

Point Source:
1,180,141 kg/yr,
37%

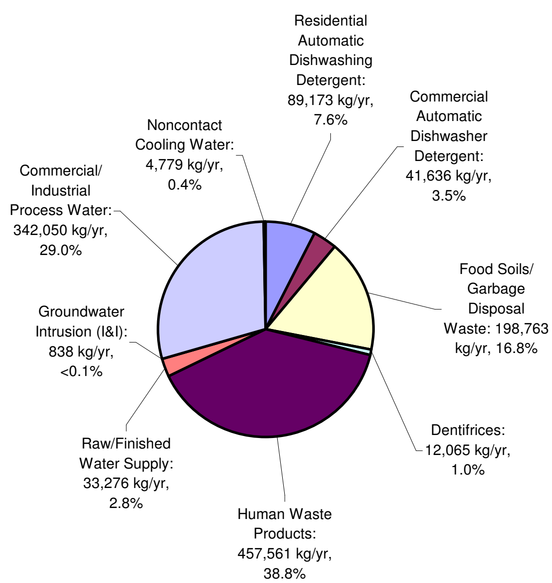
- Commercial Automatic Dishwasher Detergent
- Commercial/Industrial Process Water
- Dentifrices
- Food Soils/Garbage Disposal Waste
- Groundwater Intrusion (I&I)
- Residential Automatic Dishwasher Detergent
- Human Waste Products
- Noncontact Cooling Water
- Raw/Finished Water Supply



Nonpoint Source:
1,990,156 kg/yr,
63%

- Atmospheric Deposition
- Cropland and Pasture Runoff
- Feedlots
- Individual Sewage Treatment Systems (ISTS)/Unsewered Communities
- Non-Agriculture Rural Runoff
- Roadway and Sidewalk Deicing Chemicals
- Stream Bank Erosion
- Urban Runoff

Point Source
Total Phosphorus Contributions



(Based on data from NPDES/SDS Permit Discharge Monitoring Reports, 2001 through mid-2003.)

Nonpoint Source
Total Phosphorus Contributions

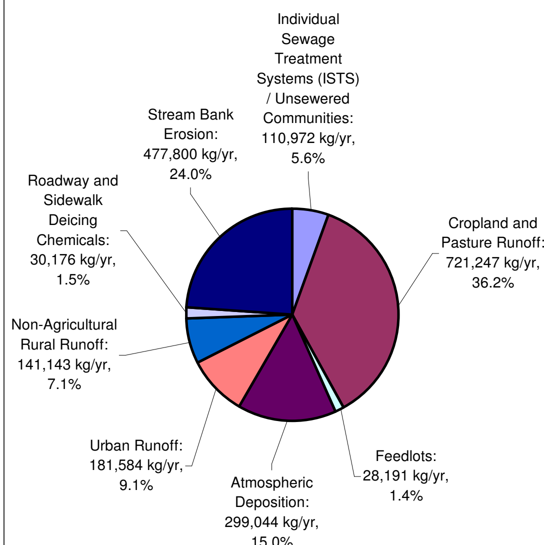
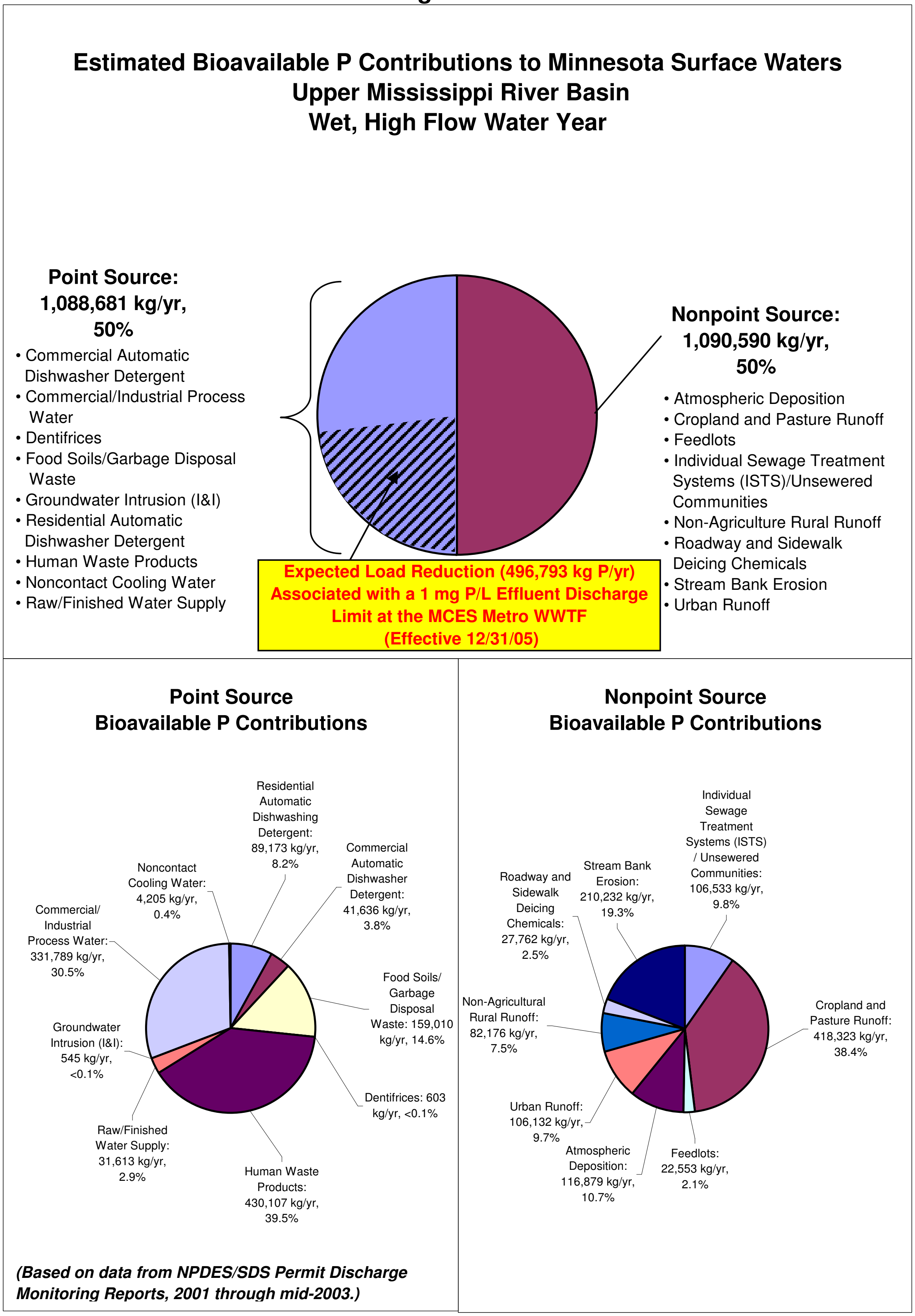


Figure 3-26



Estimated Bioavailable P Contributions to Minnesota Surface Waters
Upper Mississippi River Basin
Wet, High Flow Water Year
Point Source:
1,088,681 kg/yr,
50%
• Commercial Automatic Dishwasher Detergent
• Commercial/Industrial Process Water
• Dentifrices
• Food Soils/Garbage Disposal Waste
• Groundwater Intrusion (I&I)
• Residential Automatic Dishwasher Detergent
• Human Waste Products
• Noncontact Cooling Water
• Raw/Finished Water Supply
Nonpoint Source:
1,090,590 kg/yr,
50%
• Atmospheric Deposition
• Cropland and Pasture Runoff
• Feedlots
• Individual Sewage Treatment Systems (ISTS)/Unsewered Communities
• Non-Agriculture Rural Runoff
• Roadway and Sidewalk Deicing Chemicals
• Stream Bank Erosion
• Urban Runoff
Expected Load Reduction (496,793 kg P/yr)
Associated with a 1 mg P/L Effluent Discharge
Limit at the MCES Metro WWTF
(Effective 12/31/05)
Point Source
Bioavailable P Contributions
Residential Automatic Dishwashing Detergent: 89,173 kg/yr, 8.2%
Commercial Automatic Dishwasher Detergent: 41,636 kg/yr, 3.8%
Noncontact Cooling Water: 4,205 kg/yr, 0.4%
Commercial/ Industrial Process Water: 331,789 kg/yr, 30.5%
Food Soils/ Garbage Disposal Waste: 159,010 kg/yr, 14.6%
Groundwater Intrusion (I&I): 545 kg/yr, <0.1%
Dentifrices: 603 kg/yr, <0.1%
Raw/Finished Water Supply: 31,613 kg/yr, 2.9%
Human Waste Products: 430,107 kg/yr, 39.5%
(Based on data from NPDES/SDS Permit Discharge Monitoring Reports, 2001 through mid-2003.)
Nonpoint Source
Bioavailable P Contributions
Individual Sewage Treatment Systems (ISTS) / Unsewered Communities: 106,533 kg/yr, 9.8%
Stream Bank Erosion: 210,232 kg/yr, 19.3%
Roadway and Sidewalk Deicing Chemicals: 27,762 kg/yr, 2.5%
Cropland and Pasture Runoff: 418,323 kg/yr, 38.4%
Non-Agricultural Rural Runoff: 82,176 kg/yr, 7.5%
Urban Runoff: 106,132 kg/yr, 9.7%
Atmospheric Deposition: 116,879 kg/yr, 10.7%
Feedlots: 22,553 kg/yr, 2.1%

3.4.4 Lower Mississippi River Basin

3.4.4.1 Dry Conditions (Low Flow)

3.4.4.1.1 Total Phosphorus

Figure 3-27 shows that, under low flow conditions, the total point source phosphorus contribution represents 50 percent, while nonpoint sources of phosphorus represent 50 percent of the loadings to surface waters in the Lower Mississippi River basin. Figure 3-27 also shows that human waste products, commercial/industrial process water, and food soils represent 32, 47 and 11 percent, respectively, of the point source total phosphorus contributions. The remaining point source categories contribute less than 5 percent of the point source loadings. The combination of residential and commercial automatic dishwasher detergent represents approximately 7 percent of the point source total phosphorus contributions. As shown in Figure 3-27, cropland and pasture runoff, streambank erosion, urban runoff, and ISTS/unsewered communities represent 45, 17, 10 and 10 percent, respectively, of the nonpoint source total phosphorus loadings, with the remaining nonpoint source contributions below 5 percent.

3.4.4.1.2 Bioavailable Phosphorus

Figure 3-28 shows that, under low flow conditions, the bioavailable point source phosphorus contribution represents 61 percent of the loadings to surface waters. Figure 3-28 also shows that human waste products, commercial/industrial process water, and food soils represent 33, 48 and 9 percent, respectively, of the point source bioavailable phosphorus contributions. The remaining point source categories contribute less than 6 percent of the point source loadings. The combination of residential and commercial automatic dishwasher detergent represents approximately 8 percent of the point source bioavailable phosphorus contributions. As shown in Figure 3-28, cropland and pasture runoff, streambank erosion, urban runoff and ISTS/unsewered communities represent approximately 44, 12, 10 and 16 percent, respectively, of the nonpoint source bioavailable phosphorus loadings, with the remaining nonpoint source contributions below 7 percent.

3.4.4.2 Average Condition

3.4.4.2.1 Total Phosphorus

Under average flow conditions, Figure 3-29 shows that the total point source phosphorus contribution drops to 28 percent, compared to 50 percent for the loadings to surface waters under low flow conditions. As presented in Figure 3-29, cropland and pasture runoff and streambank erosion represent 36 and 47 percent, respectively, of the nonpoint source total phosphorus loadings, with the remaining nonpoint source contributions below 5 percent. Compared to low flow conditions (Figure 3-22), Figure 3-29 shows that the relative nonpoint source contributions of total phosphorus

Figure 3-27

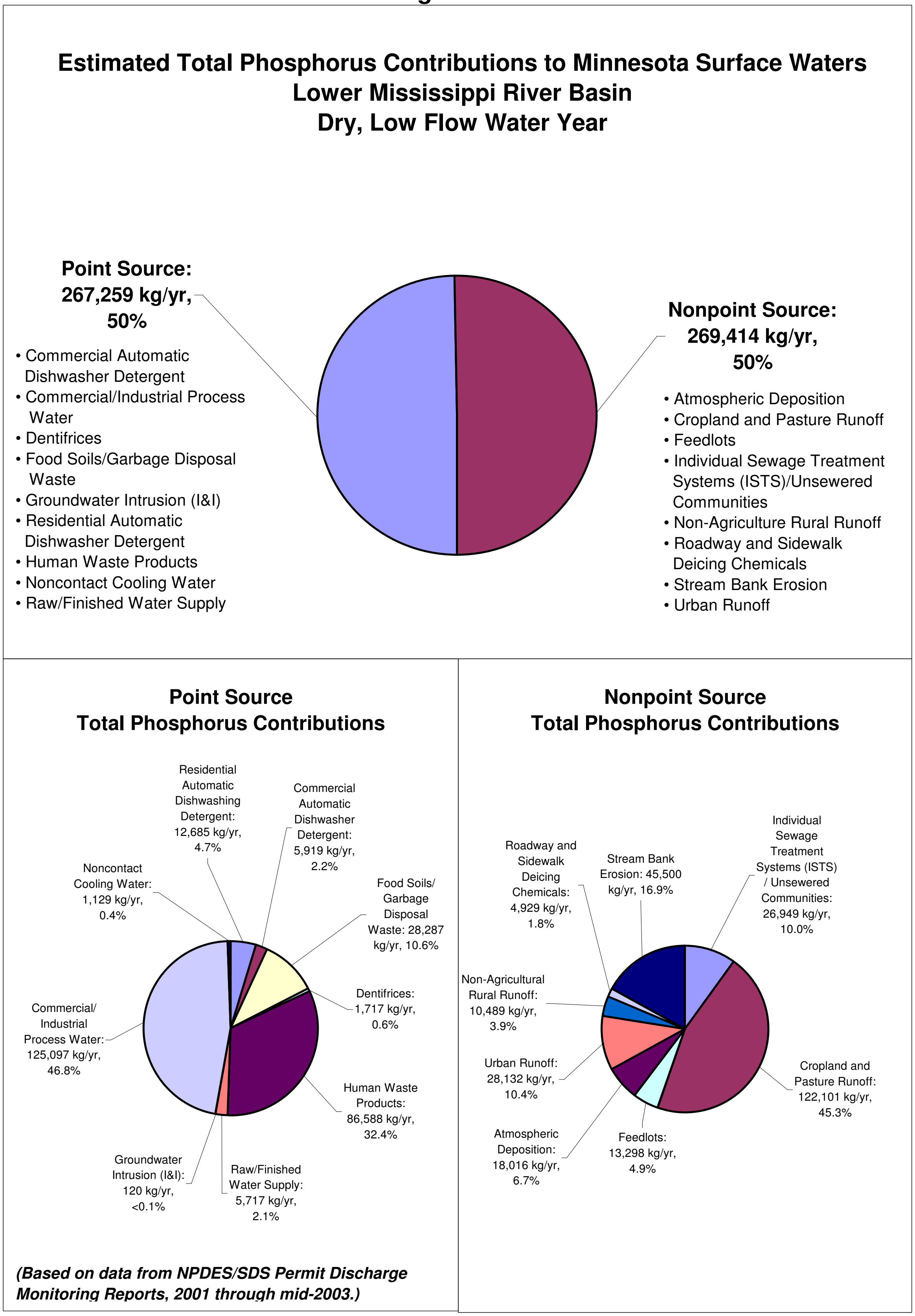
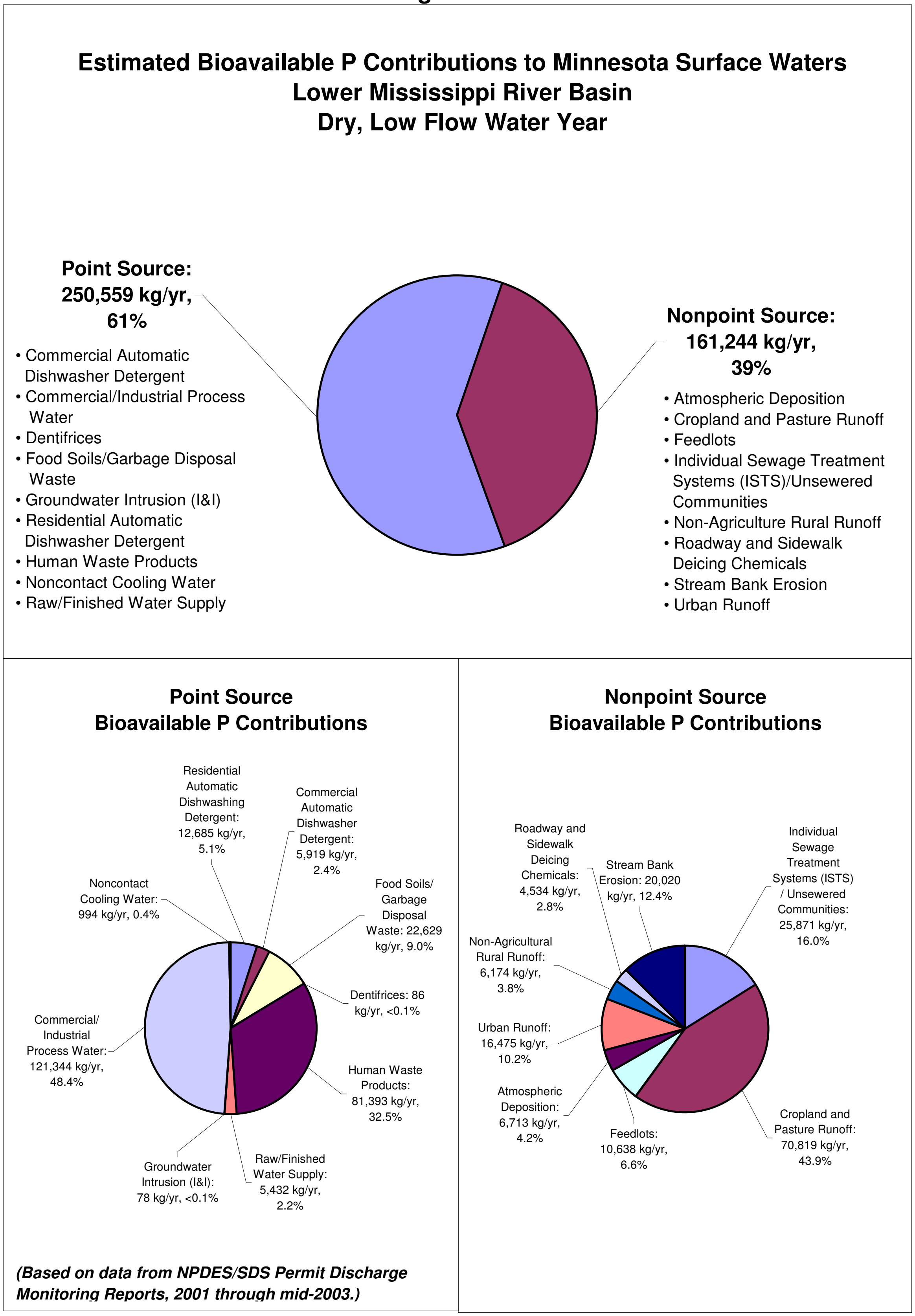
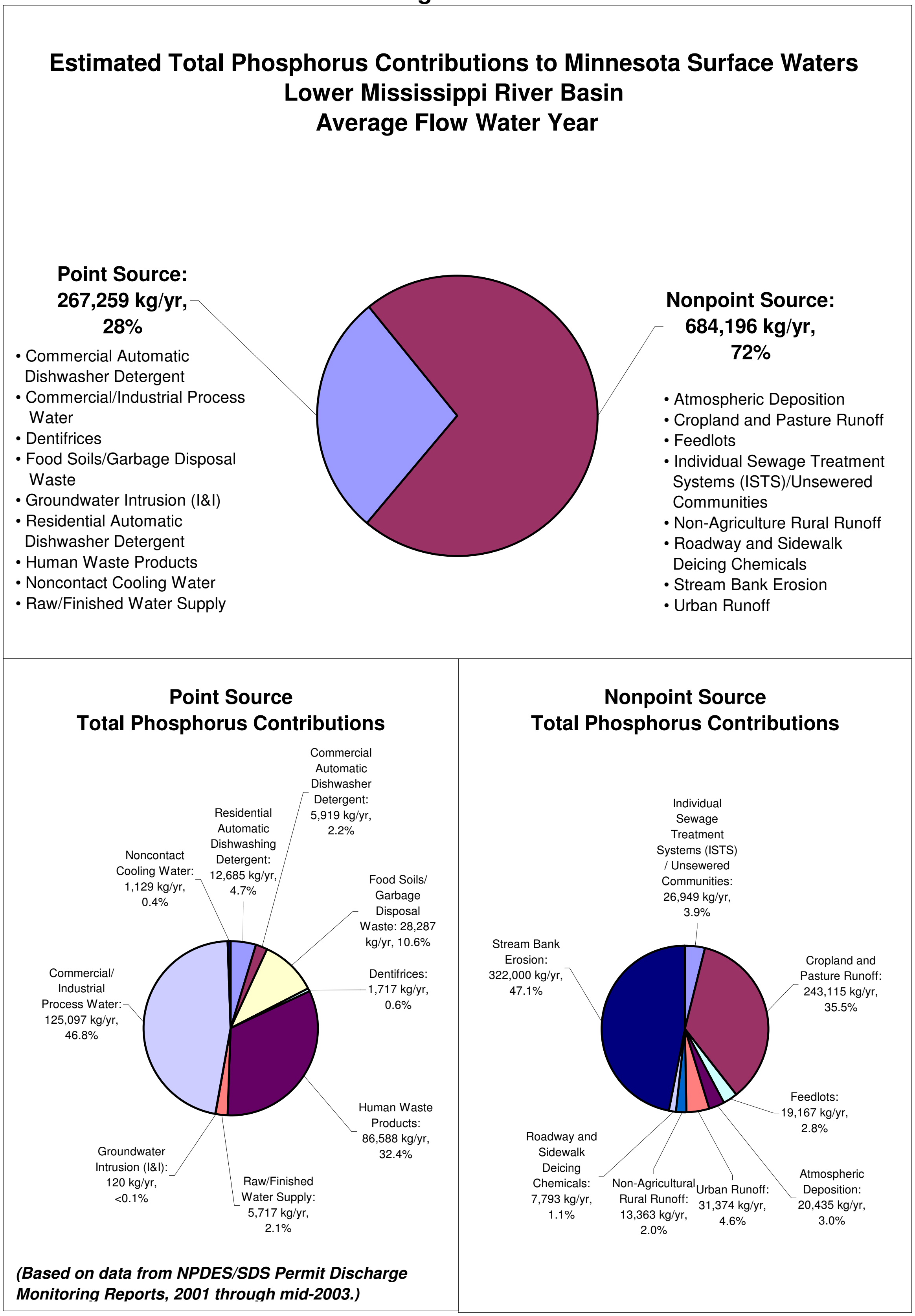

Estimated Total Phosphorus Contributions to Minnesota Surface Waters
Lower Mississippi River Basin
Dry, Low Flow Water Year
Point Source: 267,259 kg/yr, 50%
• Commercial Automatic Dishwasher Detergent
• Commercial/Industrial Process Water
• Dentifrices
• Food Soils/Garbage Disposal Waste
• Groundwater Intrusion (I&I)
• Residential Automatic Dishwasher Detergent
• Human Waste Products
• Noncontact Cooling Water
• Raw/Finished Water Supply
Nonpoint Source: 269,414 kg/yr, 50%
• Atmospheric Deposition
• Cropland and Pasture Runoff
• Feedlots
• Individual Sewage Treatment Systems (ISTS)/Unsewered Communities
• Non-Agriculture Rural Runoff
• Roadway and Sidewalk Deicing Chemicals
• Stream Bank Erosion
• Urban Runoff
Point Source
Total Phosphorus Contributions
Residential Automatic Dishwashing Detergent: 12,685 kg/yr, 4.7%
Commercial Automatic Dishwasher Detergent: 5,919 kg/yr, 2.2%
Noncontact Cooling Water: 1,129 kg/yr, 0.4%
Food Soils/ Garbage Disposal Waste: 28,287 kg/yr, 10.6%
Dentifrices: 1,717 kg/yr, 0.6%
Commercial/ Industrial Process Water: 125,097 kg/yr, 46.8%
Human Waste Products: 86,588 kg/yr, 32.4%
Groundwater Intrusion (I&I): 120 kg/yr, <0.1%
Raw/Finished Water Supply: 5,717 kg/yr, 2.1%
(Based on data from NPDES/SDS Permit Discharge Monitoring Reports, 2001 through mid-2003.)
Nonpoint Source
Total Phosphorus Contributions
Roadway and Sidewalk Deicing Chemicals: 4,929 kg/yr, 1.8%
Stream Bank Erosion: 45,500 kg/yr, 16.9%
Individual Sewage Treatment Systems (ISTS) / Unsewered Communities: 26,949 kg/yr, 10.0%
Non-Agricultural Rural Runoff: 10,489 kg/yr, 3.9%
Urban Runoff: 28,132 kg/yr, 10.4%
Cropland and Pasture Runoff: 122,101 kg/yr, 45.3%
Atmospheric Deposition: 18,016 kg/yr, 6.7%
Feedlots: 13,298 kg/yr, 4.9%

Figure 3-28



Estimated Bioavailable P Contributions to Minnesota Surface Waters
Lower Mississippi River Basin
Dry, Low Flow Water Year
Point Source: 250,559 kg/yr, 61%
• Commercial Automatic Dishwasher Detergent
• Commercial/Industrial Process Water
• Dentifrices
• Food Soils/Garbage Disposal Waste
• Groundwater Intrusion (I&I)
• Residential Automatic Dishwasher Detergent
• Human Waste Products
• Noncontact Cooling Water
• Raw/Finished Water Supply
Nonpoint Source: 161,244 kg/yr, 39%
• Atmospheric Deposition
• Cropland and Pasture Runoff
• Feedlots
• Individual Sewage Treatment Systems (ISTS)/Unsewered Communities
• Non-Agriculture Rural Runoff
• Roadway and Sidewalk Deicing Chemicals
• Stream Bank Erosion
• Urban Runoff
Point Source
Bioavailable P Contributions
Residential Automatic Dishwashing Detergent: 12,685 kg/yr, 5.1%
Commercial Automatic Dishwasher Detergent: 5,919 kg/yr, 2.4%
Noncontact Cooling Water: 994 kg/yr, 0.4%
Food Soils/ Garbage Disposal Waste: 22,629 kg/yr, 9.0%
Dentifrices: 86 kg/yr, <0.1%
Commercial/ Industrial Process Water: 121,344 kg/yr, 48.4%
Human Waste Products: 81,393 kg/yr, 32.5%
Groundwater Intrusion (I&I): 78 kg/yr, <0.1%
Raw/Finished Water Supply: 5,432 kg/yr, 2.2%
(Based on data from NPDES/SDS Permit Discharge Monitoring Reports, 2001 through mid-2003.)
Nonpoint Source
Bioavailable P Contributions
Roadway and Sidewalk Deicing Chemicals: 4,534 kg/yr, 2.8%
Stream Bank Erosion: 20,020 kg/yr, 12.4%
Individual Sewage Treatment Systems (ISTS) / Unsewered Communities: 25,871 kg/yr, 16.0%
Non-Agricultural Rural Runoff: 6,174 kg/yr, 3.8%
Urban Runoff: 16,475 kg/yr, 10.2%
Atmospheric Deposition: 6,713 kg/yr, 4.2%
Feedlots: 10,638 kg/yr, 6.6%
Cropland and Pasture Runoff: 70,819 kg/yr, 43.9%

Figure 3-29


Estimated Total Phosphorus Contributions to Minnesota Surface Waters
Lower Mississippi River Basin
Average Flow Water Year
Point Source:
267,259 kg/yr,
28%
• Commercial Automatic Dishwasher Detergent
• Commercial/Industrial Process Water
• Dentifrices
• Food Soils/Garbage Disposal Waste
• Groundwater Intrusion (I&I)
• Residential Automatic Dishwasher Detergent
• Human Waste Products
• Noncontact Cooling Water
• Raw/Finished Water Supply
Nonpoint Source:
684,196 kg/yr,
72%
• Atmospheric Deposition
• Cropland and Pasture Runoff
• Feedlots
• Individual Sewage Treatment Systems (ISTS)/Unsewered Communities
• Non-Agriculture Rural Runoff
• Roadway and Sidewalk Deicing Chemicals
• Stream Bank Erosion
• Urban Runoff
Point Source
Total Phosphorus Contributions
Commercial Automatic Dishwasher Detergent: 5,919 kg/yr, 2.2%
Residential Automatic Dishwashing Detergent: 12,685 kg/yr, 4.7%
Noncontact Cooling Water: 1,129 kg/yr, 0.4%
Food Soils/ Garbage Disposal Waste: 28,287 kg/yr, 10.6%
Commercial/ Industrial Process Water: 125,097 kg/yr, 46.8%
Dentifrices: 1,717 kg/yr, 0.6%
Human Waste Products: 86,588 kg/yr, 32.4%
Groundwater Intrusion (I&I): 120 kg/yr, <0.1%
Raw/Finished Water Supply: 5,717 kg/yr, 2.1%
(Based on data from NPDES/SDS Permit Discharge Monitoring Reports, 2001 through mid-2003.)
Nonpoint Source
Total Phosphorus Contributions
Individual Sewage Treatment Systems (ISTS) / Unsewered Communities: 26,949 kg/yr, 3.9%
Stream Bank Erosion: 322,000 kg/yr, 47.1%
Cropland and Pasture Runoff: 243,115 kg/yr, 35.5%
Feedlots: 19,167 kg/yr, 2.8%
Roadway and Sidewalk Deicing Chemicals: 7,793 kg/yr, 1.1%
Non-Agricultural Rural Runoff: 13,363 kg/yr, 2.0%
Urban Runoff: 31,374 kg/yr, 4.6%
Atmospheric Deposition: 20,435 kg/yr, 3.0%

increased significantly for streambank erosion, decreased slightly for cropland and pasture runoff, and decreased significantly for all of the remaining source categories.

3.4.4.2.2 Bioavailable Phosphorus

Under average flow conditions, Figure 3-30 shows that the bioavailable point source phosphorus contribution drops to 41 percent, compared to 61 percent for the loadings to surface waters under low flow conditions. As presented in Figure 3-30, cropland and pasture runoff and streambank erosion represent 39 and 39 percent, respectively, of the nonpoint source bioavailable phosphorus loadings, with the remaining nonpoint source contributions below 8 percent. Compared to low flow conditions (Figure 3-28), Figure 3-30 shows that the relative nonpoint source contributions of bioavailable phosphorus increased significantly for streambank erosion, decreased slightly for cropland and pasture runoff, and decreased significantly for all of the remaining source categories.

3.4.4.3 Wet Condition (High Flow)

3.4.4.3.1 Total Phosphorus

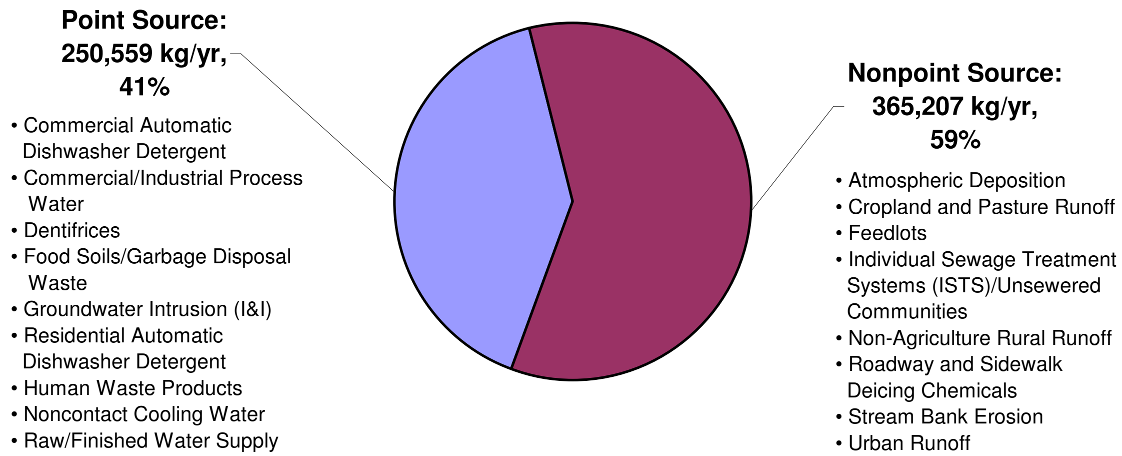
Under high flow conditions, Figure 3-31 shows that the total point source phosphorus contribution drops to 13 percent, compared to 28 and 50 percent for the loadings to surface waters under average and low flow conditions, respectively. As presented in Figure 3-31, streambank erosion and cropland and pasture runoff represent 75 and 17 percent, respectively, of the nonpoint source total phosphorus loadings, with the remaining nonpoint source contributions below 2 percent. Compared to average flow conditions (Figure 3-29), Figure 3-31 shows that the relative statewide nonpoint source contributions of total phosphorus increased significantly for streambank erosion and decreased significantly for all of the remaining source categories.

3.4.4.3.2 Bioavailable Phosphorus

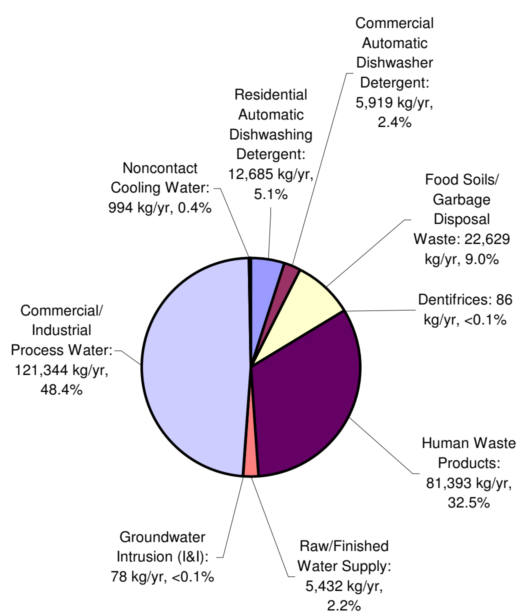
Under high flow conditions, Figure 3-32 shows that the bioavailable point source phosphorus contribution drops to 23 percent, compared to 41 and 61 percent for the loadings to surface waters under average and low flow conditions, respectively. As presented in Figure 3-32, cropland and pasture runoff and streambank erosion represent 21 and 68 percent, respectively, of the nonpoint source bioavailable phosphorus loadings, with the remaining nonpoint source contributions at or below 4 percent. Compared to average flow conditions (Figure 3-30), Figure 3-32 shows that the relative nonpoint source contributions of bioavailable phosphorus increased significantly for streambank erosion and decreased significantly for all of the remaining source categories.

Figure 3-30

Estimated Bioavailable P Contributions to Minnesota Surface Waters
Lower Mississippi River Basin
Average Flow Water Year



Point Source
Bioavailable P Contributions



(Based on data from NPDES/SDS Permit Discharge Monitoring Reports, 2001 through mid-2003.)

Nonpoint Source
Bioavailable P Contributions

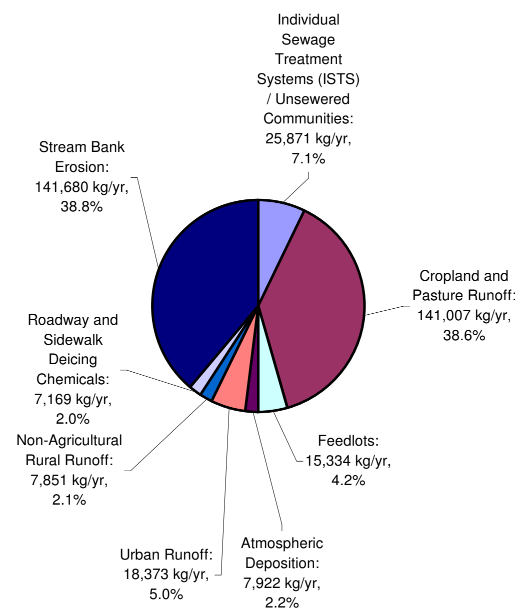
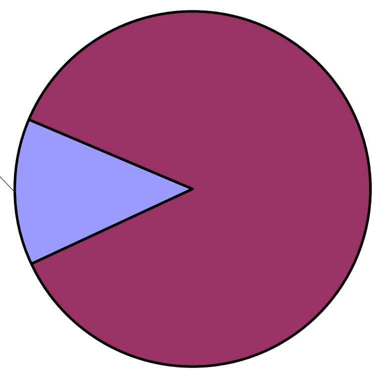


Figure 3-31

Estimated Total Phosphorus Contributions to Minnesota Surface Waters
Lower Mississippi River Basin
Wet, High Flow Water Year



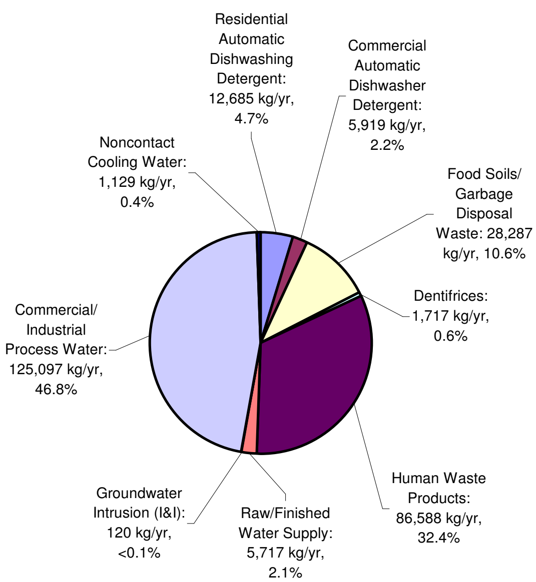
Point Source: 267,259 kg/yr, 13%

- Commercial Automatic Dishwasher Detergent
- Commercial/Industrial Process Water
- Dentifrices
- Food Soils/Garbage Disposal Waste
- Groundwater Intrusion (I&I)
- Residential Automatic Dishwasher Detergent
- Human Waste Products
- Noncontact Cooling Water
- Raw/Finished Water Supply

Nonpoint Source: 1,716,691 kg/yr, 87%

- Atmospheric Deposition
- Cropland and Pasture Runoff
- Feedlots
- Individual Sewage Treatment Systems (ISTS)/Unsewered Communities
- Non-Agriculture Rural Runoff
- Roadway and Sidewalk Deicing Chemicals
- Stream Bank Erosion
- Urban Runoff

Point Source Total Phosphorus Contributions



(Based on data from NPDES/SDS Permit Discharge Monitoring Reports, 2001 through mid-2003.)

Nonpoint Source Total Phosphorus Contributions

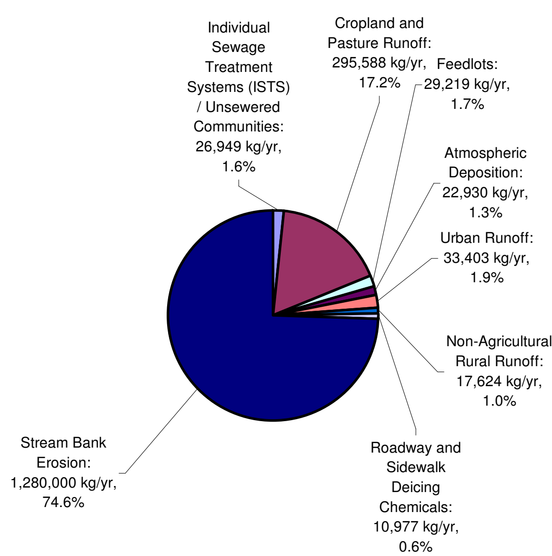
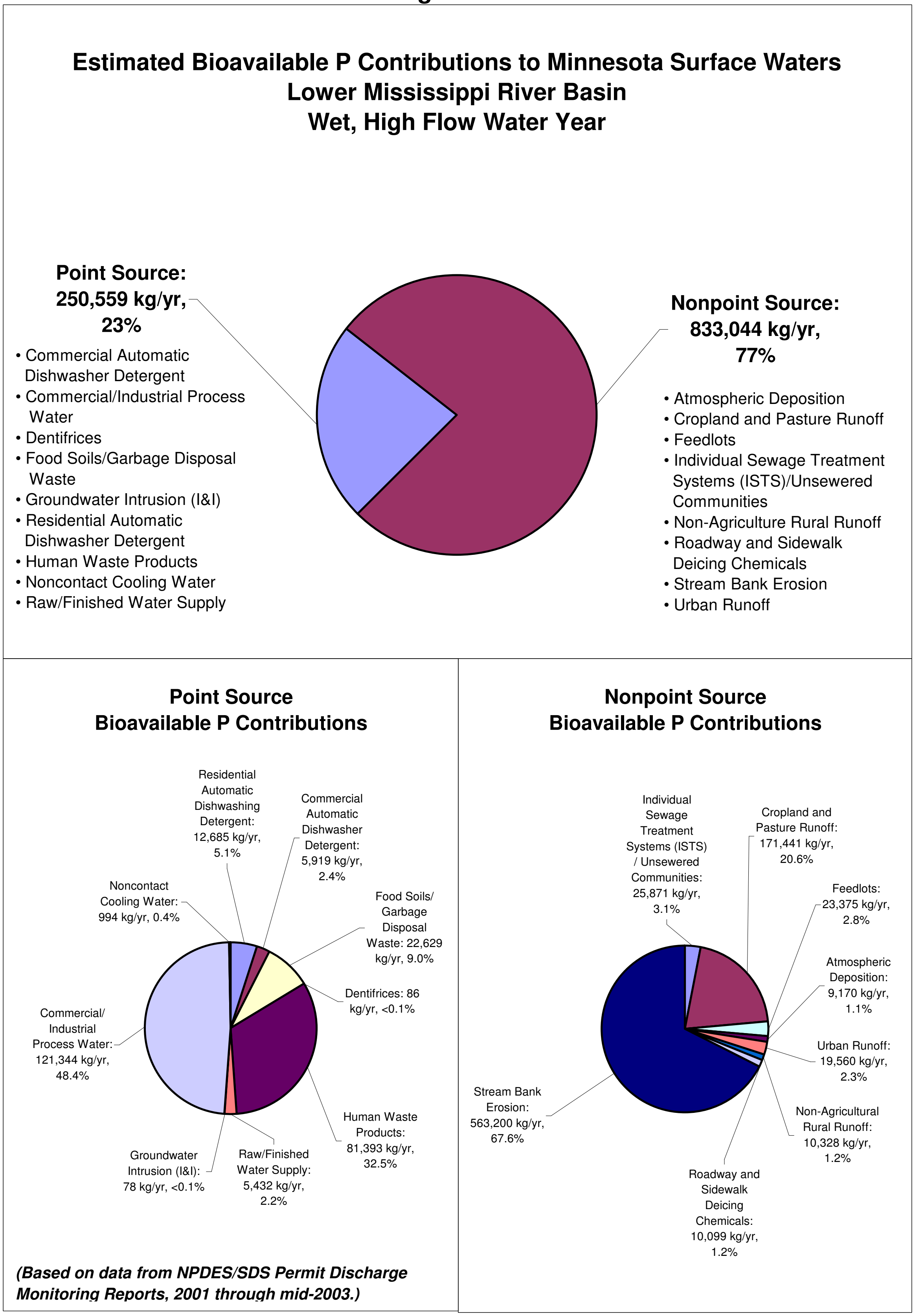


Figure 3-32



Estimated Bioavailable P Contributions to Minnesota Surface Waters
Lower Mississippi River Basin
Wet, High Flow Water Year
Point Source: 250,559 kg/yr, 23%
• Commercial Automatic Dishwasher Detergent
• Commercial/Industrial Process Water
• Dentifrices
• Food Soils/Garbage Disposal Waste
• Groundwater Intrusion (I&I)
• Residential Automatic Dishwasher Detergent
• Human Waste Products
• Noncontact Cooling Water
• Raw/Finished Water Supply
Nonpoint Source: 833,044 kg/yr, 77%
• Atmospheric Deposition
• Cropland and Pasture Runoff
• Feedlots
• Individual Sewage Treatment Systems (ISTS)/Unsewered Communities
• Non-Agriculture Rural Runoff
• Roadway and Sidewalk Deicing Chemicals
• Stream Bank Erosion
• Urban Runoff
Point Source Bioavailable P Contributions
Residential Automatic Dishwashing Detergent: 12,685 kg/yr, 5.1%
Commercial Automatic Dishwasher Detergent: 5,919 kg/yr, 2.4%
Noncontact Cooling Water: 994 kg/yr, 0.4%
Food Soils/ Garbage Disposal Waste: 22,629 kg/yr, 9.0%
Dentifrices: 86 kg/yr, <0.1%
Commercial/ Industrial Process Water: 121,344 kg/yr, 48.4%
Human Waste Products: 81,393 kg/yr, 32.5%
Groundwater Intrusion (I&I): 78 kg/yr, <0.1%
Raw/Finished Water Supply: 5,432 kg/yr, 2.2%
(Based on data from NPDES/SDS Permit Discharge Monitoring Reports, 2001 through mid-2003.)
Nonpoint Source Bioavailable P Contributions
Individual Sewage Treatment Systems (ISTS) / Unsewered Communities: 25,871 kg/yr, 3.1%
Cropland and Pasture Runoff: 171,441 kg/yr, 20.6%
Feedlots: 23,375 kg/yr, 2.8%
Atmospheric Deposition: 9,170 kg/yr, 1.1%
Urban Runoff: 19,560 kg/yr, 2.3%
Stream Bank Erosion: 563,200 kg/yr, 67.6%
Non-Agricultural Rural Runoff: 10,328 kg/yr, 1.2%
Roadway and Sidewalk Deicing Chemicals: 10,099 kg/yr, 1.2%

3.4.5 Red River Basin

3.4.5.1 Dry Conditions (Low Flow)

3.4.5.1.1 Total Phosphorus

Figure 3-33 shows that, under low flow conditions, the total point source phosphorus contribution represents 16 percent, while nonpoint sources of phosphorus represent 84 percent of the loadings to surface waters in the Red River basin. Figure 3-33 also shows that human waste products, commercial/industrial process water, and food soils represent 37, 31 and 14 percent, respectively, of the point source total phosphorus contributions. The remaining point source categories contribute less than 7 percent of the point source loadings. The combination of residential and commercial automatic dishwasher detergent represents approximately 9 percent of the point source total phosphorus contributions. As shown in Figure 3-33, cropland and pasture runoff and atmospheric deposition represent 33 and 52 percent, respectively, of the nonpoint source total phosphorus loadings, with the remaining nonpoint source contributions below 6 percent.

3.4.5.1.2 Bioavailable Phosphorus

Figure 3-34 shows that, under low flow conditions, the bioavailable point source phosphorus contribution represents 28 percent of the loadings to surface waters. Figure 3-34 also shows that human waste products, commercial/industrial process water, and food soils represent 37, 32 and 12 percent, respectively, of the point source bioavailable phosphorus contributions. The remaining point source categories contribute less than 7 percent of the point source loadings. The combination of residential and commercial automatic dishwasher detergent represents approximately 10 percent of the point source bioavailable phosphorus contributions. As shown in Figure 3-34, cropland and pasture runoff and atmospheric deposition represent approximately 41 and 35 percent, respectively, of the nonpoint source bioavailable phosphorus loadings, with the remaining nonpoint source contributions below 12 percent.

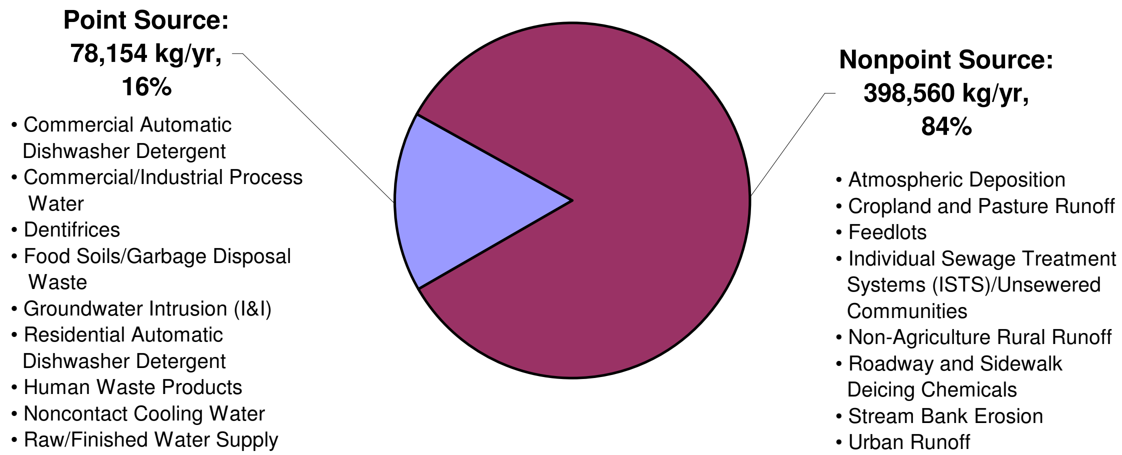
3.4.5.2 Average Condition

3.4.5.2.1 Total Phosphorus

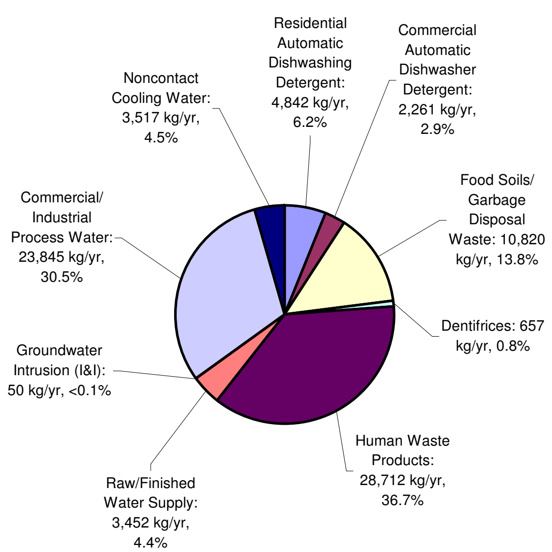
Under average flow conditions, the total point source phosphorus contribution drops to 10 percent, compared to 16 percent for the loadings to surface waters under low flow conditions (Figure 3-35). Cropland and pasture runoff and atmospheric deposition represent 54 and 32 percent, respectively, of the nonpoint source total phosphorus loadings, with the remaining nonpoint source contributions below 6 percent. Compared to low flow conditions (Figure 3-33), Figure 3-35 shows that the relative nonpoint source contributions of total phosphorus increased significantly for cropland and pasture runoff and decreased significantly for several of the remaining source categories.

Figure 3-33

Estimated Total Phosphorus Contributions to Minnesota Surface Waters
Red River Basin
Dry, Low Flow Water Year



Point Source Total Phosphorus Contributions



(Based on data from NPDES/SDS Permit Discharge Monitoring Reports, 2001 through mid-2003.)

Nonpoint Source Total Phosphorus Contributions

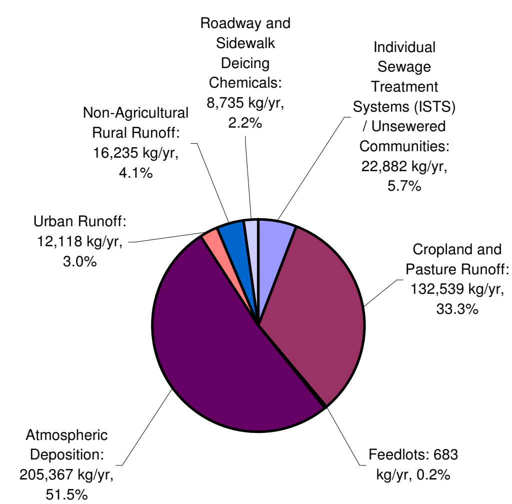
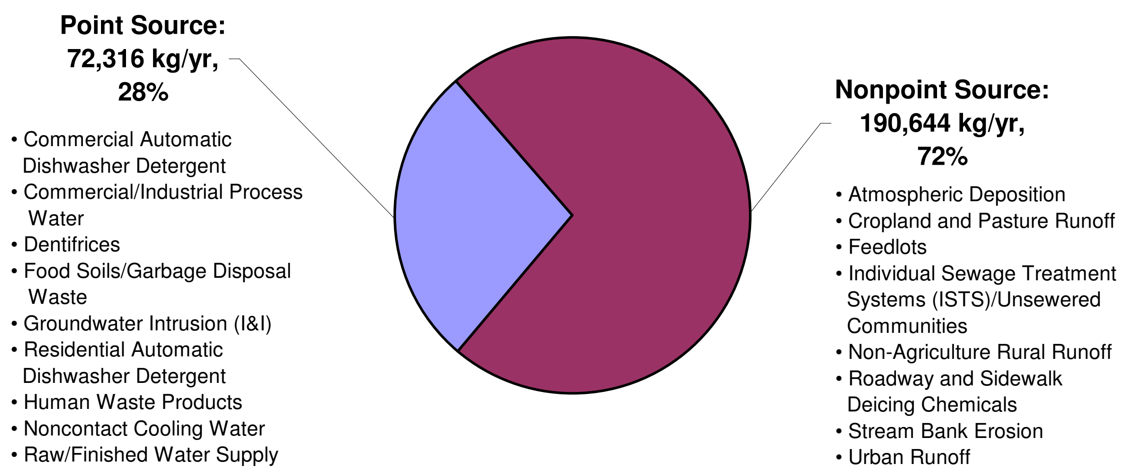
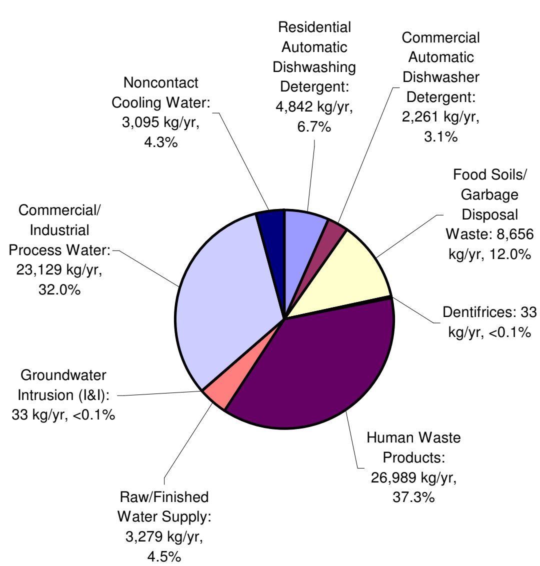


Figure 3-34

Estimated Bioavailable P Contributions to Minnesota Surface Waters
Red River Basin
Dry, Low Flow Water Year



Point Source Bioavailable P Contributions



(Based on data from NPDES/SDS Permit Discharge Monitoring Reports, 2001 through mid-2003.)

Nonpoint Source Bioavailable P Contributions

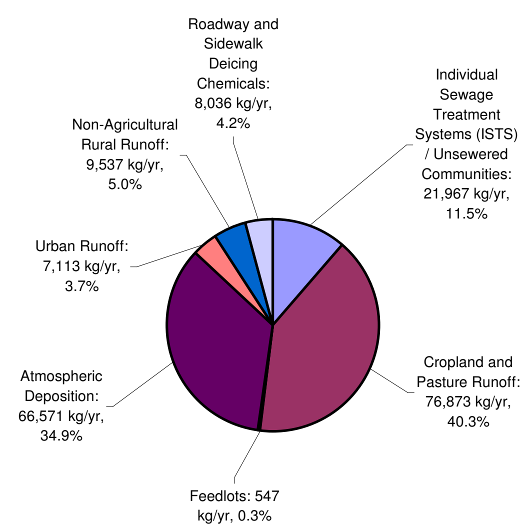
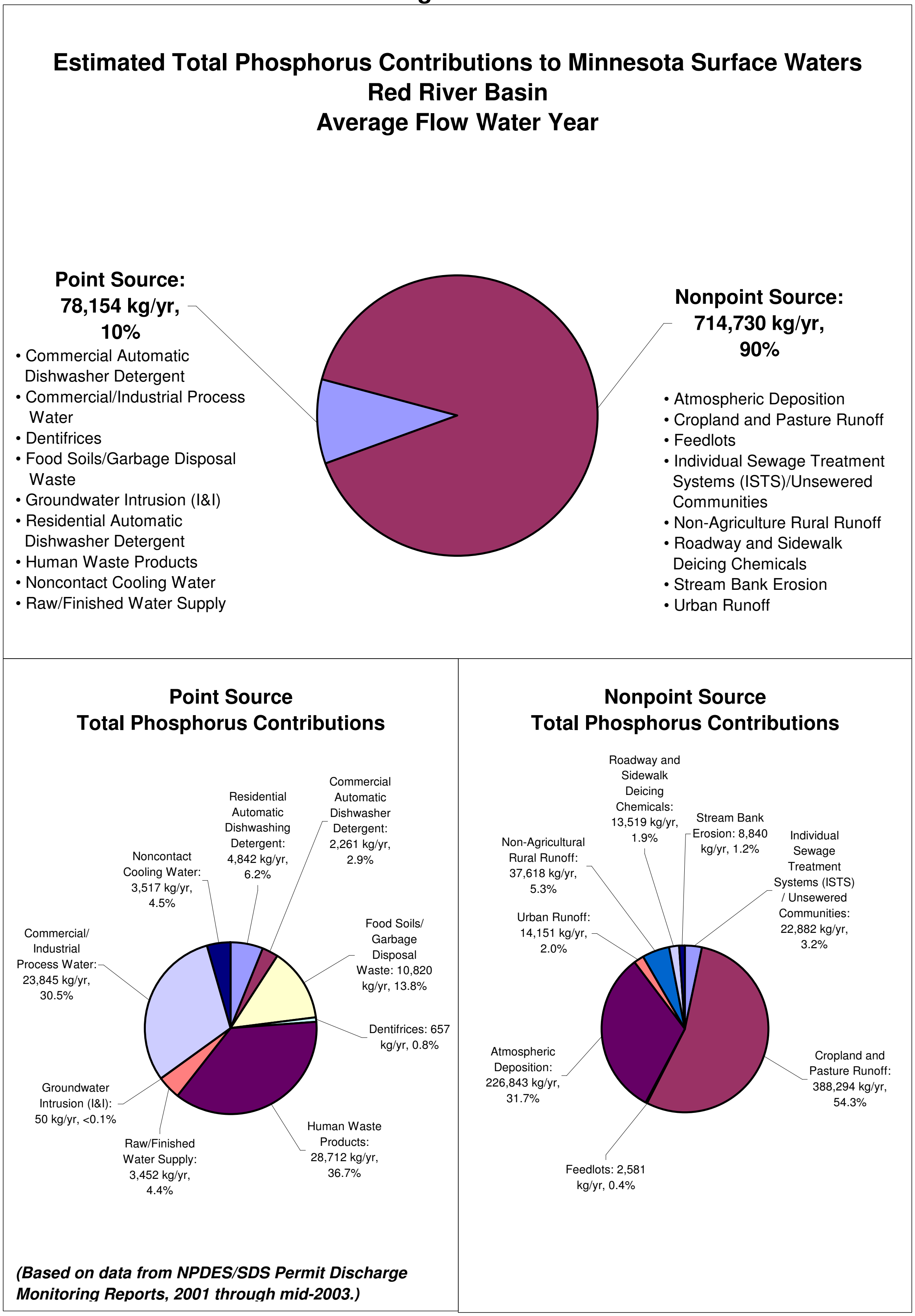


Figure 3-35



Estimated Total Phosphorus Contributions to Minnesota Surface Waters
Red River Basin
Average Flow Water Year
Point Source:
78,154 kg/yr,
10%
• Commercial Automatic Dishwasher Detergent
• Commercial/Industrial Process Water
• Dentifrices
• Food Soils/Garbage Disposal Waste
• Groundwater Intrusion (I&I)
• Residential Automatic Dishwasher Detergent
• Human Waste Products
• Noncontact Cooling Water
• Raw/Finished Water Supply
Nonpoint Source:
714,730 kg/yr,
90%
• Atmospheric Deposition
• Cropland and Pasture Runoff
• Feedlots
• Individual Sewage Treatment Systems (ISTS)/Unsewered Communities
• Non-Agriculture Rural Runoff
• Roadway and Sidewalk Deicing Chemicals
• Stream Bank Erosion
• Urban Runoff
Point Source
Total Phosphorus Contributions
Residential Automatic Dishwashing Detergent: 4,842 kg/yr, 6.2%
Commercial Automatic Dishwasher Detergent: 2,261 kg/yr, 2.9%
Noncontact Cooling Water: 3,517 kg/yr, 4.5%
Food Soils/ Garbage Disposal Waste: 10,820 kg/yr, 13.8%
Commercial/ Industrial Process Water: 23,845 kg/yr, 30.5%
Dentifrices: 657 kg/yr, 0.8%
Groundwater Intrusion (I&I): 50 kg/yr, <0.1%
Raw/Finished Water Supply: 3,452 kg/yr, 4.4%
Human Waste Products: 28,712 kg/yr, 36.7%
(Based on data from NPDES/SDS Permit Discharge Monitoring Reports, 2001 through mid-2003.)
Nonpoint Source
Total Phosphorus Contributions
Roadway and Sidewalk Deicing Chemicals: 13,519 kg/yr, 1.9%
Stream Bank Erosion: 8,840 kg/yr, 1.2%
Non-Agricultural Rural Runoff: 37,618 kg/yr, 5.3%
Individual Sewage Treatment Systems (ISTS) / Unsewered Communities: 22,882 kg/yr, 3.2%
Urban Runoff: 14,151 kg/yr, 2.0%
Atmospheric Deposition: 226,843 kg/yr, 31.7%
Cropland and Pasture Runoff: 388,294 kg/yr, 54.3%
Feedlots: 2,581 kg/yr, 0.4%

3.4.5.2.2 Bioavailable Phosphorus

Under average flow conditions, Figure 3-36 shows that the bioavailable point source phosphorus contribution drops to 16 percent, compared to 28 percent for the loadings to surface waters under low flow conditions. As presented in Figure 3-36, cropland and pasture runoff and atmospheric deposition represent 60 and 21 percent, respectively, of the nonpoint source bioavailable phosphorus loadings, with the remaining nonpoint source contributions below 6 percent. Compared to low flow conditions (Figure 3-34), Figure 3-36 shows that the relative nonpoint source contributions of bioavailable phosphorus increased significantly for cropland and pasture runoff and decreased significantly for several of the remaining source categories.

3.4.5.3 Wet Condition (High Flow)

3.4.5.3.1 Total Phosphorus

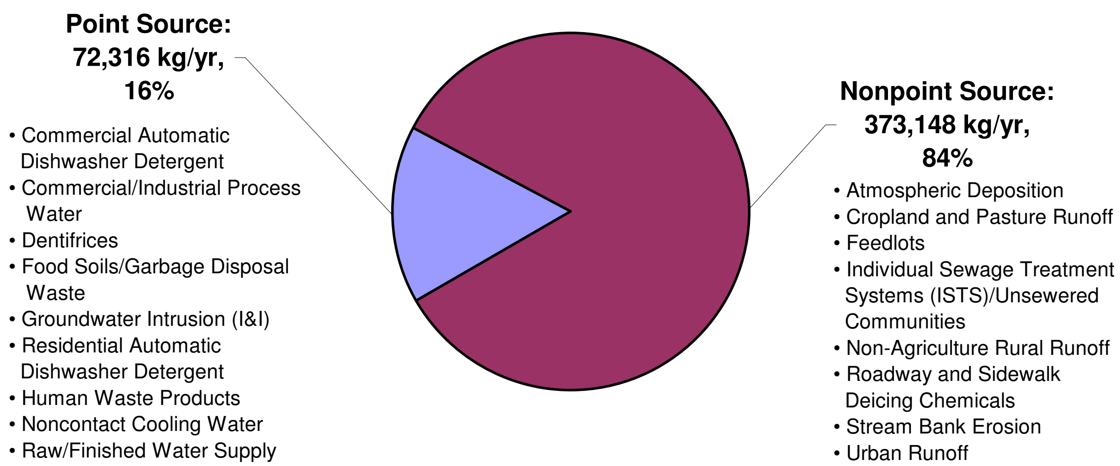
Under high flow conditions, Figure 3-37 shows that the total point source phosphorus contribution drops to 7 percent, compared to 10 and 16 percent for the loadings to surface waters under average and low flow conditions, respectively. As presented in Figure 3-37, streambank erosion, atmospheric deposition and cropland and pasture runoff represent 14, 24 and 51 percent, respectively, of the nonpoint source total phosphorus loadings, with the remaining nonpoint source contributions below 6 percent. Compared to average flow conditions (Figure 3-35), Figure 3-37 shows that the relative statewide nonpoint source contributions of total phosphorus increased significantly for streambank erosion and decreased significantly for all of the remaining source categories, except cropland and pasture runoff.

3.4.5.3.2 Bioavailable Phosphorus

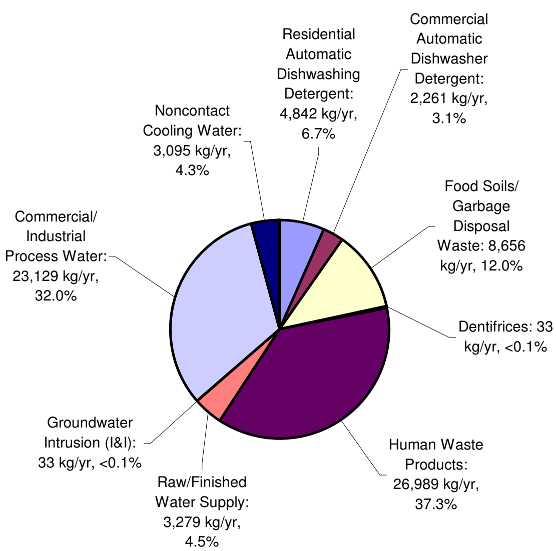
Under high flow conditions, Figure 3-38 shows that the bioavailable point source phosphorus contribution drops to 11 percent, compared to 16 and 28 percent for the loadings to surface waters under average and low flow conditions, respectively. As presented in Figure 3-38, cropland and pasture runoff, atmospheric deposition and streambank erosion represent 57, 16 and 11 percent, respectively, of the nonpoint source bioavailable phosphorus loadings, with the remaining nonpoint source contributions below 7 percent. Compared to average flow conditions (Figure 3-36), Figure 3-38 shows that the relative nonpoint source contributions of bioavailable phosphorus increased significantly for streambank erosion and decreased significantly for all of the remaining source categories, except cropland and pasture runoff.

Figure 3-36

Estimated Bioavailable P Contributions to Minnesota Surface Waters
Red River Basin
Average Flow Water Year



Point Source Bioavailable P Contributions



(Based on data from NPDES/SDS Permit Discharge Monitoring Reports, 2001 through mid-2003.)

Nonpoint Source Bioavailable P Contributions

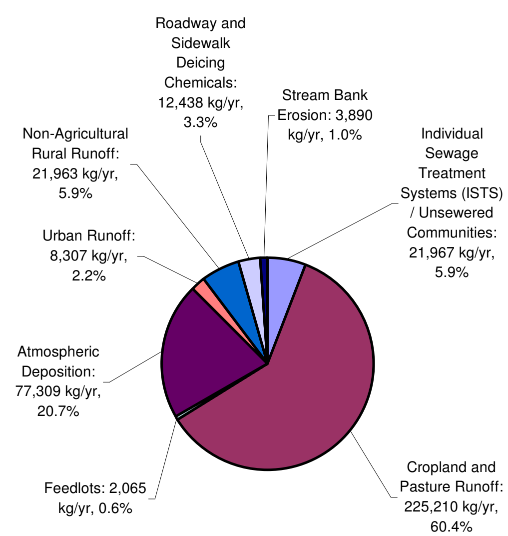
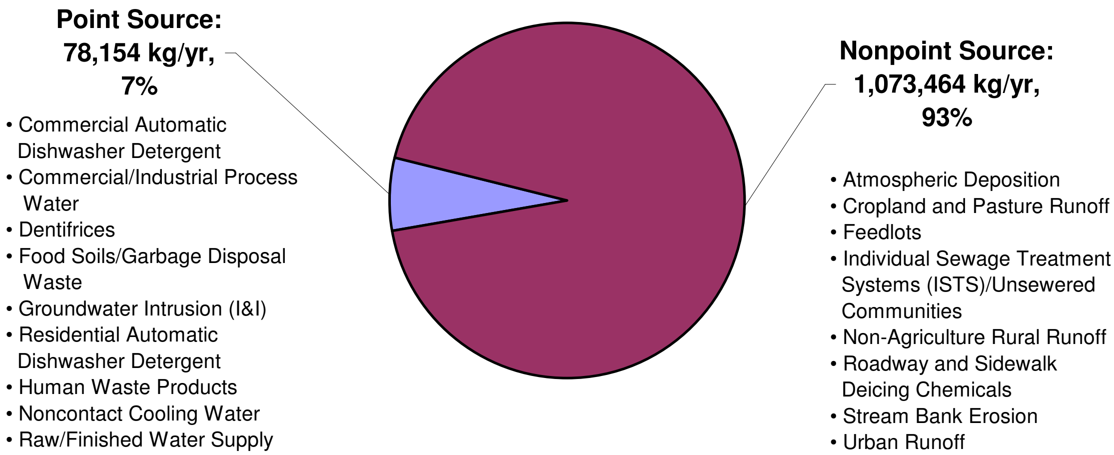
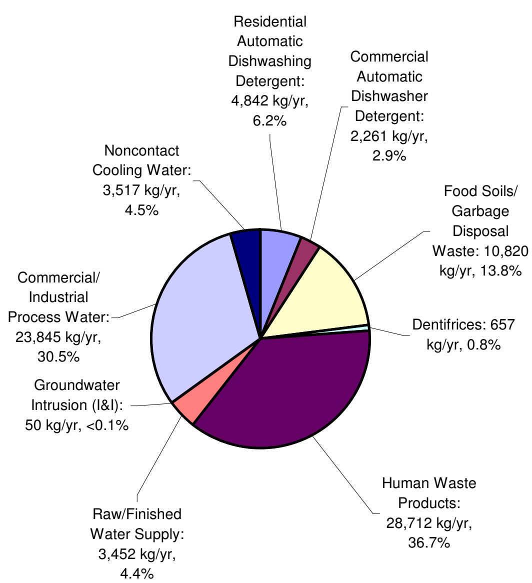


Figure 3-37

Estimated Total Phosphorus Contributions to Minnesota Surface Waters
Red River Basin
Wet, High Flow Water Year



Point Source Total Phosphorus Contributions



(Based on data from NPDES/SDS Permit Discharge Monitoring Reports, 2001 through mid-2003.)

Nonpoint Source Total Phosphorus Contributions

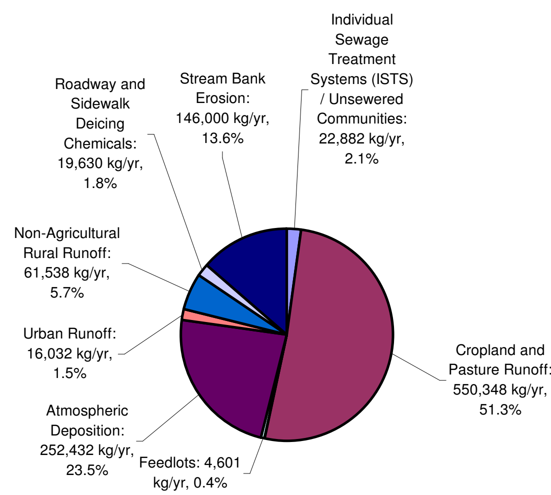
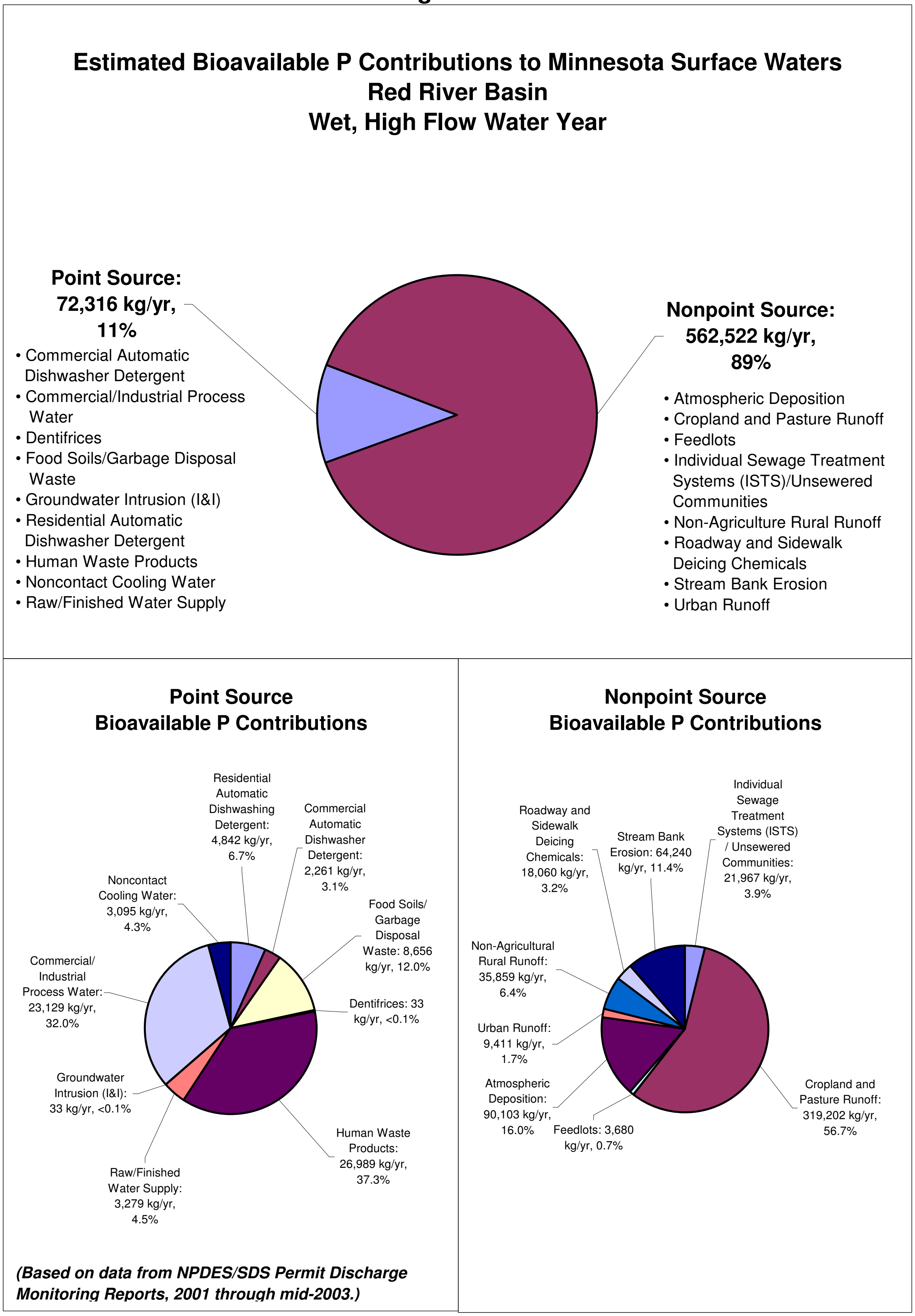


Figure 3-38



Estimated Bioavailable P Contributions to Minnesota Surface Waters
Red River Basin
Wet, High Flow Water Year
Point Source:
72,316 kg/yr,
11%
• Commercial Automatic Dishwasher Detergent
• Commercial/Industrial Process Water
• Dentifrices
• Food Soils/Garbage Disposal Waste
• Groundwater Intrusion (I&I)
• Residential Automatic Dishwasher Detergent
• Human Waste Products
• Noncontact Cooling Water
• Raw/Finished Water Supply
Nonpoint Source:
562,522 kg/yr,
89%
• Atmospheric Deposition
• Cropland and Pasture Runoff
• Feedlots
• Individual Sewage Treatment Systems (ISTS)/Unsewered Communities
• Non-Agriculture Rural Runoff
• Roadway and Sidewalk Deicing Chemicals
• Stream Bank Erosion
• Urban Runoff
Point Source
Bioavailable P Contributions
Residential Automatic Dishwashing Detergent: 4,842 kg/yr, 6.7%
Commercial Automatic Dishwasher Detergent: 2,261 kg/yr, 3.1%
Food Soils/ Garbage Disposal Waste: 8,656 kg/yr, 12.0%
Dentifrices: 33 kg/yr, <0.1%
Human Waste Products: 26,989 kg/yr, 37.3%
Raw/Finished Water Supply: 3,279 kg/yr, 4.5%
Groundwater Intrusion (I&I): 33 kg/yr, <0.1%
Commercial/ Industrial Process Water: 23,129 kg/yr, 32.0%
Noncontact Cooling Water: 3,095 kg/yr, 4.3%
(Based on data from NPDES/SDS Permit Discharge Monitoring Reports, 2001 through mid-2003.)
Nonpoint Source
Bioavailable P Contributions
Roadway and Sidewalk Deicing Chemicals: 18,060 kg/yr, 3.2%
Stream Bank Erosion: 64,240 kg/yr, 11.4%
Individual Sewage Treatment Systems (ISTS) / Unsewered Communities: 21,967 kg/yr, 3.9%
Non-Agricultural Rural Runoff: 35,859 kg/yr, 6.4%
Urban Runoff: 9,411 kg/yr, 1.7%
Atmospheric Deposition: 90,103 kg/yr, 16.0%
Feedlots: 3,680 kg/yr, 0.7%
Cropland and Pasture Runoff: 319,202 kg/yr, 56.7%

3.4.6 Rainy River Basin

3.4.6.1 Dry Conditions (Low Flow)

3.4.6.1.1 Total Phosphorus

Figure 3-39 shows that, under low flow conditions, the total point source phosphorus contribution represents 15 percent, while nonpoint sources of phosphorus represent 85 percent of the loadings to surface waters in the Rainy River basin. Figure 3-39 also shows that commercial/industrial process water represents 91 percent of the point source total phosphorus contributions. The remaining point source categories contribute less than 7 percent of the point source loadings. The combination of residential and commercial automatic dishwasher detergent represents approximately 1 percent of the point source total phosphorus contributions. As shown in Figure 3-39, non-agricultural rural runoff and atmospheric deposition represent 28 and 62 percent, respectively, of the nonpoint source total phosphorus loadings, with the remaining nonpoint source contributions below 4 percent.

3.4.6.1.2 Bioavailable Phosphorus

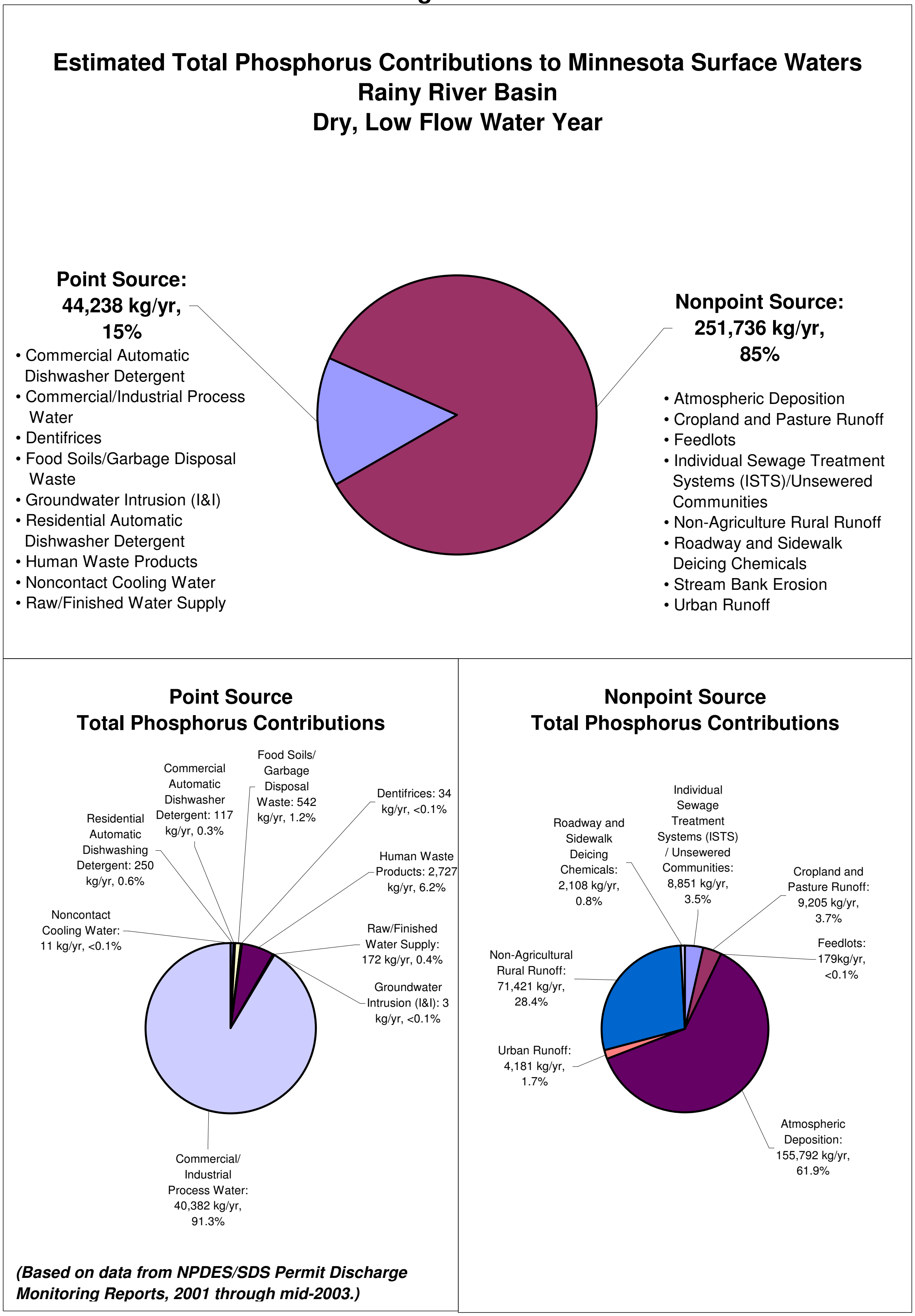
Figure 3-40 shows that, under low flow conditions, the bioavailable point source phosphorus contribution represents 27 percent of the loadings to surface waters. Figure 3-40 also shows that commercial/industrial process water represents 92 percent of the point source bioavailable phosphorus contributions. The remaining point source categories contribute less than 7 percent of the point source loadings. The combination of residential and commercial automatic dishwasher detergent represents approximately 1 percent of the point source bioavailable phosphorus contributions. As shown in Figure 3-40, non-agricultural rural runoff and atmospheric deposition represent approximately 35 and 49 percent, respectively, of the nonpoint source bioavailable phosphorus loadings, with the remaining nonpoint source contributions below 8 percent.

3.4.6.2 Average Condition

3.4.6.2.1 Total Phosphorus

Under average flow conditions, Figure 3-41 shows that the total point source phosphorus contribution drops to 10 percent, compared to 15 percent for the loadings to surface waters under low flow conditions. As presented in Figure 3-41, non-agricultural rural runoff and atmospheric deposition represent 30 and 45 percent, respectively, of the nonpoint source total phosphorus loadings, with the remaining nonpoint source contributions below 15 percent. Compared to low flow conditions (Figure 3-39), Figure 3-41 shows that the relative nonpoint source contributions of total phosphorus increased significantly for streambank erosion and decreased significantly for atmospheric deposition.

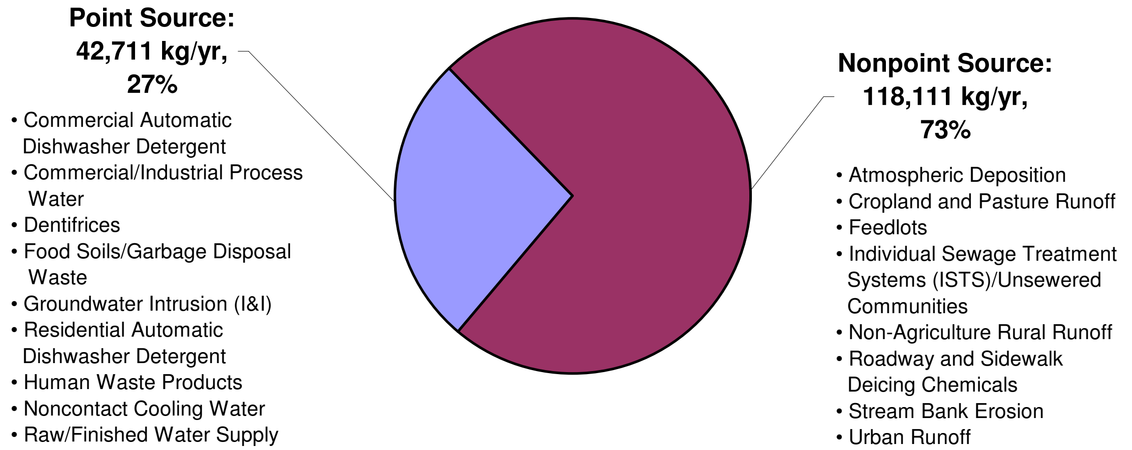
Figure 3-39



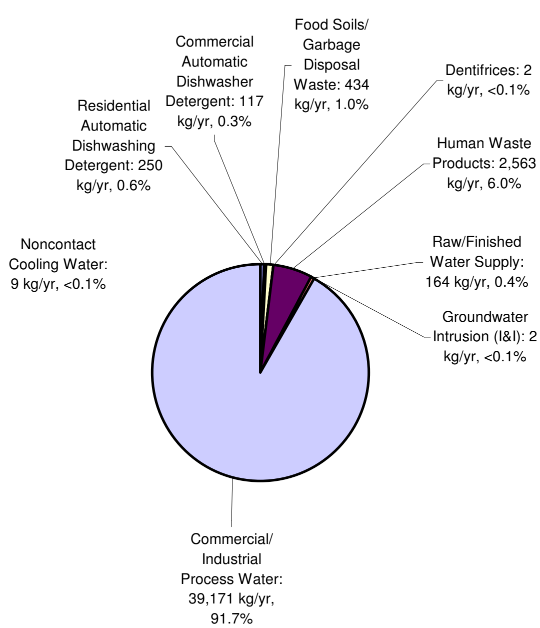
Estimated Total Phosphorus Contributions to Minnesota Surface Waters
Rainy River Basin
Dry, Low Flow Water Year
Point Source: 44,238 kg/yr, 15%
• Commercial Automatic Dishwasher Detergent
• Commercial/Industrial Process Water
• Dentifrices
• Food Soils/Garbage Disposal Waste
• Groundwater Intrusion (I&I)
• Residential Automatic Dishwasher Detergent
• Human Waste Products
• Noncontact Cooling Water
• Raw/Finished Water Supply
Nonpoint Source: 251,736 kg/yr, 85%
• Atmospheric Deposition
• Cropland and Pasture Runoff
• Feedlots
• Individual Sewage Treatment Systems (ISTS)/Unsewered Communities
• Non-Agriculture Rural Runoff
• Roadway and Sidewalk Deicing Chemicals
• Stream Bank Erosion
• Urban Runoff
Point Source
Total Phosphorus Contributions
Commercial Automatic Dishwasher Detergent: 117 kg/yr, 0.3%
Food Soils/ Garbage Disposal Waste: 542 kg/yr, 1.2%
Dentifrices: 34 kg/yr, <0.1%
Residential Automatic Dishwashing Detergent: 250 kg/yr, 0.6%
Human Waste Products: 2,727 kg/yr, 6.2%
Noncontact Cooling Water: 11 kg/yr, <0.1%
Raw/Finished Water Supply: 172 kg/yr, 0.4%
Groundwater Intrusion (I&I): 3 kg/yr, <0.1%
Commercial/ Industrial Process Water: 40,382 kg/yr, 91.3%
(Based on data from NPDES/SDS Permit Discharge Monitoring Reports, 2001 through mid-2003.)
Nonpoint Source
Total Phosphorus Contributions
Individual Sewage Treatment Systems (ISTS) / Unsewered Communities: 8,851 kg/yr, 3.5%
Roadway and Sidewalk Deicing Chemicals: 2,108 kg/yr, 0.8%
Cropland and Pasture Runoff: 9,205 kg/yr, 3.7%
Feedlots: 179kg/yr, <0.1%
Non-Agricultural Rural Runoff: 71,421 kg/yr, 28.4%
Urban Runoff: 4,181 kg/yr, 1.7%
Atmospheric Deposition: 155,792 kg/yr, 61.9%

Figure 3-40

Estimated Bioavailable P Contributions to Minnesota Surface Waters
Rainy River Basin
Dry, Low Flow Water Year



Point Source Bioavailable P Contributions



(Based on data from NPDES/SDS Permit Discharge Monitoring Reports, 2001 through mid-2003.)

Nonpoint Source Bioavailable P Contributions

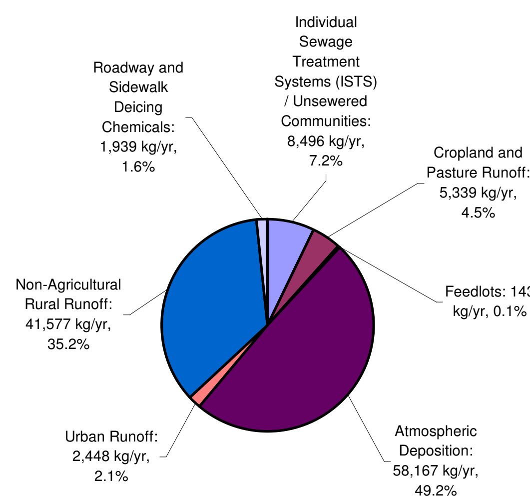
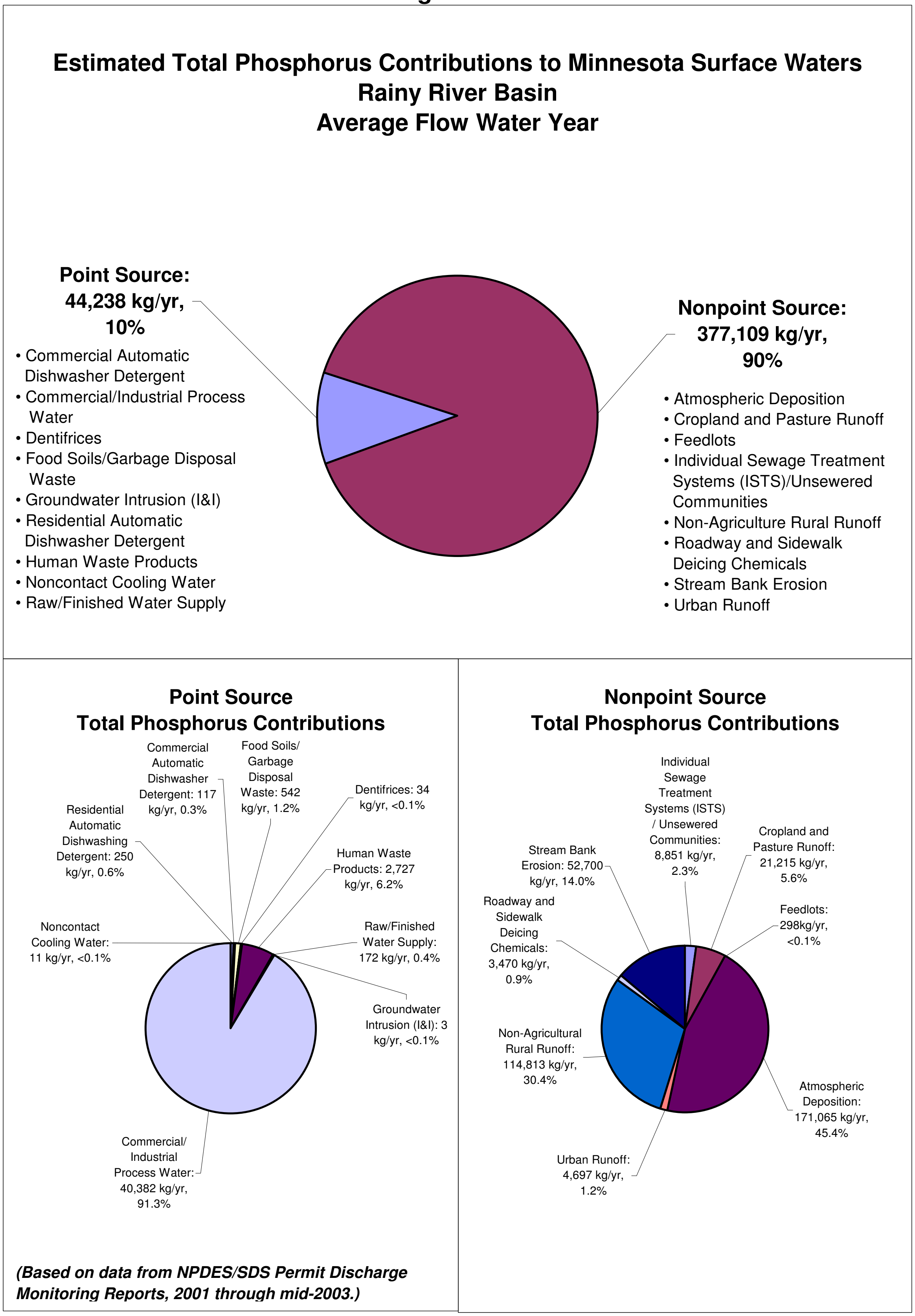


Figure 3-41


Estimated Total Phosphorus Contributions to Minnesota Surface Waters
Rainy River Basin
Average Flow Water Year
Point Source:
44,238 kg/yr,
10%
• Commercial Automatic Dishwasher Detergent
• Commercial/Industrial Process Water
• Dentifrices
• Food Soils/Garbage Disposal Waste
• Groundwater Intrusion (I&I)
• Residential Automatic Dishwasher Detergent
• Human Waste Products
• Noncontact Cooling Water
• Raw/Finished Water Supply
Nonpoint Source:
377,109 kg/yr,
90%
• Atmospheric Deposition
• Cropland and Pasture Runoff
• Feedlots
• Individual Sewage Treatment Systems (ISTS)/Unsewered Communities
• Non-Agriculture Rural Runoff
• Roadway and Sidewalk Deicing Chemicals
• Stream Bank Erosion
• Urban Runoff
Point Source
Total Phosphorus Contributions
Commercial Automatic Dishwasher Detergent: 117 kg/yr, 0.3%
Food Soils/ Garbage Disposal Waste: 542 kg/yr, 1.2%
Dentifrices: 34 kg/yr, <0.1%
Residential Automatic Dishwashing Detergent: 250 kg/yr, 0.6%
Human Waste Products: 2,727 kg/yr, 6.2%
Noncontact Cooling Water: 11 kg/yr, <0.1%
Raw/Finished Water Supply: 172 kg/yr, 0.4%
Groundwater Intrusion (I&I): 3 kg/yr, <0.1%
Commercial/ Industrial Process Water: 40,382 kg/yr, 91.3%
Nonpoint Source
Total Phosphorus Contributions
Individual Sewage Treatment Systems (ISTS) / Unsewered Communities: 8,851 kg/yr, 2.3%
Stream Bank Erosion: 52,700 kg/yr, 14.0%
Cropland and Pasture Runoff: 21,215 kg/yr, 5.6%
Roadway and Sidewalk Deicing Chemicals: 3,470 kg/yr, 0.9%
Feedlots: 298kg/yr, <0.1%
Non-Agricultural Rural Runoff: 114,813 kg/yr, 30.4%
Atmospheric Deposition: 171,065 kg/yr, 45.4%
Urban Runoff: 4,697 kg/yr, 1.2%
(Based on data from NPDES/SDS Permit Discharge Monitoring Reports, 2001 through mid-2003.)

3.4.6.2.2 Bioavailable Phosphorus

Under average flow conditions, Figure 3-42 shows that the bioavailable point source phosphorus contribution drops to 19 percent, compared to 27 percent for the loadings to surface waters under low flow conditions. As presented in Figure 3-42, non-agricultural rural runoff and atmospheric deposition represent 37 and 36 percent, respectively, of the nonpoint source bioavailable phosphorus loadings, with the remaining nonpoint source contributions below 13 percent. Compared to low flow conditions (Figure 3-40), Figure 3-42 shows that the relative nonpoint source contributions of bioavailable phosphorus increased significantly for streambank erosion and decreased significantly for atmospheric deposition.

3.4.6.3 Wet Condition (High Flow)

3.4.6.3.1 Total Phosphorus

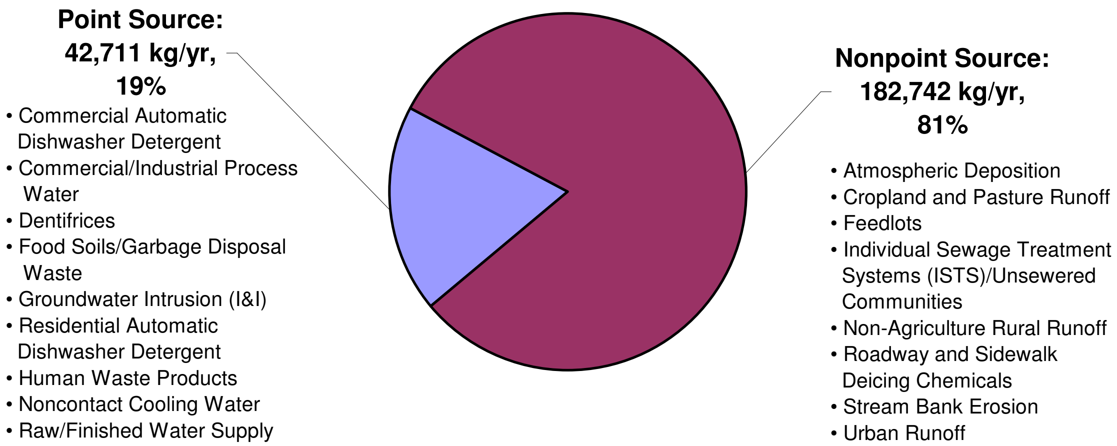
Under high flow conditions, Figure 3-43 shows that the total point source phosphorus contribution drops to 6 percent, compared to 10 and 15 percent for the loadings to surface waters under average and low flow conditions, respectively. As presented in Figure 3-43, streambank erosion, atmospheric deposition and non-agricultural runoff represent 44, 27 and 22 percent, respectively, of the nonpoint source total phosphorus loadings, with the remaining nonpoint source contributions below 6 percent. Compared to average flow conditions (Figure 3-41), Figure 3-43 shows that the relative statewide nonpoint source contributions of total phosphorus increased significantly for streambank erosion and decreased significantly for all of the remaining source categories, except cropland and pasture runoff.

3.4.6.3.2 Bioavailable Phosphorus

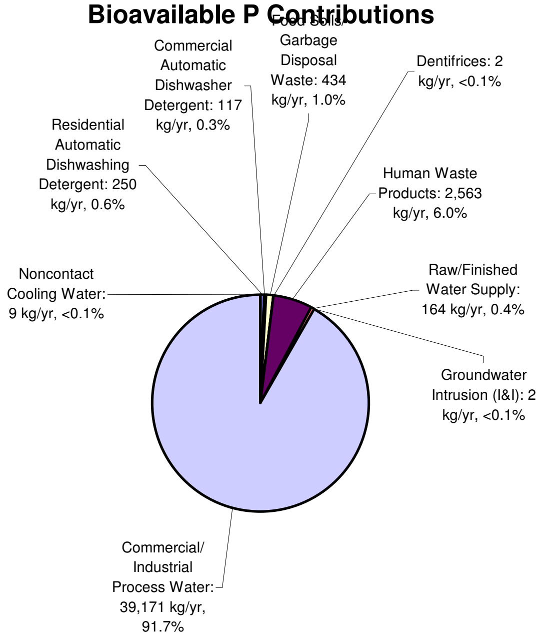
Under high flow conditions, Figure 3-44 shows that the bioavailable point source phosphorus contribution drops to 11 percent, compared to 19 and 27 percent for the loadings to surface waters under average and low flow conditions, respectively. As presented in Figure 3-44, non-agricultural rural runoff, atmospheric deposition and streambank erosion represent 27, 22 and 40 percent, respectively, of the nonpoint source bioavailable phosphorus loadings, with the remaining nonpoint source contributions below 7 percent. Compared to average flow conditions (Figure 3-42), Figure 3-44 shows that the relative nonpoint source contributions of bioavailable phosphorus increased significantly for streambank erosion and decreased significantly for all of the remaining source categories, except cropland and pasture runoff.

Figure 3-42

Estimated Bioavailable P Contributions to Minnesota Surface Waters
Rainy River Basin
Average Flow Water Year



Point Source Bioavailable P Contributions



(Based on data from NPDES/SDS Permit Discharge Monitoring Reports, 2001 through mid-2003.)

Nonpoint Source Bioavailable P Contributions

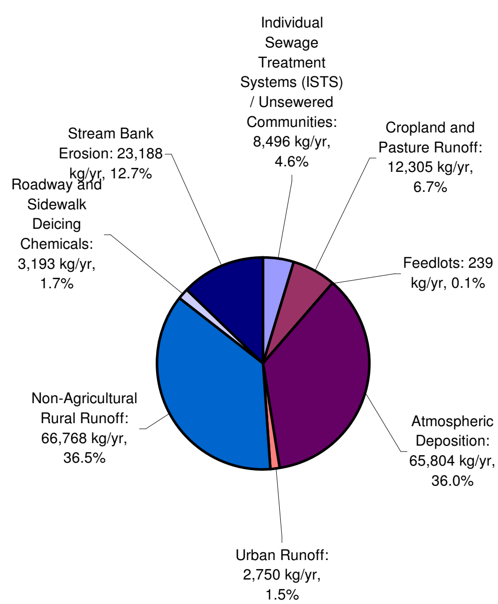
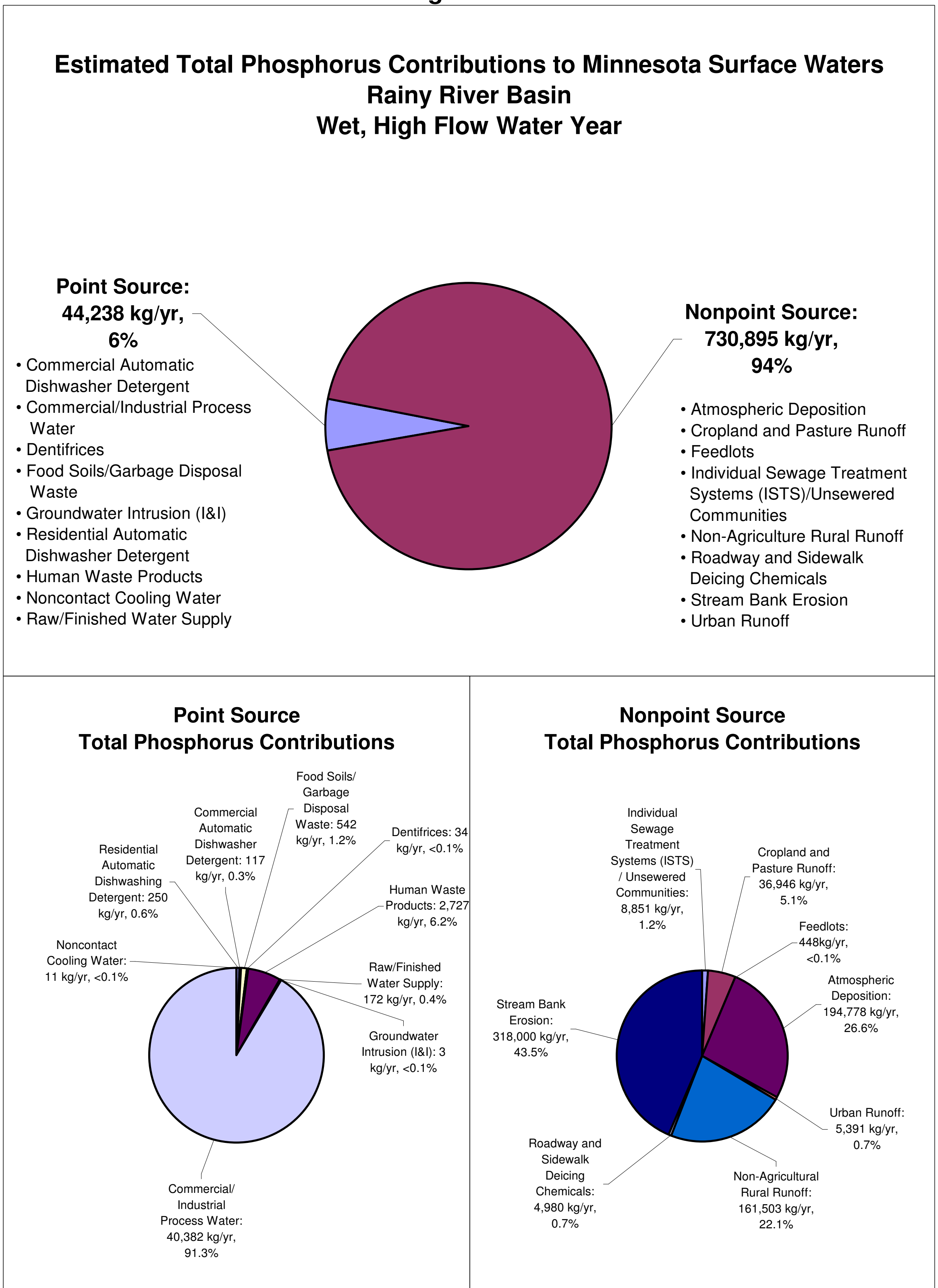
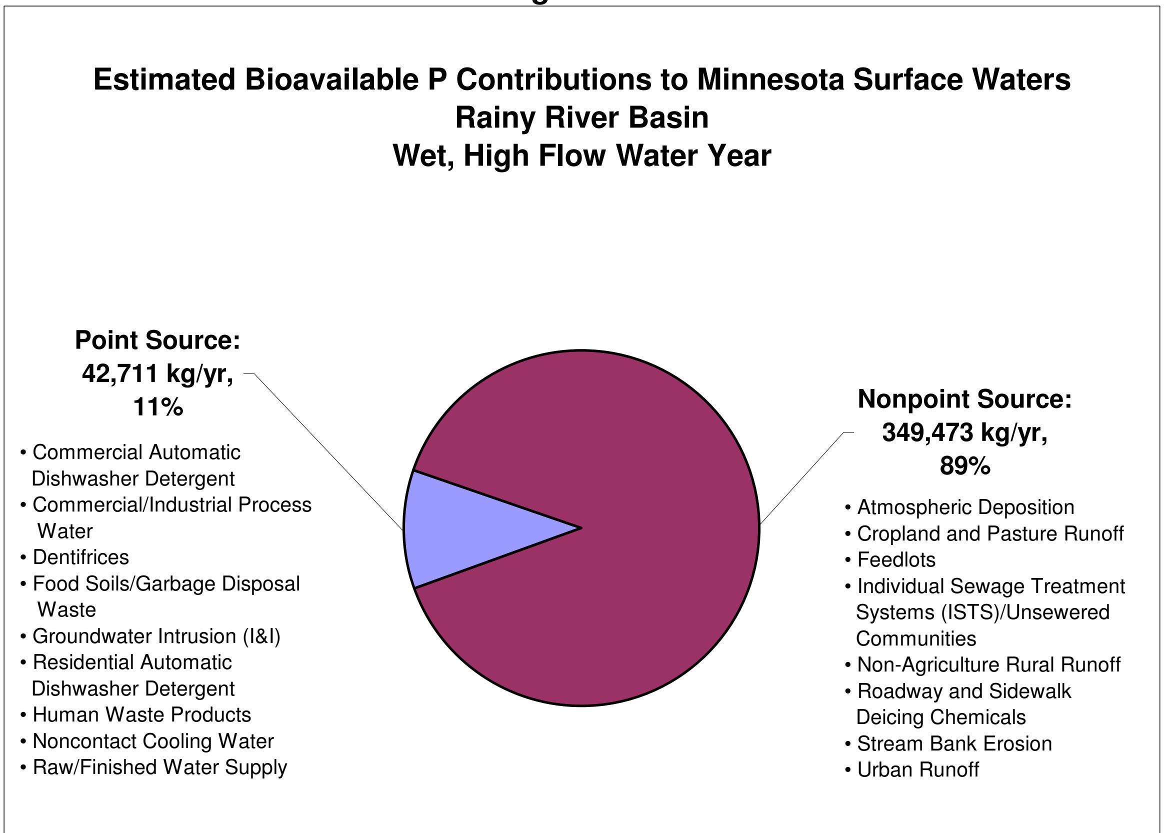


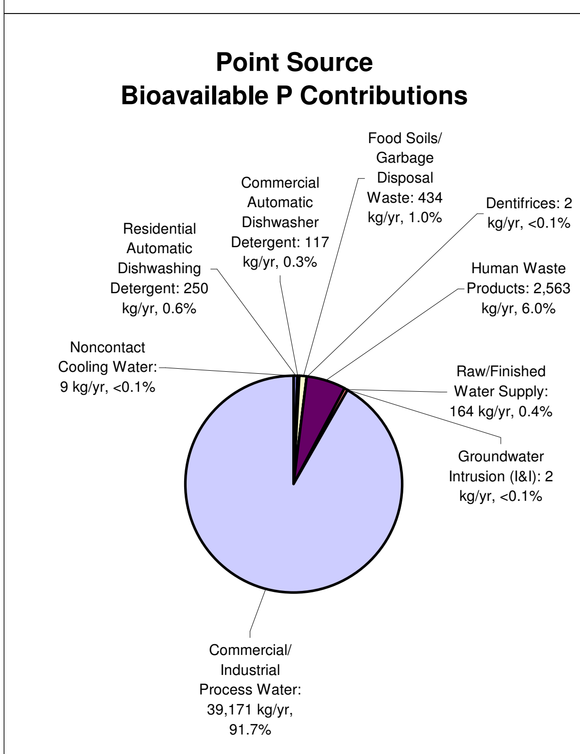
Figure 3-43



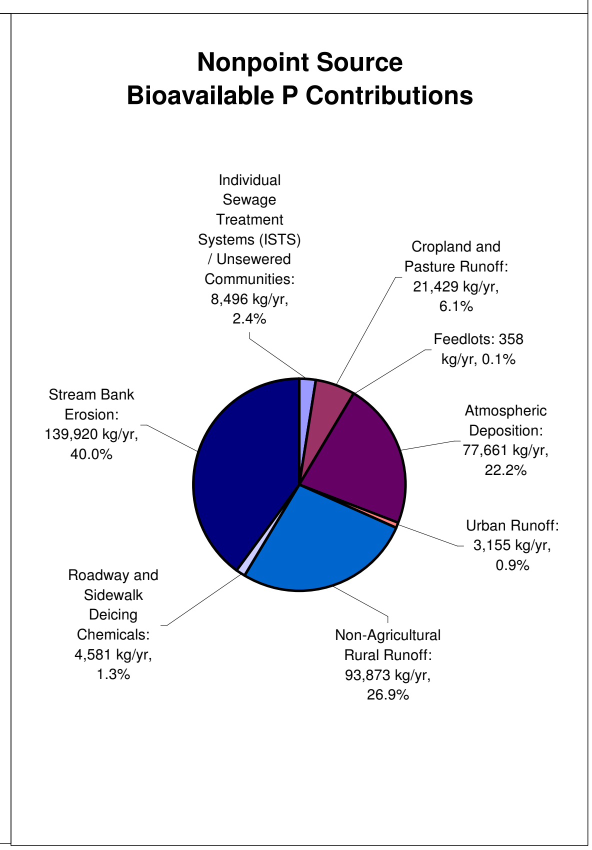
(Based on data from NPDES/SDS Permit Discharge Monitoring Reports, 2001 through mid-2003.)

Figure 3-44





(Based on data from NPDES/SDS Permit Discharge Monitoring Reports, 2001 through mid-2003.)



3.4.7 Lake Superior Basin

3.4.7.1 Dry Conditions (Low Flow)

3.4.7.1.1 Total Phosphorus

Figure 3-45 shows that, under low flow conditions, the total point source phosphorus contribution represents 18 percent, while nonpoint sources of phosphorus represent 82 percent of the loadings to surface waters in the Lake Superior basin. Figure 3-45 also shows that human waste products, commercial/industrial process water, and food soils represent 51, 22, and 15 percent, respectively, of the point source total phosphorus contributions. The remaining point source categories contribute less than 7 percent of the point source loadings. The combination of residential and commercial automatic dishwasher detergent represents approximately 10 percent of the point source total phosphorus contributions. As shown in Figure 3-45, urban runoff, non-agricultural rural runoff and atmospheric deposition represent 14, 30 and 41 percent, respectively, of the nonpoint source total phosphorus loadings, with the remaining nonpoint source contributions below 6 percent.

3.4.7.1.2 Bioavailable Phosphorus

Figure 3-46 shows that, under low flow conditions, the bioavailable point source phosphorus contribution represents 28 percent of the loadings to surface waters. Figure 3-46 also shows that human waste products, commercial/industrial process water, and food soils represent 52, 23, and 13 percent, respectively, of the point source bioavailable phosphorus contributions. The remaining point source categories contribute less than 8 percent of the point source loadings. The combination of residential and commercial automatic dishwasher detergent represents approximately 10 percent of the point source bioavailable phosphorus contributions. As shown in Figure 3-46, urban runoff, non-agricultural rural runoff, and atmospheric deposition represent approximately 16, 34, and 30 percent, respectively, of the nonpoint source bioavailable phosphorus loadings, with the remaining nonpoint source contributions below 10 percent.

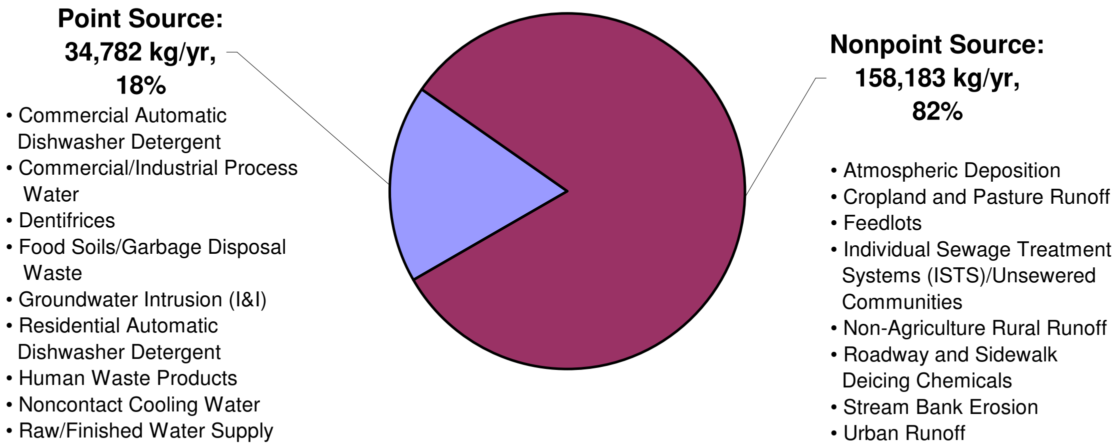
3.4.7.2 Average Condition

3.4.7.2.1 Total Phosphorus

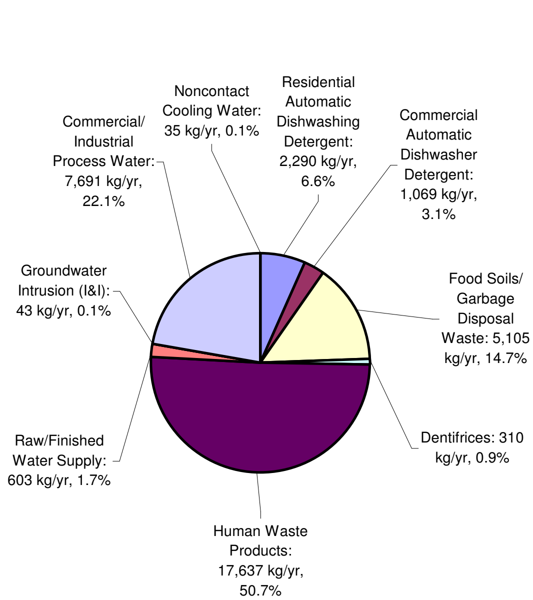
Under average flow conditions, Figure 3-47 shows that the total point source phosphorus contribution drops to 13 percent, compared to 18 percent for the loadings to surface waters under low flow conditions. As presented in Figure 3-47, non-agricultural rural runoff and atmospheric deposition represent 32 and 31 percent, respectively, of the nonpoint source total phosphorus loadings, with the remaining nonpoint source contributions below 16 percent. Compared to low flow conditions (Figure 3-45), Figure 3-47 shows that the relative nonpoint source contributions of total phosphorus increased significantly for streambank erosion and decreased significantly for atmospheric deposition.

Figure 3-45

Estimated Total Phosphorus Contributions to Minnesota Surface Waters
Lake Superior Basin
Dry, Low Flow Water Year



Point Source Total Phosphorus Contributions



(Based on data from NPDES/SDS Permit Discharge Monitoring Reports, 2001 through mid-2003.)

Nonpoint Source Total Phosphorus Contributions

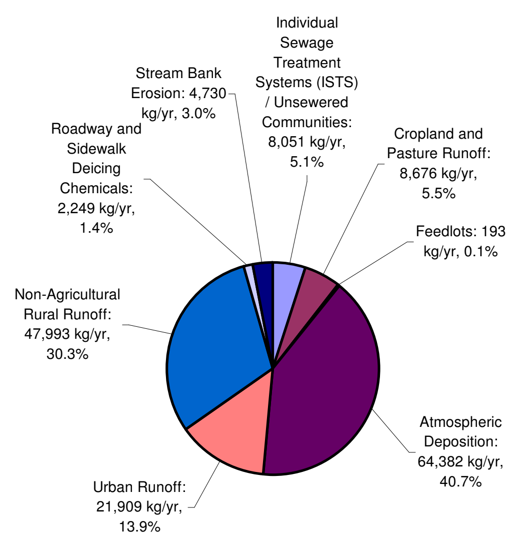
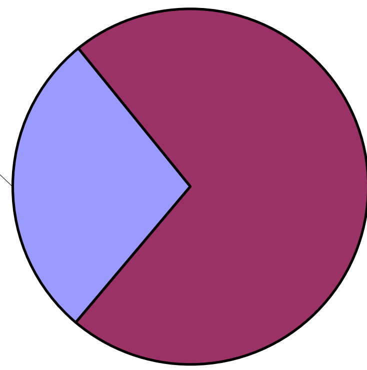


Figure 3-46

Estimated Bioavailable P Contributions to Minnesota Surface Waters
Lake Superior Basin
Dry, Low Flow Water Year

**Point Source:
32,129 kg/yr,
28%**

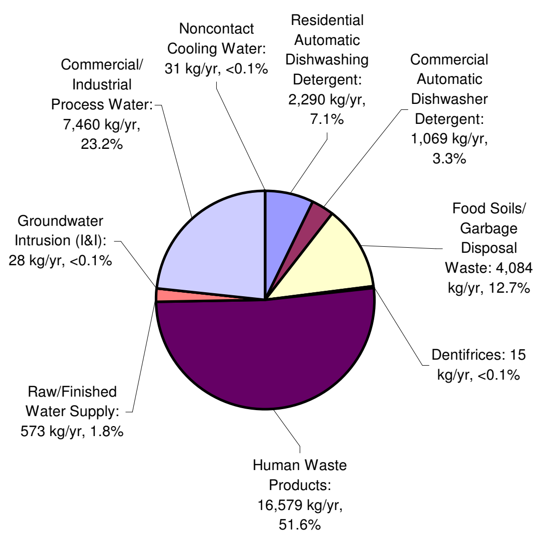
- Commercial Automatic Dishwasher Detergent
- Commercial/Industrial Process Water
- Dentifrices
- Food Soils/Garbage Disposal Waste
- Groundwater Intrusion (I&I)
- Residential Automatic Dishwasher Detergent
- Human Waste Products
- Noncontact Cooling Water
- Raw/Finished Water Supply



**Nonpoint Source:
82,894 kg/yr,
72%**

- Atmospheric Deposition
- Cropland and Pasture Runoff
- Feedlots
- Individual Sewage Treatment Systems (ISTS)/Unsewered Communities
- Non-Agriculture Rural Runoff
- Roadway and Sidewalk Deicing Chemicals
- Stream Bank Erosion
- Urban Runoff

Point Source
Bioavailable P Contributions



(Based on data from NPDES/SDS Permit Discharge Monitoring Reports, 2001 through mid-2003.)

Nonpoint Source
Bioavailable P Contributions

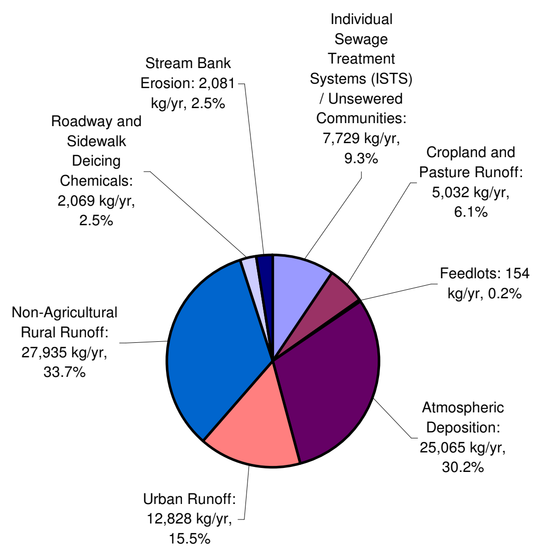
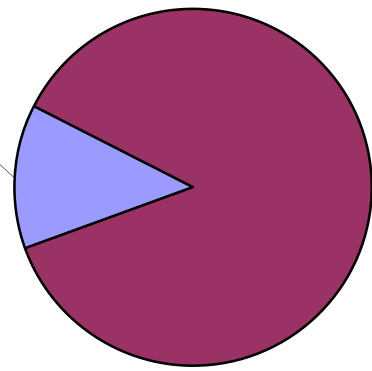


Figure 3-47

Estimated Total Phosphorus Contributions to Minnesota Surface Waters
Lake Superior Basin
Average Flow Water Year

Point Source:
34,782 kg/yr,
13%

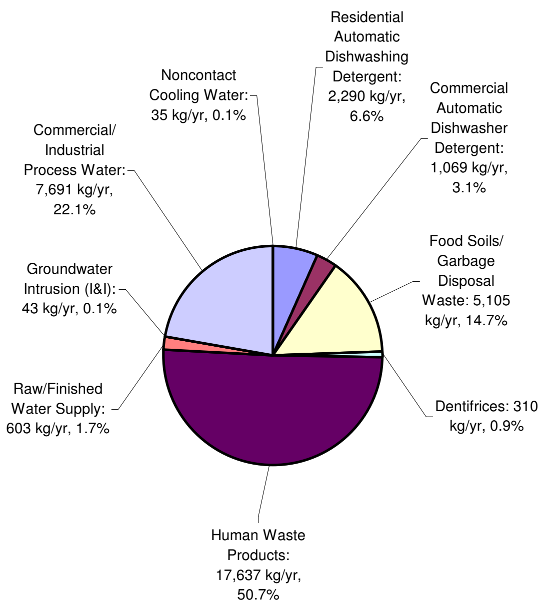
- Commercial Automatic Dishwasher Detergent
- Commercial/Industrial Process Water
- Dentifrices
- Food Soils/Garbage Disposal Waste
- Groundwater Intrusion (I&I)
- Residential Automatic Dishwasher Detergent
- Human Waste Products
- Noncontact Cooling Water
- Raw/Finished Water Supply



Nonpoint Source:
229,660 kg/yr,
87%

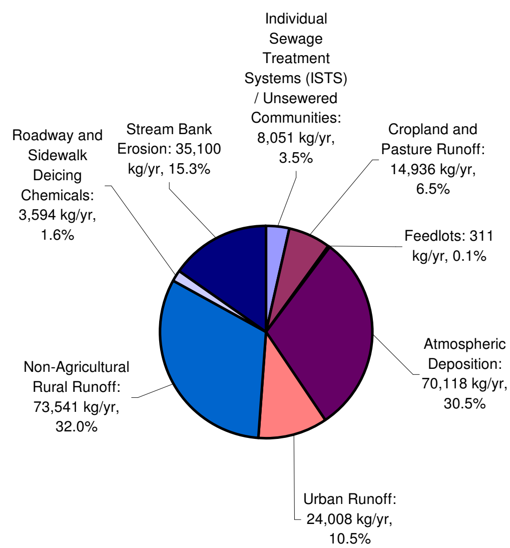
- Atmospheric Deposition
- Cropland and Pasture Runoff
- Feedlots
- Individual Sewage Treatment Systems (ISTS)/Unsewered Communities
- Non-Agriculture Rural Runoff
- Roadway and Sidewalk Deicing Chemicals
- Stream Bank Erosion
- Urban Runoff

Point Source
Total Phosphorus Contributions



(Based on data from NPDES/SDS Permit Discharge Monitoring Reports, 2001 through mid-2003.)

Nonpoint Source
Total Phosphorus Contributions



3.4.7.2.2 Bioavailable Phosphorus

Under average flow conditions, Figure 3-48 shows that the bioavailable point source phosphorus contribution drops to 21 percent, compared to 28 percent for the loadings to surface waters under low flow conditions. As presented in Figure 3-48, non-agricultural rural runoff and atmospheric deposition represent 36 and 23 percent, respectively, of the nonpoint source bioavailable phosphorus loadings, with the remaining nonpoint source contributions below 13 percent. Compared to low flow conditions (Figure 3-46), Figure 3-48 shows that the relative nonpoint source contributions of bioavailable phosphorus increased significantly for streambank erosion and decreased significantly for atmospheric deposition and ISTS/unsewered communities.

3.4.7.3 Wet Condition (High Flow)

3.4.7.3.1 Total Phosphorus

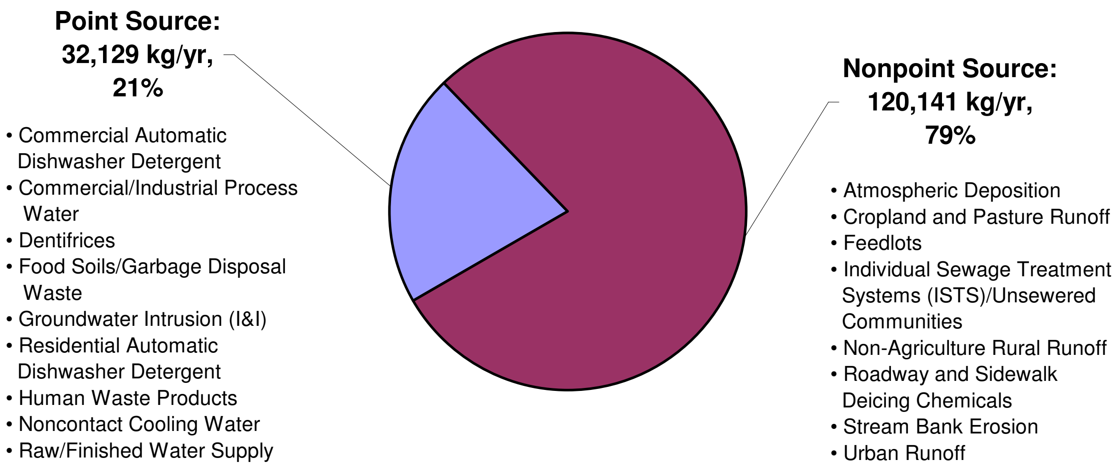
Under high flow conditions, Figure 3-49 shows that the total point source phosphorus contribution drops to 7 percent, compared to 13 and 18 percent for the loadings to surface waters under average and low flow conditions, respectively. As presented in Figure 3-49, streambank erosion, atmospheric deposition and non-agricultural runoff represent 46, 18 and 22 percent, respectively, of the nonpoint source total phosphorus loadings, with the remaining nonpoint source contributions at or below 6 percent. Compared to average flow conditions (Figure 3-47), Figure 3-49 shows that the relative statewide nonpoint source contributions of total phosphorus increased significantly for streambank erosion and decreased significantly for all of the remaining source categories, except cropland and pasture runoff.

3.4.7.3.2 Bioavailable Phosphorus

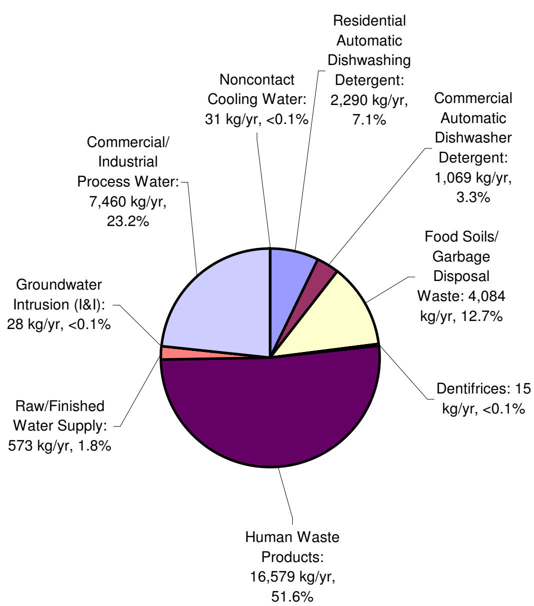
Under high flow conditions, Figure 3-50 shows that the bioavailable point source phosphorus contribution drops to 13 percent, compared to 21 and 28 percent for the loadings to surface waters under average and low flow conditions, respectively. As presented in Figure 3-50, non-agricultural rural runoff, atmospheric deposition, and streambank erosion represent 25, 15, and 41 percent, respectively, of the nonpoint source bioavailable phosphorus loadings, with the remaining nonpoint source contributions at or below 7 percent. Compared to average flow conditions (Figure 3-48), Figure 3-50 shows that the relative nonpoint source contributions of bioavailable phosphorus increased significantly for streambank erosion and decreased significantly for all of the remaining source categories, except cropland and pasture runoff.

Figure 3-48

Estimated Bioavailable P Contributions to Minnesota Surface Waters
Lake Superior Basin
Average Flow Water Year



Point Source
Bioavailable P Contributions



(Based on data from NPDES/SDS Permit Discharge Monitoring Reports, 2001 through mid-2003.)

Nonpoint Source
Bioavailable P Contributions

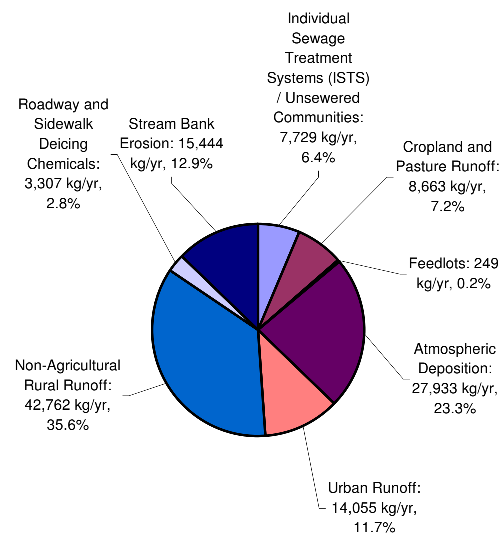
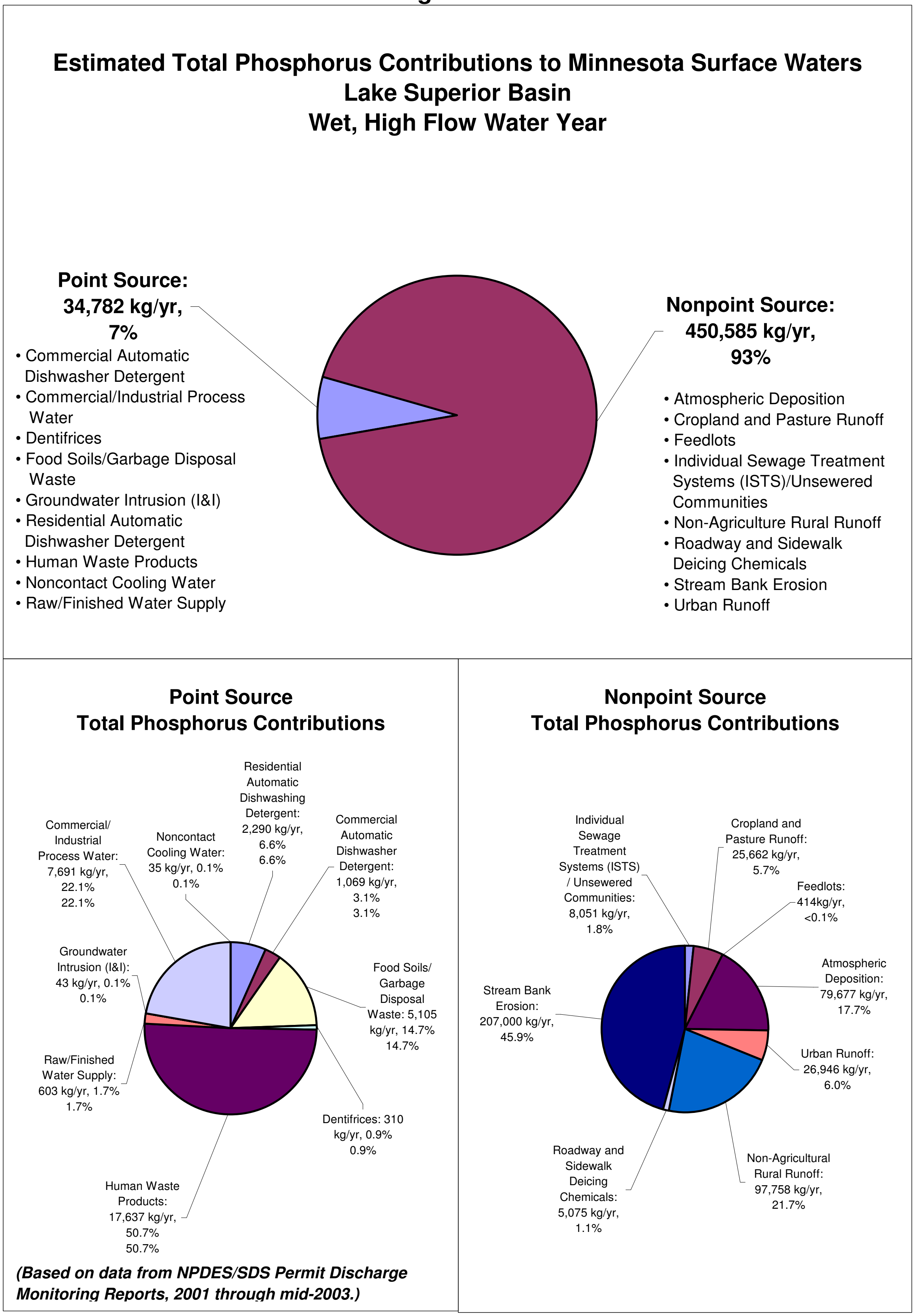


Figure 3-49



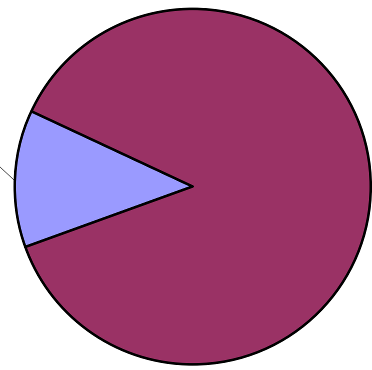
Estimated Total Phosphorus Contributions to Minnesota Surface Waters
Lake Superior Basin
Wet, High Flow Water Year
Point Source:
34,782 kg/yr,
7%
• Commercial Automatic Dishwasher Detergent
• Commercial/Industrial Process Water
• Dentifrices
• Food Soils/Garbage Disposal Waste
• Groundwater Intrusion (I&I)
• Residential Automatic Dishwasher Detergent
• Human Waste Products
• Noncontact Cooling Water
• Raw/Finished Water Supply
Nonpoint Source:
450,585 kg/yr,
93%
• Atmospheric Deposition
• Cropland and Pasture Runoff
• Feedlots
• Individual Sewage Treatment Systems (ISTS)/Unsewered Communities
• Non-Agriculture Rural Runoff
• Roadway and Sidewalk Deicing Chemicals
• Stream Bank Erosion
• Urban Runoff
Point Source
Total Phosphorus Contributions
Residential Automatic Dishwashing Detergent: 2,290 kg/yr, 6.6% 6.6%
Commercial/ Industrial Process Water: 7,691 kg/yr, 22.1% 22.1%
Noncontact Cooling Water: 35 kg/yr, 0.1% 0.1%
Commercial Automatic Dishwasher Detergent: 1,069 kg/yr, 3.1% 3.1%
Groundwater Intrusion (I&I): 43 kg/yr, 0.1% 0.1%
Food Soils/ Garbage Disposal Waste: 5,105 kg/yr, 14.7% 14.7%
Raw/Finished Water Supply: 603 kg/yr, 1.7% 1.7%
Dentifrices: 310 kg/yr, 0.9% 0.9%
Human Waste Products: 17,637 kg/yr, 50.7% 50.7%
(Based on data from NPDES/SDS Permit Discharge Monitoring Reports, 2001 through mid-2003.)
Nonpoint Source
Total Phosphorus Contributions
Individual Sewage Treatment Systems (ISTS) / Unsewered Communities: 8,051 kg/yr, 1.8%
Cropland and Pasture Runoff: 25,662 kg/yr, 5.7%
Feedlots: 414kg/yr, <0.1%
Atmospheric Deposition: 79,677 kg/yr, 17.7%
Stream Bank Erosion: 207,000 kg/yr, 45.9%
Urban Runoff: 26,946 kg/yr, 6.0%
Roadway and Sidewalk Deicing Chemicals: 5,075 kg/yr, 1.1%
Non-Agricultural Rural Runoff: 97,758 kg/yr, 21.7%

Figure 3-50

Estimated Bioavailable P Contributions to Minnesota Surface Waters
Lake Superior Basin
Wet, High Flow Water Year

Point Source:
32,129 kg/yr,
13%

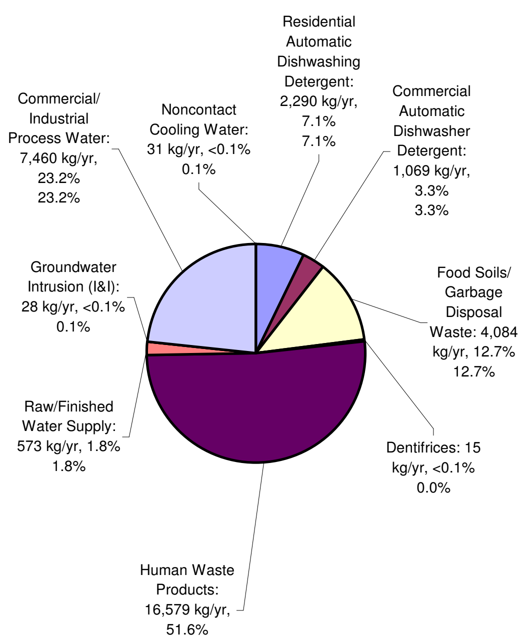
- Commercial Automatic Dishwasher Detergent
- Commercial/Industrial Process Water
- Dentifrices
- Food Soils/Garbage Disposal Waste
- Groundwater Intrusion (I&I)
- Residential Automatic Dishwasher Detergent
- Human Waste Products
- Noncontact Cooling Water
- Raw/Finished Water Supply



Nonpoint Source:
223,993 kg/yr,
87%

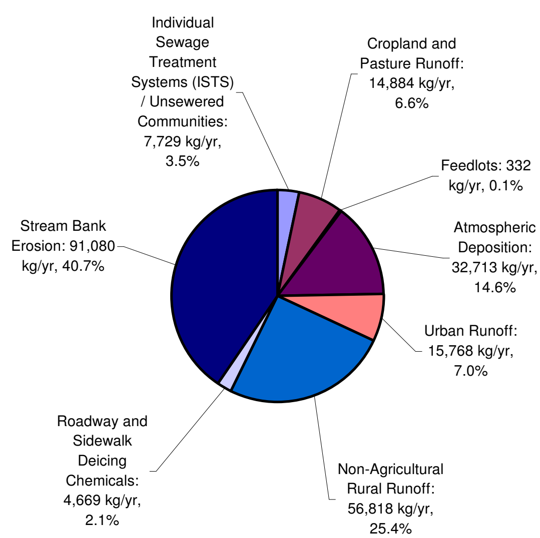
- Atmospheric Deposition
- Cropland and Pasture Runoff
- Feedlots
- Individual Sewage Treatment Systems (ISTS)/Unsewered Communities
- Non-Agriculture Rural Runoff
- Roadway and Sidewalk Deicing Chemicals
- Stream Bank Erosion
- Urban Runoff

Point Source Bioavailable P Contributions



(Based on data from NPDES/SDS Permit Discharge Monitoring Reports, 2001 through mid-2003.)

Nonpoint Source Bioavailable P Contributions



3.4.8 Missouri River Basin

3.4.8.1 Dry Conditions (Low Flow)

3.4.8.1.1 Total Phosphorus

Figure 3-51 shows that, under low flow conditions, the total point source phosphorus contribution represents 21 percent, while nonpoint sources of phosphorus represent 79 percent of the loadings to surface waters in the Missouri River basin. Figure 3-51 also shows that human waste products, commercial/industrial process water, and food soils represent 43, 31 and 13 percent, respectively, of the point source total phosphorus contributions. The remaining point source categories contribute less than 6 percent of the point source loadings. The combination of residential and commercial automatic dishwasher detergent represents approximately 9 percent of the point source total phosphorus contributions. As shown in Figure 3-51, cropland and pasture runoff and ISTS/unsewered communities represent 73 and 8 percent, respectively, of the nonpoint source total phosphorus loadings, with the remaining nonpoint source contributions at or below 5 percent.

3.4.8.1.2 Bioavailable Phosphorus

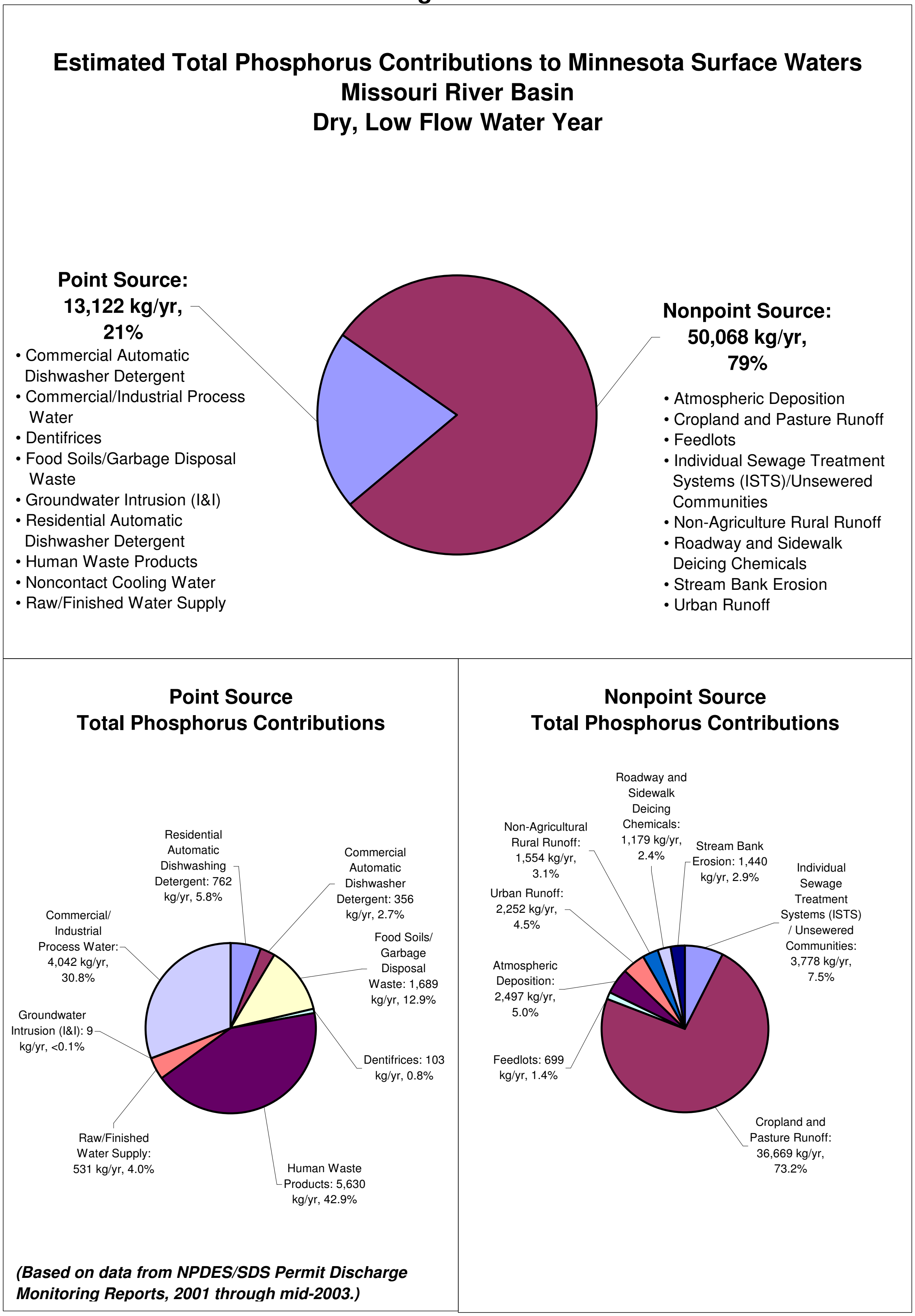
Figure 3-52 shows that, under low flow conditions, the bioavailable point source phosphorus contribution represents 29 percent of the loadings to surface waters. Figure 3-52 also shows that human waste products, commercial/industrial process water, and food soils represent 43, 32 and 11 percent, respectively, of the point source bioavailable phosphorus contributions. The remaining point source categories contribute less than 7 percent of the point source loadings. The combination of residential and commercial automatic dishwasher detergent represents approximately 9 percent of the point source bioavailable phosphorus contributions. As shown in Figure 3-52, cropland and pasture runoff and ISTS/unsewered communities represent approximately 70 and 12 percent, respectively, of the nonpoint source bioavailable phosphorus loadings, with the remaining nonpoint source contributions below 5 percent.

3.4.8.2 Average Condition

3.4.8.2.1 Total Phosphorus

Under average flow conditions, Figure 3-53 shows that the total point source phosphorus contribution drops to 12 percent, compared to 21 percent for the loadings to surface waters under low flow conditions. As presented in Figure 3-53, cropland and pasture runoff and streambank erosion represent 64 and 17 percent, respectively, of the nonpoint source total phosphorus loadings, with the remaining nonpoint source contributions below 5 percent. Compared to low flow conditions (Figure 3-51), Figure 3-53 shows that the relative nonpoint source contributions of total phosphorus increased significantly for streambank erosion, decreased slightly for cropland and pasture runoff, urban runoff and non-agricultural runoff, and decreased significantly for atmospheric deposition.

Figure 3-51



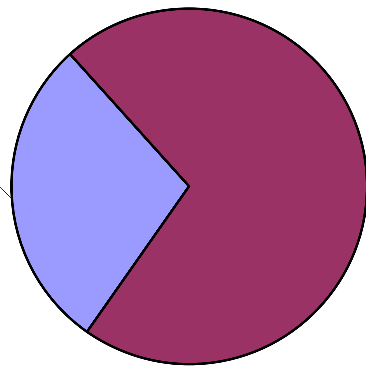
Estimated Total Phosphorus Contributions to Minnesota Surface Waters
Missouri River Basin
Dry, Low Flow Water Year
Point Source:
13,122 kg/yr,
21%
• Commercial Automatic Dishwasher Detergent
• Commercial/Industrial Process Water
• Dentifrices
• Food Soils/Garbage Disposal Waste
• Groundwater Intrusion (I&I)
• Residential Automatic Dishwasher Detergent
• Human Waste Products
• Noncontact Cooling Water
• Raw/Finished Water Supply
Nonpoint Source:
50,068 kg/yr,
79%
• Atmospheric Deposition
• Cropland and Pasture Runoff
• Feedlots
• Individual Sewage Treatment Systems (ISTS)/Unsewered Communities
• Non-Agriculture Rural Runoff
• Roadway and Sidewalk Deicing Chemicals
• Stream Bank Erosion
• Urban Runoff
Point Source
Total Phosphorus Contributions
Residential Automatic Dishwashing Detergent: 762 kg/yr, 5.8%
Commercial Automatic Dishwasher Detergent: 356 kg/yr, 2.7%
Commercial/ Industrial Process Water: 4,042 kg/yr, 30.8%
Food Soils/ Garbage Disposal Waste: 1,689 kg/yr, 12.9%
Groundwater Intrusion (I&I): 9 kg/yr, <0.1%
Dentifrices: 103 kg/yr, 0.8%
Raw/Finished Water Supply: 531 kg/yr, 4.0%
Human Waste Products: 5,630 kg/yr, 42.9%
(Based on data from NPDES/SDS Permit Discharge Monitoring Reports, 2001 through mid-2003.)
Nonpoint Source
Total Phosphorus Contributions
Roadway and Sidewalk Deicing Chemicals: 1,179 kg/yr, 2.4%
Non-Agricultural Rural Runoff: 1,554 kg/yr, 3.1%
Stream Bank Erosion: 1,440 kg/yr, 2.9%
Individual Sewage Treatment Systems (ISTS) / Unsewered Communities: 3,778 kg/yr, 7.5%
Urban Runoff: 2,252 kg/yr, 4.5%
Atmospheric Deposition: 2,497 kg/yr, 5.0%
Feedlots: 699 kg/yr, 1.4%
Cropland and Pasture Runoff: 36,669 kg/yr, 73.2%

Figure 3-52

Estimated Bioavailable P Contributions to Minnesota Surface Waters
Missouri River Basin
Dry, Low Flow Water Year

Point Source:
12,198 kg/yr,
29%

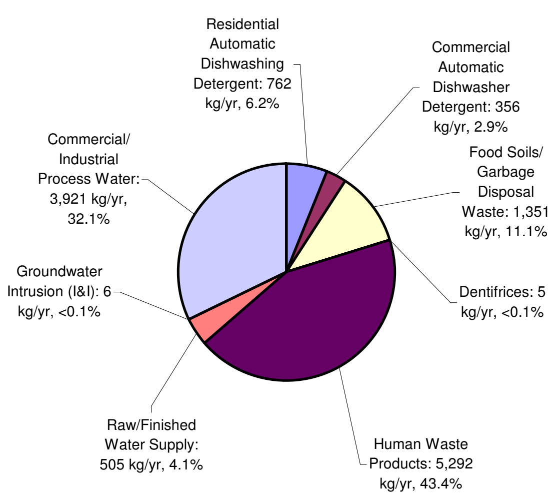
- Commercial Automatic Dishwasher Detergent
- Commercial/Industrial Process Water
- Dentifrices
- Food Soils/Garbage Disposal Waste
- Groundwater Intrusion (I&I)
- Residential Automatic Dishwasher Detergent
- Human Waste Products
- Noncontact Cooling Water
- Raw/Finished Water Supply



Nonpoint Source:
30,424 kg/yr,
71%

- Atmospheric Deposition
- Cropland and Pasture Runoff
- Feedlots
- Individual Sewage Treatment Systems (ISTS)/Unsewered Communities
- Non-Agriculture Rural Runoff
- Roadway and Sidewalk Deicing Chemicals
- Stream Bank Erosion
- Urban Runoff

Point Source Bioavailable P Contributions



(Based on data from NPDES/SDS Permit Discharge Monitoring Reports, 2001 through mid-2003.)

Nonpoint Source Bioavailable P Contributions

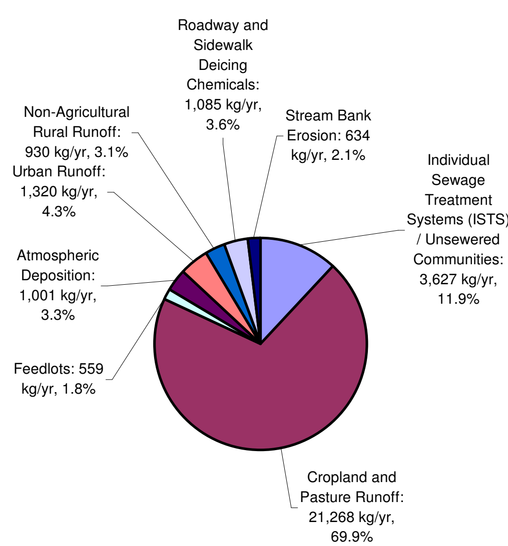
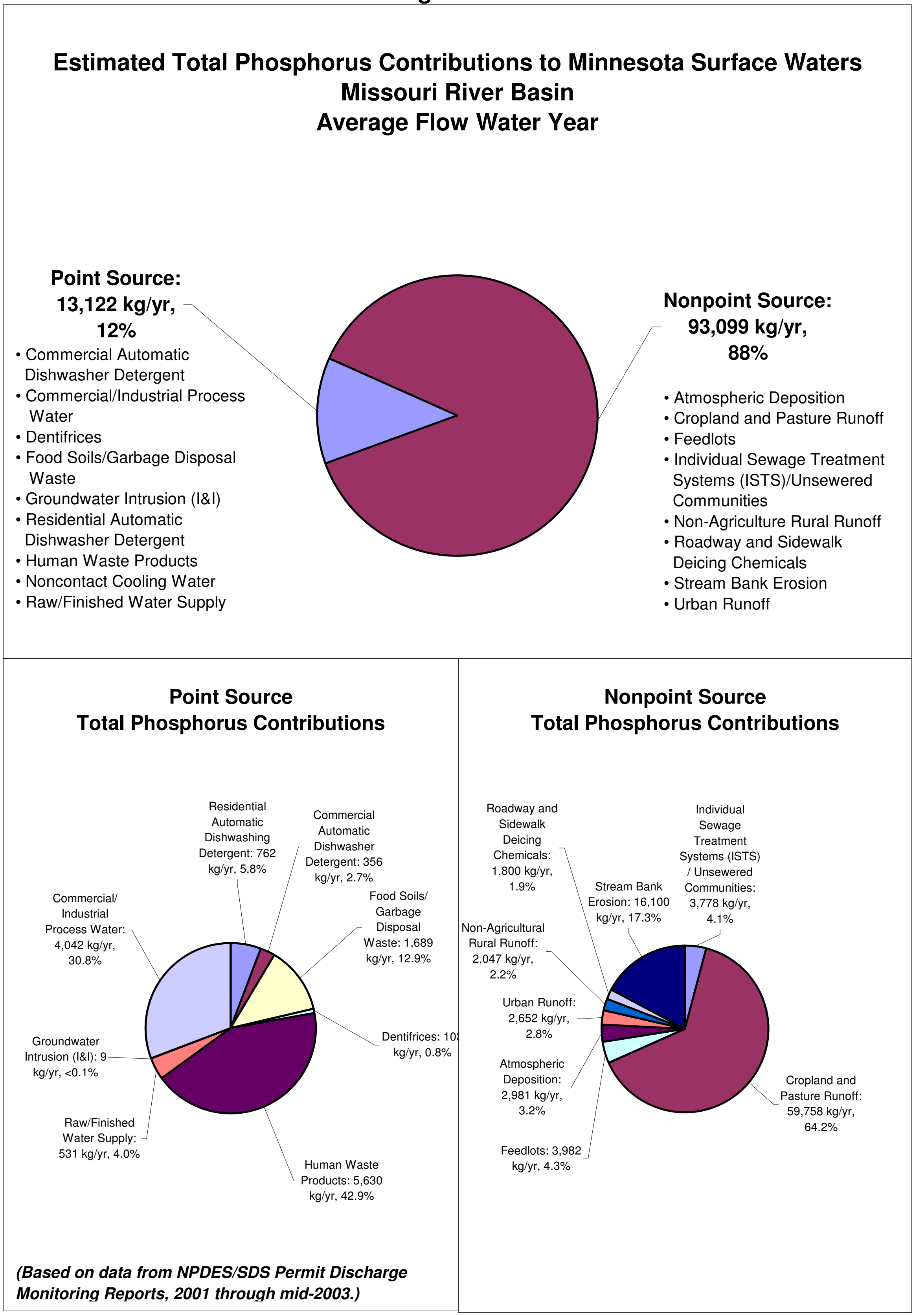


Figure 3-53


Estimated Total Phosphorus Contributions to Minnesota Surface Waters
Missouri River Basin
Average Flow Water Year
Point Source:
13,122 kg/yr,
12%
• Commercial Automatic Dishwasher Detergent
• Commercial/Industrial Process Water
• Dentifrices
• Food Soils/Garbage Disposal Waste
• Groundwater Intrusion (I&I)
• Residential Automatic Dishwasher Detergent
• Human Waste Products
• Noncontact Cooling Water
• Raw/Finished Water Supply
Nonpoint Source:
93,099 kg/yr,
88%
• Atmospheric Deposition
• Cropland and Pasture Runoff
• Feedlots
• Individual Sewage Treatment Systems (ISTS)/Unsewered Communities
• Non-Agriculture Rural Runoff
• Roadway and Sidewalk Deicing Chemicals
• Stream Bank Erosion
• Urban Runoff
Point Source
Total Phosphorus Contributions
Residential Automatic Dishwashing Detergent: 762 kg/yr, 5.8%
Commercial Automatic Dishwasher Detergent: 356 kg/yr, 2.7%
Food Soils/ Garbage Disposal Waste: 1,689 kg/yr, 12.9%
Commercial/ Industrial Process Water: 4,042 kg/yr, 30.8%
Dentifrices: 10
kg/yr, 0.8%
Groundwater Intrusion (I&I): 9 kg/yr, <0.1%
Raw/Finished Water Supply: 531 kg/yr, 4.0%
Human Waste Products: 5,630 kg/yr, 42.9%
(Based on data from NPDES/SDS Permit Discharge Monitoring Reports, 2001 through mid-2003.)
Nonpoint Source
Total Phosphorus Contributions
Roadway and Sidewalk Deicing Chemicals: 1,800 kg/yr, 1.9%
Individual Sewage Treatment Systems (ISTS) / Unsewered Communities: 3,778 kg/yr, 4.1%
Stream Bank Erosion: 16,100 kg/yr, 17.3%
Non-Agricultural Rural Runoff: 2,047 kg/yr, 2.2%
Urban Runoff: 2,652 kg/yr, 2.8%
Atmospheric Deposition: 2,981 kg/yr, 3.2%
Cropland and Pasture Runoff: 59,758 kg/yr, 64.2%
Feedlots: 3,982 kg/yr, 4.3%

3.4.8.2.2 Bioavailable Phosphorus

Under average flow conditions, Figure 3-54 shows that the bioavailable point source phosphorus contribution drops to 18 percent, compared to 29 percent for the loadings to surface waters under low flow conditions. As presented in Figure 3-54, cropland and pasture runoff and streambank erosion represent 64 and 13 percent, respectively, of the nonpoint source bioavailable phosphorus loadings, with the remaining nonpoint source contributions below 7 percent. Compared to low flow conditions (Figure 3-52), Figure 3-54 shows that the relative nonpoint source contributions of bioavailable phosphorus increased significantly for streambank erosion, decreased slightly for cropland and pasture runoff, urban runoff, non-agricultural runoff and atmospheric deposition.

3.4.8.3 Wet Condition (High Flow)

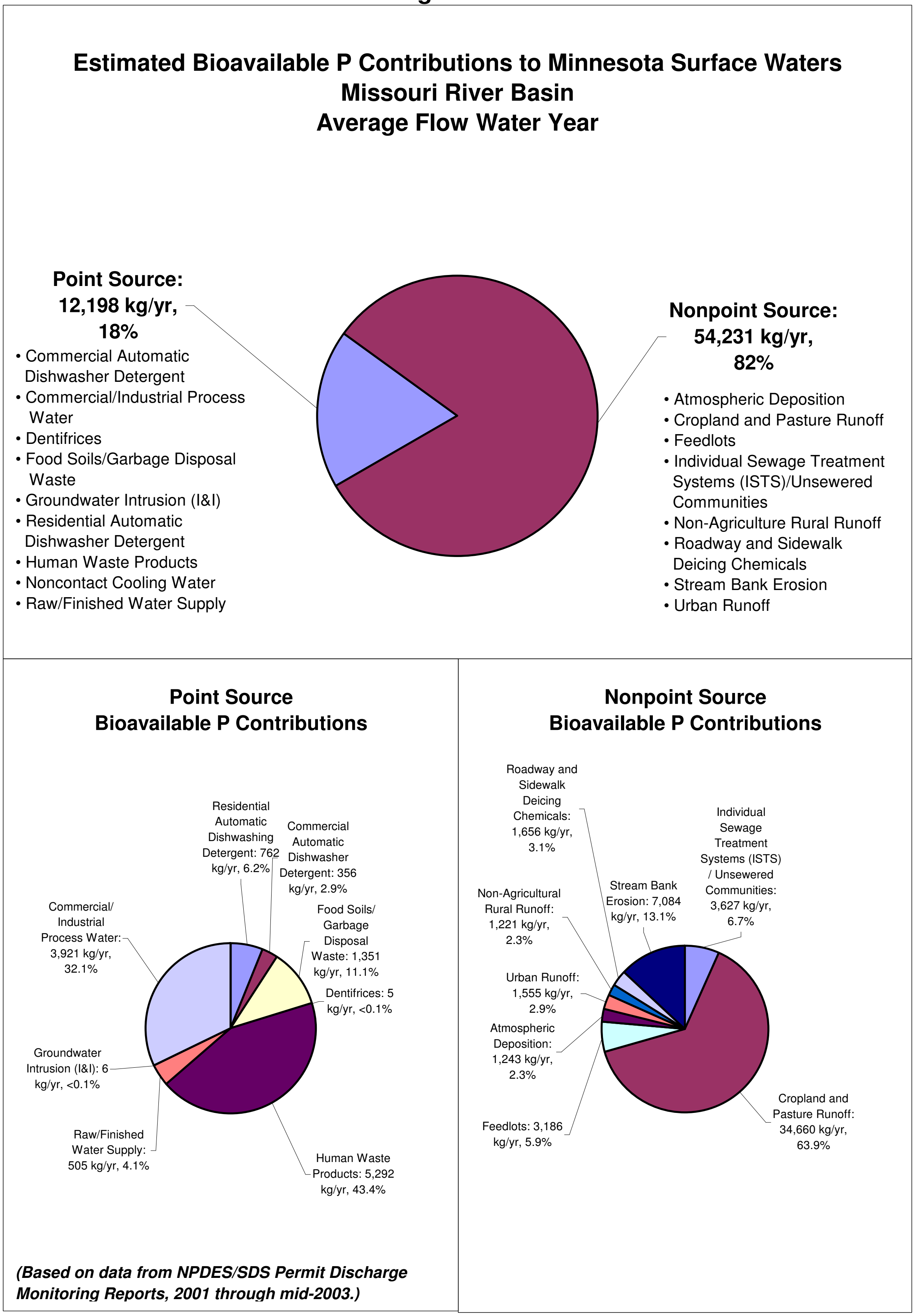
3.4.8.3.1 Total Phosphorus

Under high flow conditions, Figure 3-55 shows that the total point source phosphorus contribution drops to 6 percent, compared to 12 and 21 percent for the loadings to surface waters under average and low flow conditions, respectively. As presented in Figure 3-55, streambank erosion and cropland and pasture runoff represent 34 and 53 percent, respectively, of the nonpoint source total phosphorus loadings, with the remaining nonpoint source contributions below 5 percent. Compared to average flow conditions (Figure 3-53), Figure 3-55 shows that the relative statewide nonpoint source contributions of total phosphorus increased significantly for streambank erosion and decreased significantly for all of the remaining source categories, except feedlots and cropland and pasture runoff.

3.4.8.3.2 Bioavailable Phosphorus

Under high flow conditions, Figure 3-56 shows that the bioavailable point source phosphorus contribution drops to 10 percent, compared to 18 and 29 percent for the loadings to surface waters under average and low flow conditions, respectively. As presented in Figure 3-56, cropland and pasture runoff and streambank erosion represent 56 and 28 percent, respectively, of the nonpoint source bioavailable phosphorus loadings, with the remaining nonpoint source contributions below 7 percent. Compared to average flow conditions (Figure 3-54), Figure 3-56 shows that the relative nonpoint source contributions of bioavailable phosphorus increased significantly for streambank erosion and decreased significantly for all of the remaining source categories, except feedlots and cropland and pasture runoff.

Figure 3-54



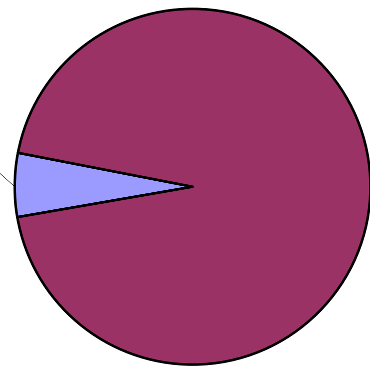
Estimated Bioavailable P Contributions to Minnesota Surface Waters
Missouri River Basin
Average Flow Water Year
Point Source:
12,198 kg/yr,
18%
• Commercial Automatic Dishwasher Detergent
• Commercial/Industrial Process Water
• Dentifrices
• Food Soils/Garbage Disposal Waste
• Groundwater Intrusion (I&I)
• Residential Automatic Dishwasher Detergent
• Human Waste Products
• Noncontact Cooling Water
• Raw/Finished Water Supply
Nonpoint Source:
54,231 kg/yr,
82%
• Atmospheric Deposition
• Cropland and Pasture Runoff
• Feedlots
• Individual Sewage Treatment Systems (ISTS)/Unsewered Communities
• Non-Agriculture Rural Runoff
• Roadway and Sidewalk Deicing Chemicals
• Stream Bank Erosion
• Urban Runoff
Point Source
Bioavailable P Contributions
Residential Automatic Dishwashing Detergent: 762 kg/yr, 6.2%
Commercial Automatic Dishwasher Detergent: 356 kg/yr, 2.9%
Food Soils/ Garbage Disposal Waste: 1,351 kg/yr, 11.1%
Dentifrices: 5 kg/yr, <0.1%
Commercial/ Industrial Process Water: 3,921 kg/yr, 32.1%
Groundwater Intrusion (I&I): 6 kg/yr, <0.1%
Raw/Finished Water Supply: 505 kg/yr, 4.1%
Human Waste Products: 5,292 kg/yr, 43.4%
(Based on data from NPDES/SDS Permit Discharge Monitoring Reports, 2001 through mid-2003.)
Nonpoint Source
Bioavailable P Contributions
Roadway and Sidewalk Deicing Chemicals: 1,656 kg/yr, 3.1%
Individual Sewage Treatment Systems (ISTS) / Unsewered Communities: 3,627 kg/yr, 6.7%
Stream Bank Erosion: 7,084 kg/yr, 13.1%
Non-Agricultural Rural Runoff: 1,221 kg/yr, 2.3%
Urban Runoff: 1,555 kg/yr, 2.9%
Atmospheric Deposition: 1,243 kg/yr, 2.3%
Feedlots: 3,186 kg/yr, 5.9%
Cropland and Pasture Runoff: 34,660 kg/yr, 63.9%

Figure 3-55

Estimated Total Phosphorus Contributions to Minnesota Surface Waters
Missouri River Basin
Wet, High Flow Water Year

Point Source:
13,122 kg/yr,
6%

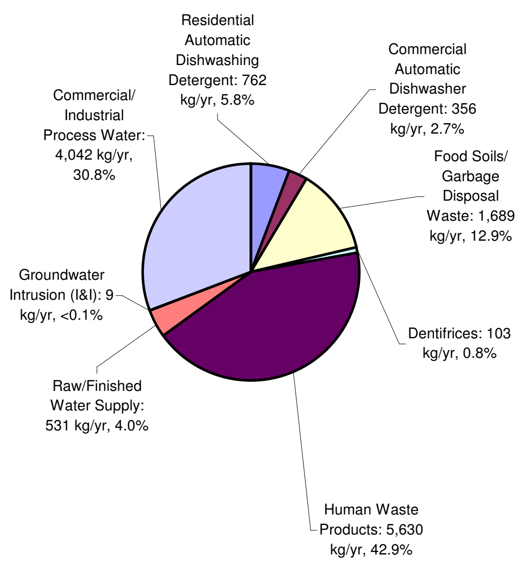
- Commercial Automatic Dishwasher Detergent
- Commercial/Industrial Process Water
- Dentifrices
- Food Soils/Garbage Disposal Waste
- Groundwater Intrusion (I&I)
- Residential Automatic Dishwasher Detergent
- Human Waste Products
- Noncontact Cooling Water
- Raw/Finished Water Supply



Nonpoint Source:
207,901 kg/yr,
94%

- Atmospheric Deposition
- Cropland and Pasture Runoff
- Feedlots
- Individual Sewage Treatment Systems (ISTS)/Unsewered Communities
- Non-Agriculture Rural Runoff
- Roadway and Sidewalk Deicing Chemicals
- Stream Bank Erosion
- Urban Runoff

Point Source
Total Phosphorus Contributions



(Based on data from NPDES/SDS Permit Discharge Monitoring Reports, 2001 through mid-2003.)

Nonpoint Source
Total Phosphorus Contributions

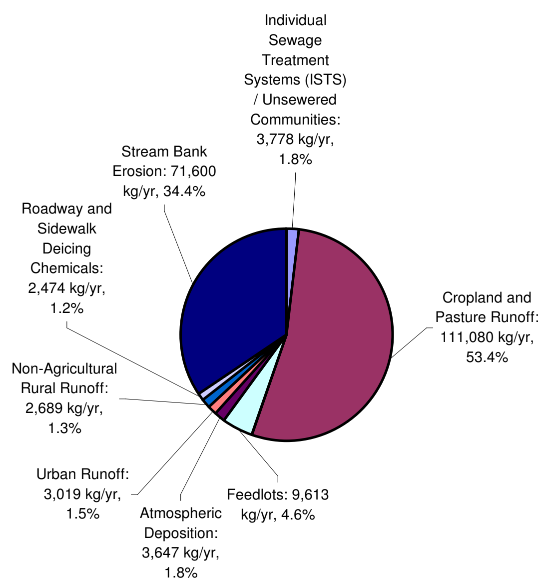
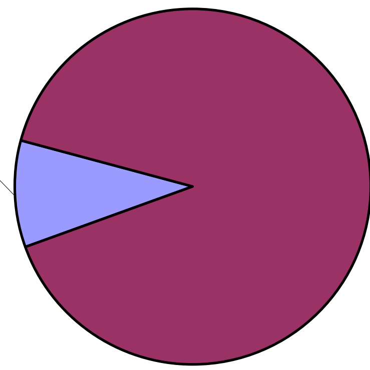


Figure 3-56

Estimated Bioavailable P Contributions to Minnesota Surface Waters
Missouri River Basin
Wet, High Flow Water Year

**Point Source:
12,198 kg/yr,
10%**

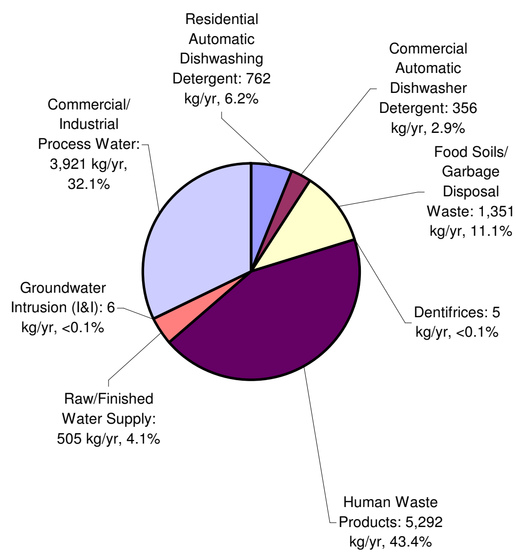
- Commercial Automatic Dishwasher Detergent
- Commercial/Industrial Process Water
- Dentifrices
- Food Soils/Garbage Disposal Waste
- Groundwater Intrusion (I&I)
- Residential Automatic Dishwasher Detergent
- Human Waste Products
- Noncontact Cooling Water
- Raw/Finished Water Supply



**Nonpoint Source:
114,468 kg/yr,
90%**

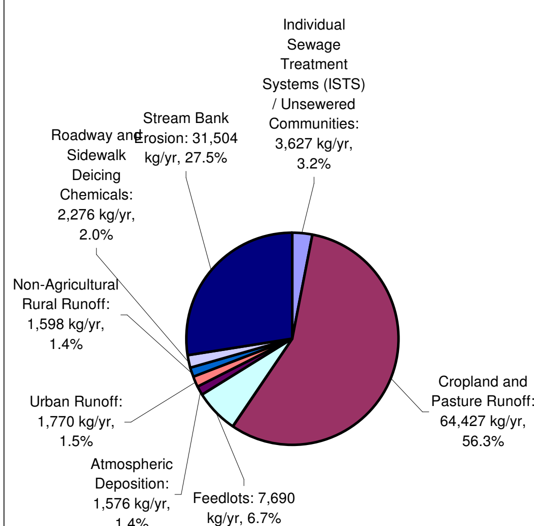
- Atmospheric Deposition
- Cropland and Pasture Runoff
- Feedlots
- Individual Sewage Treatment Systems (ISTS)/Unsewered Communities
- Non-Agriculture Rural Runoff
- Roadway and Sidewalk Deicing Chemicals
- Stream Bank Erosion
- Urban Runoff

Point Source Bioavailable P Contributions



(Based on data from NPDES/SDS Permit Discharge Monitoring Reports, 2001 through mid-2003.)

Nonpoint Source Bioavailable P Contributions



3.4.9 Minnesota River Basin

3.4.9.1 Dry Conditions (Low Flow)

3.4.9.1.1 Total Phosphorus

Figure 3-57 shows that, under low flow conditions, the total point source phosphorus contribution represents 41 percent, while nonpoint sources of phosphorus represent 59 percent of the loadings to surface waters in the Minnesota River basin. Figure 3-57 also shows that human waste products, commercial/industrial process water, and food soils represent 23, 58 and 9 percent, respectively, of the point source total phosphorus contributions. The remaining point source categories contribute less than 5 percent of the point source loadings. The combination of residential and commercial automatic dishwasher detergent represents approximately 6 percent of the point source total phosphorus contributions. As shown in Figure 3-57, cropland and pasture runoff, atmospheric deposition, and agricultural tile drainage represent 50, 12 and 12 percent, respectively, of the nonpoint source total phosphorus loadings, with the remaining nonpoint source contributions below 11 percent.

3.4.9.1.2 Bioavailable Phosphorus

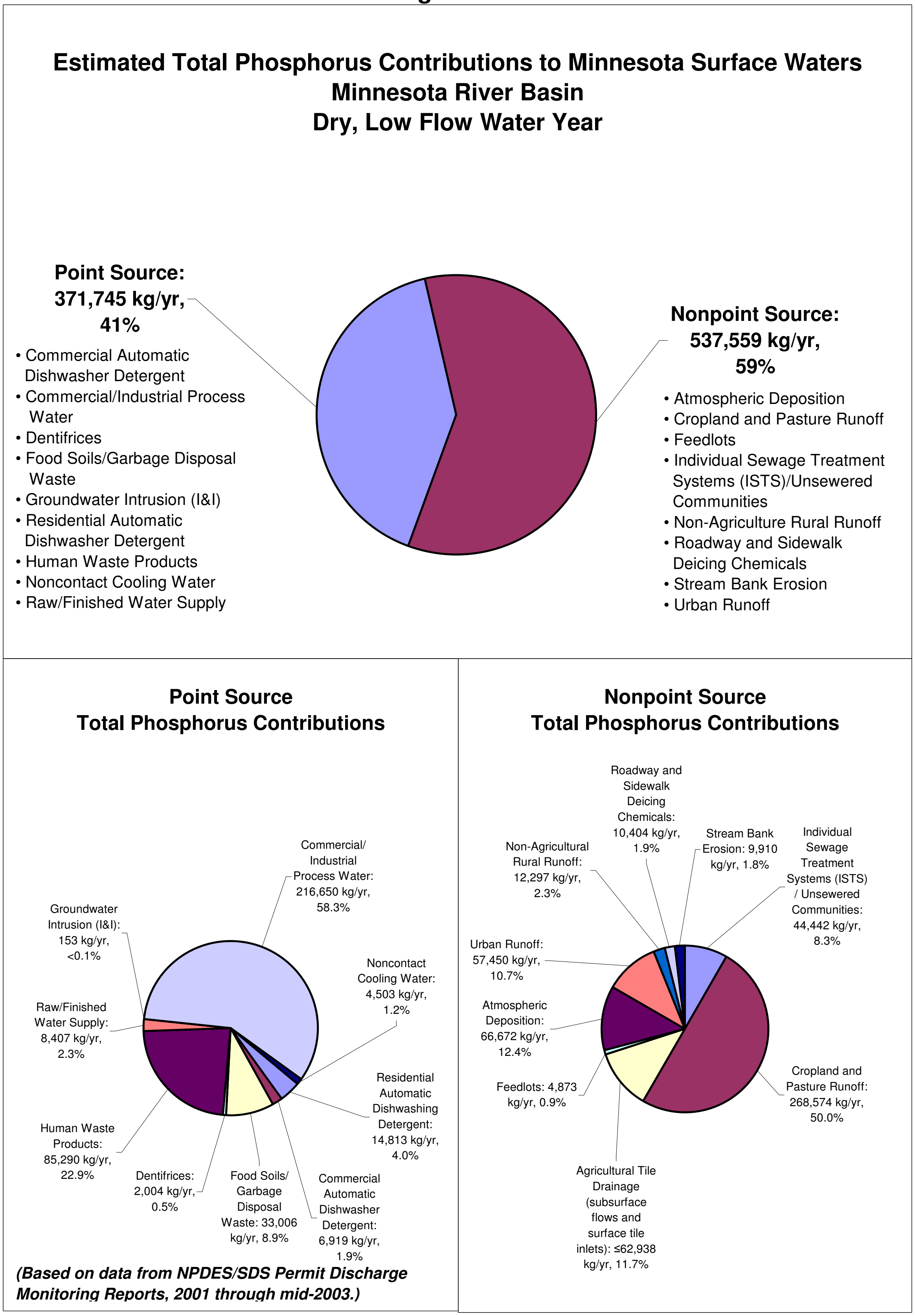
Figure 3-58 shows that, under low flow conditions, the bioavailable point source phosphorus contribution represents 52 percent of the loadings to surface waters. Figure 3-58 also shows that human waste products, commercial/industrial process water, and food soils represent 23, 60 and 8 percent, respectively, of the point source bioavailable phosphorus contributions. The remaining point source categories contribute less than 5 percent of the point source loadings. The combination of residential and commercial automatic dishwasher detergent represents approximately 6 percent of the point source bioavailable phosphorus contributions. As shown in Figure 3-58, cropland and pasture runoff, agricultural tile drainage, and ISTS/unsewered communities represent approximately 49, 12, and 13 percent, respectively, of the nonpoint source bioavailable phosphorus loadings, with the remaining nonpoint source contributions below 11 percent.

3.4.9.2 Average Condition

3.4.9.2.1 Total Phosphorus

Under average flow conditions, Figure 3-59 shows that the total point source phosphorus contribution drops to 25 percent, compared to 41 percent for the loadings to surface waters under low flow conditions. As presented in Figure 3-59, cropland and pasture runoff and streambank erosion represent 48 and 18 percent, respectively, of the nonpoint source total phosphorus loadings, with the remaining nonpoint source contributions below 12 percent. Compared to low flow conditions (Figure 3-57), Figure 3-59 shows that the relative nonpoint source contributions of total phosphorus increased significantly for streambank erosion, decreased slightly for cropland and pasture runoff, and decreased significantly for urban runoff and atmospheric deposition.

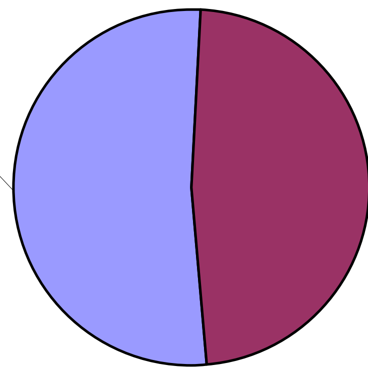
Figure 3-57



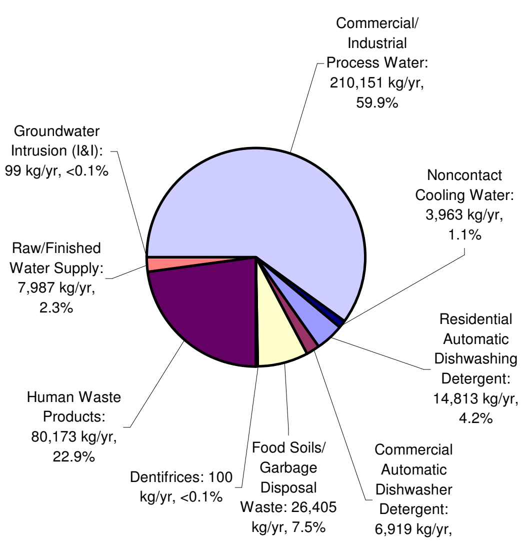
Estimated Total Phosphorus Contributions to Minnesota Surface Waters
Minnesota River Basin
Dry, Low Flow Water Year
Point Source:
371,745 kg/yr,
41%
• Commercial Automatic Dishwasher Detergent
• Commercial/Industrial Process Water
• Dentifrices
• Food Soils/Garbage Disposal Waste
• Groundwater Intrusion (I&I)
• Residential Automatic Dishwasher Detergent
• Human Waste Products
• Noncontact Cooling Water
• Raw/Finished Water Supply
Nonpoint Source:
537,559 kg/yr,
59%
• Atmospheric Deposition
• Cropland and Pasture Runoff
• Feedlots
• Individual Sewage Treatment Systems (ISTS)/Unsewered Communities
• Non-Agriculture Rural Runoff
• Roadway and Sidewalk Deicing Chemicals
• Stream Bank Erosion
• Urban Runoff
Point Source
Total Phosphorus Contributions
Commercial/ Industrial Process Water: 216,650 kg/yr, 58.3%
Groundwater Intrusion (I&I): 153 kg/yr, <0.1%
Noncontact Cooling Water: 4,503 kg/yr, 1.2%
Raw/Finished Water Supply: 8,407 kg/yr, 2.3%
Residential Automatic Dishwashing Detergent: 14,813 kg/yr, 4.0%
Human Waste Products: 85,290 kg/yr, 22.9%
Dentifrices: 2,004 kg/yr, 0.5%
Food Soils/ Garbage Disposal Waste: 33,006 kg/yr, 8.9%
Commercial Automatic Dishwasher Detergent: 6,919 kg/yr, 1.9%
(Based on data from NPDES/SDS Permit Discharge Monitoring Reports, 2001 through mid-2003.)
Nonpoint Source
Total Phosphorus Contributions
Roadway and Sidewalk Deicing Chemicals: 10,404 kg/yr, 1.9%
Non-Agricultural Rural Runoff: 12,297 kg/yr, 2.3%
Stream Bank Erosion: 9,910 kg/yr, 1.8%
Individual Sewage Treatment Systems (ISTS) / Unsewered Communities: 44,442 kg/yr, 8.3%
Urban Runoff: 57,450 kg/yr, 10.7%
Atmospheric Deposition: 66,672 kg/yr, 12.4%
Feedlots: 4,873 kg/yr, 0.9%
Cropland and Pasture Runoff: 268,574 kg/yr, 50.0%
Agricultural Tile Drainage (subsurface flows and surface tile inlets): ≤62,938 kg/yr, 11.7%

Figure 3-58

Estimated Bioavailable P Contributions to Minnesota Surface Waters
Minnesota River Basin
Dry, Low Flow Water Year



Point Source
Bioavailable P Contributions



(Based on data from NPDES/SDS Permit Discharge Monitoring Reports, 2001 through mid-2003.)

Nonpoint Source
Bioavailable P Contributions

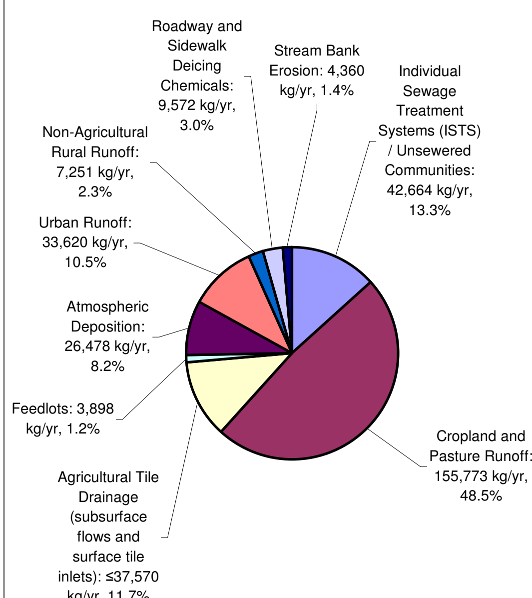
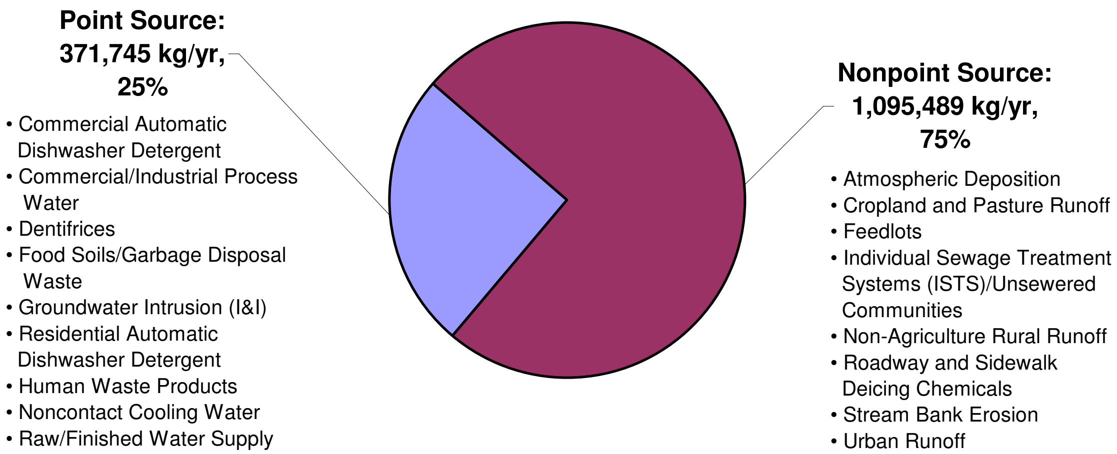
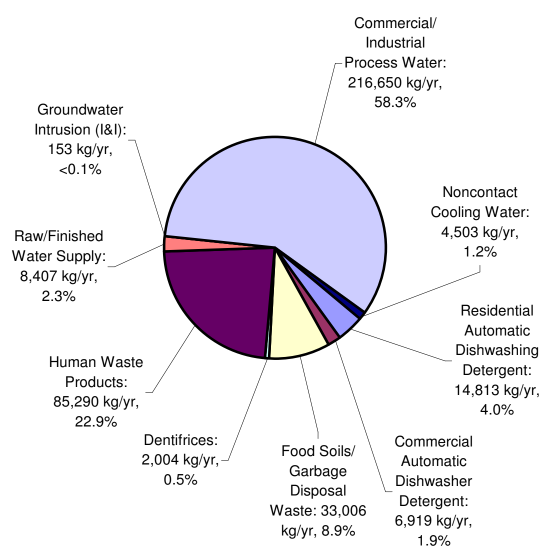


Figure 3-59

Estimated Total Phosphorus Contributions to Minnesota Surface Waters
Minnesota River Basin
Average Flow Water Year

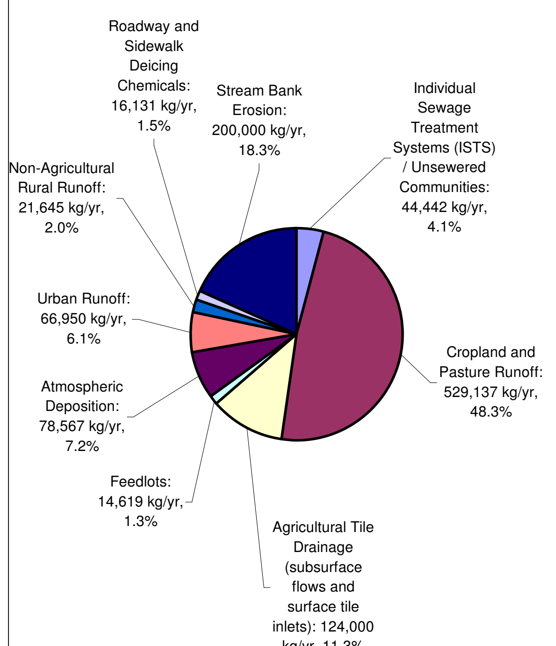


Point Source Total Phosphorus Contributions



(Based on data from NPDES/SDS Permit Discharge Monitoring Reports, 2001 through mid-2003.)

Nonpoint Source Total Phosphorus Contributions



3.4.9.2.2 Bioavailable Phosphorus

Under average flow conditions, Figure 3-60 shows that the bioavailable point source phosphorus contribution drops to 36 percent, compared to 52 percent for the loadings to surface waters under low flow conditions. As presented in Figure 3-60, cropland and pasture runoff, agricultural tile drainage, and streambank erosion represent 49, 12 and 14 percent, respectively, of the nonpoint source bioavailable phosphorus loadings, with the remaining nonpoint source contributions below 7 percent. Compared to low flow conditions (Figure 3-58), Figure 3-60 shows that the relative nonpoint source contributions of bioavailable phosphorus increased significantly for streambank erosion and decreased significantly for urban runoff and atmospheric deposition.

3.4.9.3 Wet Condition (High Flow)

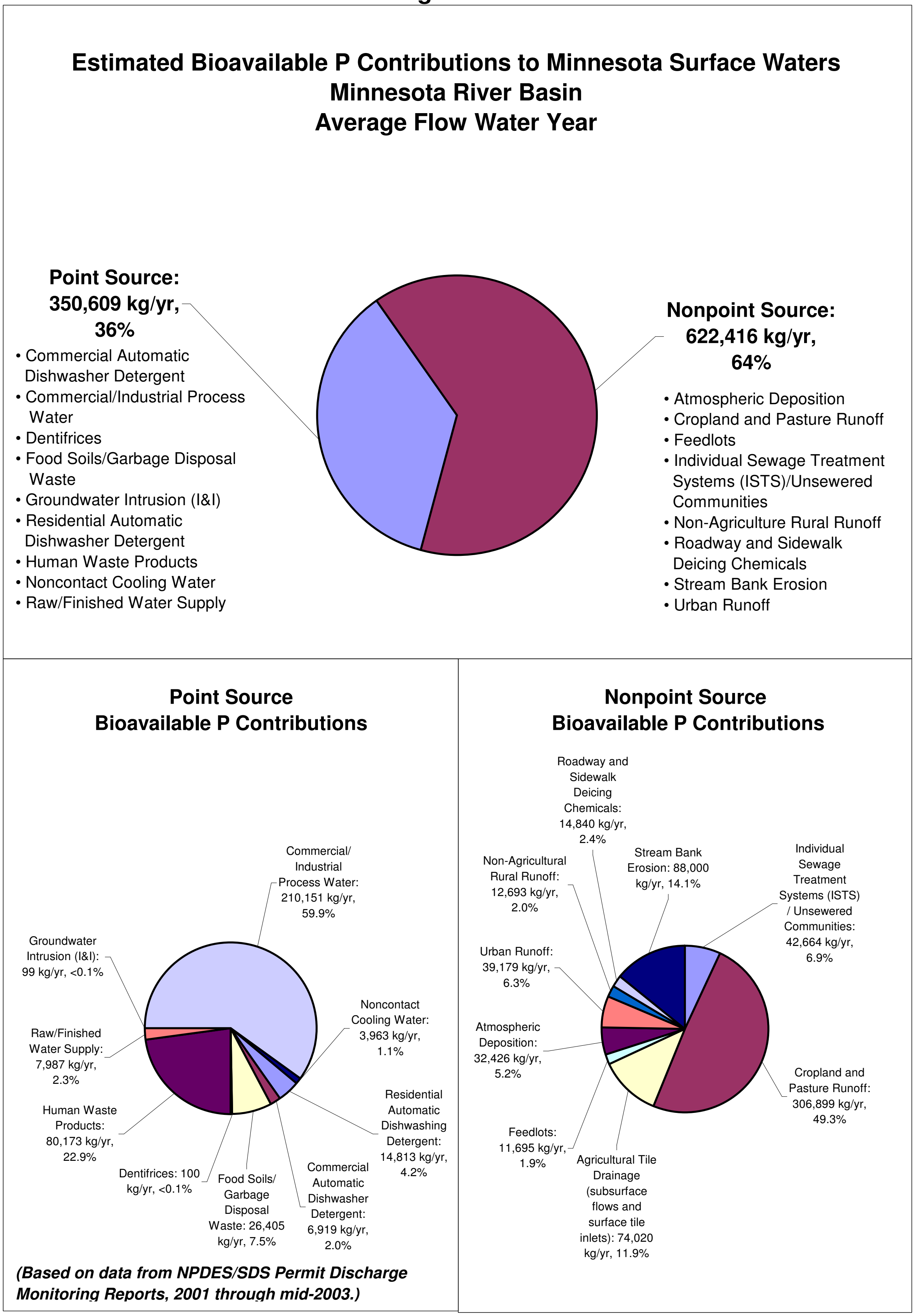
3.4.9.3.1 Total Phosphorus

Under high flow conditions, Figure 3-61 shows that the total point source phosphorus contribution drops to 15 percent, compared to 25 and 41 percent for the loadings to surface waters under average and low flow conditions, respectively. As presented in Figure 3-61, streambank erosion and cropland and pasture runoff represent 42 and 36 percent, respectively, of the nonpoint source total phosphorus loadings, with the remaining nonpoint source contributions below 9 percent. Compared to average flow conditions (Figure 3-59), Figure 3-61 shows that the relative statewide nonpoint source contributions of total phosphorus increased significantly for streambank erosion and decreased significantly for all of the remaining source categories, except feedlots.

3.4.9.3.2 Bioavailable Phosphorus

Under high flow conditions, Figure 3-62 shows that the bioavailable point source phosphorus contribution drops to 23 percent, compared to 36 and 52 percent for the loadings to surface waters under average and low flow conditions, respectively. As presented in Figure 3-62, cropland and pasture runoff and streambank erosion represent 39 and 35 percent, respectively, of the nonpoint source bioavailable phosphorus loadings, with the remaining nonpoint source contributions below 10 percent. Compared to average flow conditions (Figure 3-60), Figure 3-62 shows that the relative nonpoint source contributions of bioavailable phosphorus increased significantly for streambank erosion and decreased significantly for all of the remaining source categories, except feedlots.

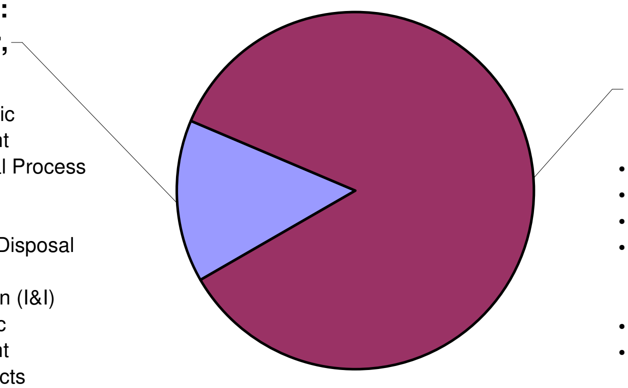
Figure 3-60



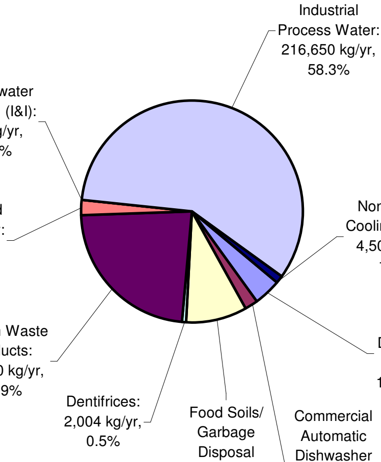
Estimated Bioavailable P Contributions to Minnesota Surface Waters
Minnesota River Basin
Average Flow Water Year
Point Source: 350,609 kg/yr, 36%
• Commercial Automatic Dishwasher Detergent
• Commercial/Industrial Process Water
• Dentifrices
• Food Soils/Garbage Disposal Waste
• Groundwater Intrusion (I&I)
• Residential Automatic Dishwasher Detergent
• Human Waste Products
• Noncontact Cooling Water
• Raw/Finished Water Supply
Nonpoint Source: 622,416 kg/yr, 64%
• Atmospheric Deposition
• Cropland and Pasture Runoff
• Feedlots
• Individual Sewage Treatment Systems (ISTS)/Unsewered Communities
• Non-Agriculture Rural Runoff
• Roadway and Sidewalk Deicing Chemicals
• Stream Bank Erosion
• Urban Runoff
Point Source
Bioavailable P Contributions
Commercial/ Industrial Process Water: 210,151 kg/yr, 59.9%
Groundwater Intrusion (I&I): 99 kg/yr, <0.1%
Noncontact Cooling Water: 3,963 kg/yr, 1.1%
Raw/Finished Water Supply: 7,987 kg/yr, 2.3%
Residential Automatic Dishwashing Detergent: 14,813 kg/yr, 4.2%
Human Waste Products: 80,173 kg/yr, 22.9%
Commercial Automatic Dishwasher Detergent: 6,919 kg/yr, 2.0%
Dentifrices: 100 kg/yr, <0.1%
Food Soils/ Garbage Disposal Waste: 26,405 kg/yr, 7.5%
(Based on data from NPDES/SDS Permit Discharge Monitoring Reports, 2001 through mid-2003.)
Nonpoint Source
Bioavailable P Contributions
Roadway and Sidewalk Deicing Chemicals: 14,840 kg/yr, 2.4%
Non-Agricultural Rural Runoff: 12,693 kg/yr, 2.0%
Stream Bank Erosion: 88,000 kg/yr, 14.1%
Individual Sewage Treatment Systems (ISTS) / Unsewered Communities: 42,664 kg/yr, 6.9%
Urban Runoff: 39,179 kg/yr, 6.3%
Atmospheric Deposition: 32,426 kg/yr, 5.2%
Cropland and Pasture Runoff: 306,899 kg/yr, 49.3%
Feedlots: 11,695 kg/yr, 1.9%
Agricultural Tile Drainage (subsurface flows and surface tile inlets): 74,020 kg/yr, 11.9%

Figure 3-61

Estimated Total Phosphorus Contributions to Minnesota Surface Waters
Minnesota River Basin
Wet, High Flow Water Year



Point Source Total Phosphorus Contributions



(Based on data from NPDES/SDS Permit Discharge Monitoring Reports, 2001 through mid-2003.)

Nonpoint Source Total Phosphorus Contributions

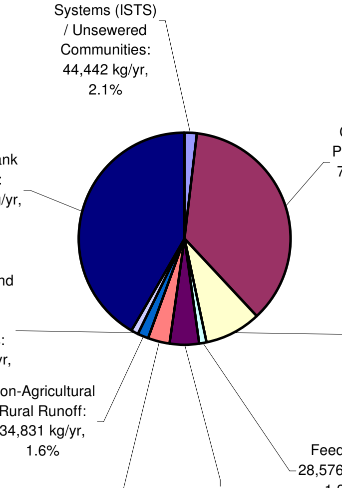
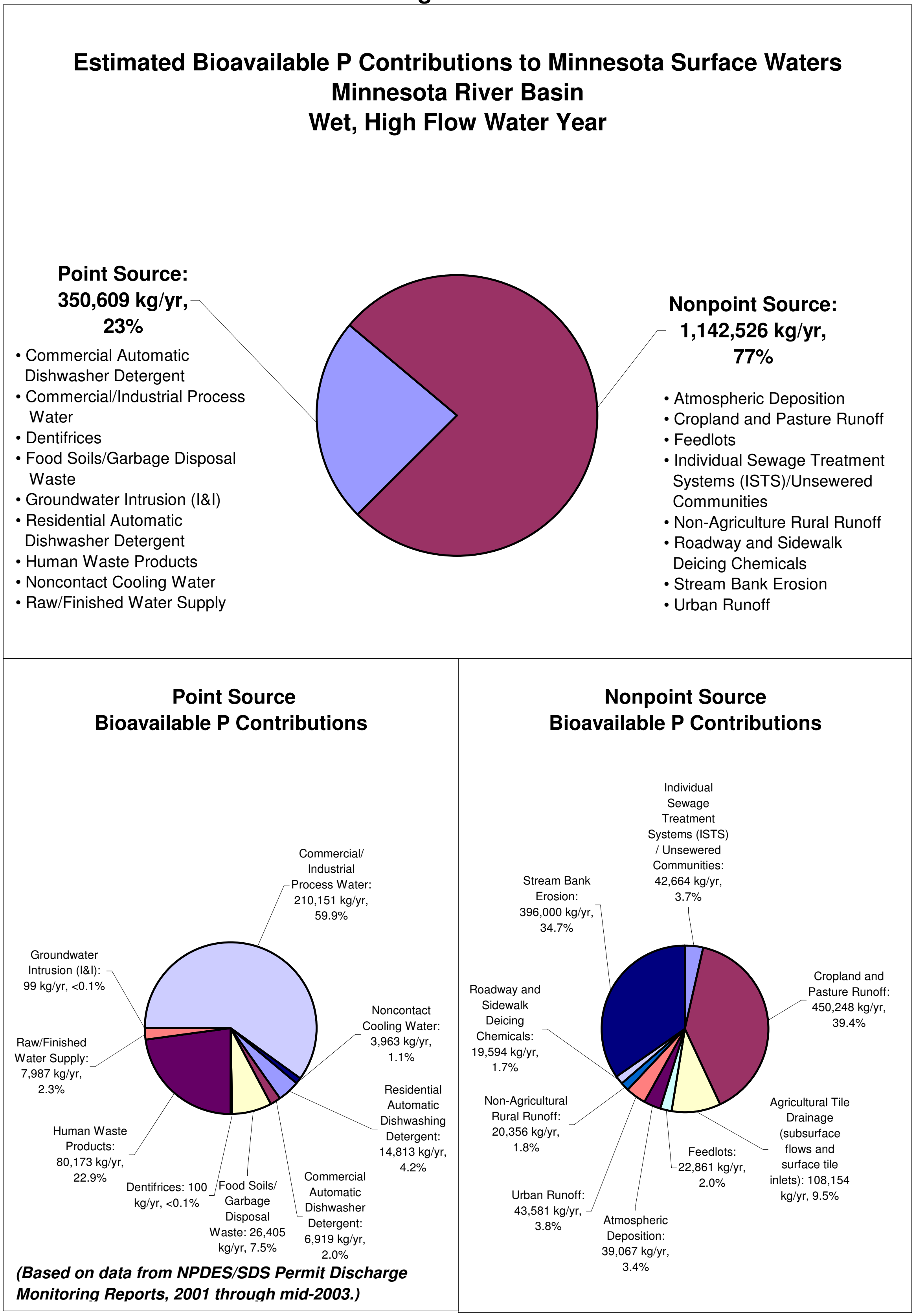


Figure 3-62



Estimated Bioavailable P Contributions to Minnesota Surface Waters
Minnesota River Basin
Wet, High Flow Water Year
Point Source:
350,609 kg/yr,
23%
• Commercial Automatic Dishwasher Detergent
• Commercial/Industrial Process Water
• Dentifrices
• Food Soils/Garbage Disposal Waste
• Groundwater Intrusion (I&I)
• Residential Automatic Dishwasher Detergent
• Human Waste Products
• Noncontact Cooling Water
• Raw/Finished Water Supply
Nonpoint Source:
1,142,526 kg/yr,
77%
• Atmospheric Deposition
• Cropland and Pasture Runoff
• Feedlots
• Individual Sewage Treatment Systems (ISTS)/Unsewered Communities
• Non-Agriculture Rural Runoff
• Roadway and Sidewalk Deicing Chemicals
• Stream Bank Erosion
• Urban Runoff
Point Source
Bioavailable P Contributions
Commercial/ Industrial Process Water: 210,151 kg/yr, 59.9%
Groundwater Intrusion (I&I): 99 kg/yr, <0.1%
Noncontact Cooling Water: 3,963 kg/yr, 1.1%
Raw/Finished Water Supply: 7,987 kg/yr, 2.3%
Residential Automatic Dishwashing Detergent: 14,813 kg/yr, 4.2%
Human Waste Products: 80,173 kg/yr, 22.9%
Dentifrices: 100 kg/yr, <0.1%
Food Soils/ Garbage Disposal Waste: 26,405 kg/yr, 7.5%
Commercial Automatic Dishwasher Detergent: 6,919 kg/yr, 2.0%
(Based on data from NPDES/SDS Permit Discharge Monitoring Reports, 2001 through mid-2003.)
Nonpoint Source
Bioavailable P Contributions
Individual Sewage Treatment Systems (ISTS) / Unsewered Communities: 42,664 kg/yr, 3.7%
Stream Bank Erosion: 396,000 kg/yr, 34.7%
Cropland and Pasture Runoff: 450,248 kg/yr, 39.4%
Roadway and Sidewalk Deicing Chemicals: 19,594 kg/yr, 1.7%
Non-Agricultural Rural Runoff: 20,356 kg/yr, 1.8%
Agricultural Tile Drainage (subsurface flows and surface tile inlets): 108,154 kg/yr, 9.5%
Feedlots: 22,861 kg/yr, 2.0%
Urban Runoff: 43,581 kg/yr, 3.8%
Atmospheric Deposition: 39,067 kg/yr, 3.4%

3.4.10 Cedar River Basin

3.4.10.1 Dry Conditions (Low Flow)

3.4.10.1.1 Total Phosphorus

Figure 3-63 shows that, under low flow conditions, the total point source phosphorus contribution represents 66 percent, while nonpoint sources of phosphorus represent 34 percent of the loadings to surface waters in the Cedar River basin. Figure 3-63 also shows that human waste products, commercial/industrial process water, and food soils represent 68, 13 and 8 percent, respectively, of the point source total phosphorus contributions. The remaining point source categories contribute less than 4 percent of the point source loadings. The combination of residential and commercial automatic dishwasher detergent represents approximately 5 percent of the point source total phosphorus contributions. As shown in Figure 3-63, cropland and pasture runoff, atmospheric deposition, urban runoff, and ISTS/unsewered communities represent 48, 14, 14, and 13 percent, respectively, of the nonpoint source total phosphorus loadings, with the remaining nonpoint source contributions below 6 percent.

3.4.10.1.2 Bioavailable Phosphorus

Figure 3-64 shows that, under low flow conditions, the bioavailable point source phosphorus contribution represents 75 percent of the loadings to surface waters. Figure 3-64 also shows that human waste products, commercial/industrial process water, and food soils represent 69, 14 and 7 percent, respectively, of the point source bioavailable phosphorus contributions. The remaining point source categories contribute less than 5 percent of the point source loadings. The combination of residential and commercial automatic dishwasher detergent represents approximately 6 percent of the point source bioavailable phosphorus contributions. As shown in Figure 3-64, cropland and pasture runoff, urban runoff and ISTS/unsewered communities represent approximately 46, 14, and 21 percent, respectively, of the nonpoint source bioavailable phosphorus loadings, with the remaining nonpoint source contributions below 8 percent.

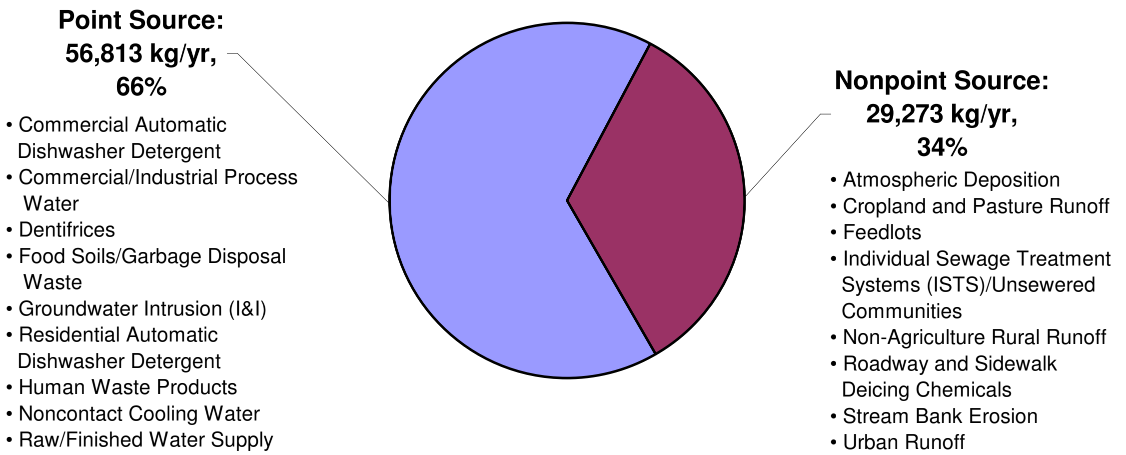
3.4.10.2 Average Condition

3.4.10.2.1 Total Phosphorus

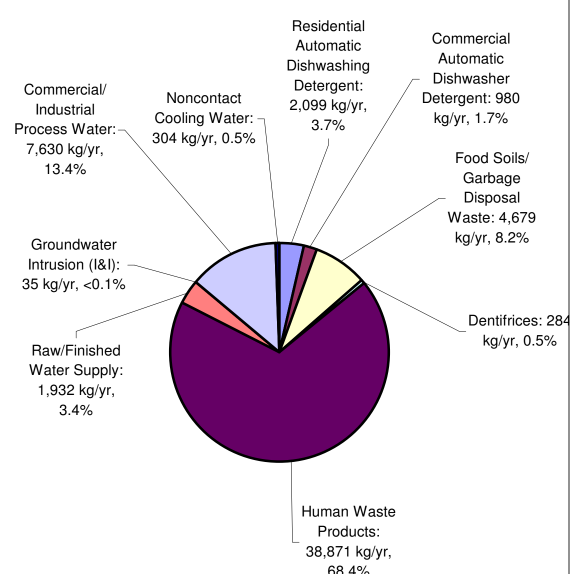
Under average flow conditions, Figure 3-65 shows that the total point source phosphorus contribution drops to 47 percent, compared to 66 percent for the loadings to surface waters under low flow conditions. As presented in Figure 3-65, cropland and pasture runoff and streambank erosion represent 54 and 19 percent, respectively, of the nonpoint source total phosphorus loadings, with the remaining nonpoint source contributions below 8 percent. Compared to low flow conditions (Figure 3-63), Figure 3-65 shows that the relative nonpoint source contributions of total phosphorus increased significantly for streambank erosion, increased slightly for cropland and pasture runoff, and decreased significantly for urban runoff and atmospheric deposition.

Figure 3-63

Estimated Total Phosphorus Contributions to Minnesota Surface Waters
Cedar River Basin
Dry, Low Flow Water Year



Point Source Total Phosphorus Contributions



(Based on data from NPDES/SDS Permit Discharge Monitoring Reports, 2001 through mid-2003.)

Nonpoint Source Total Phosphorus Contributions

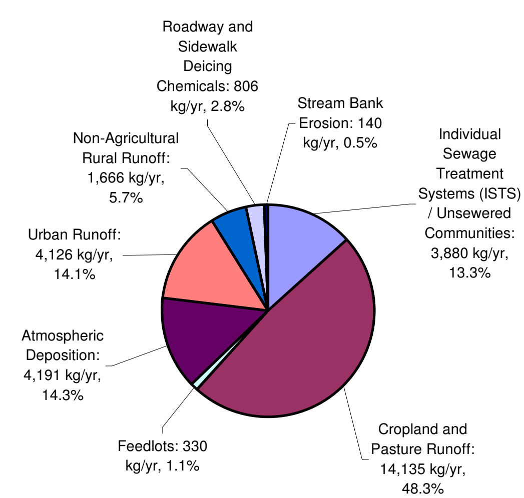
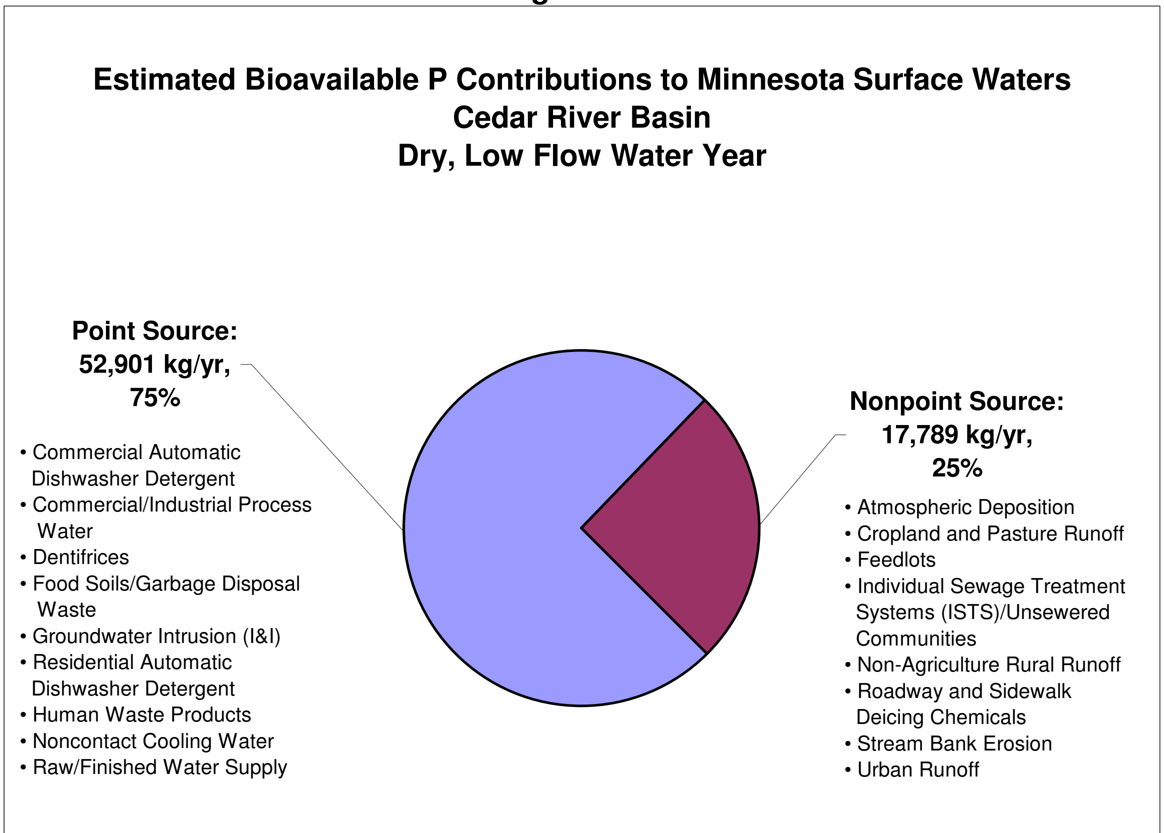
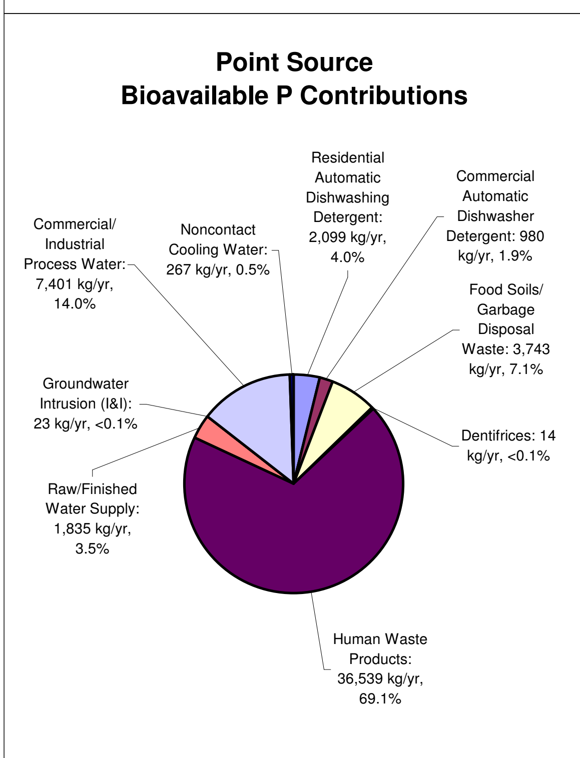


Figure 3-64





(Based on data from NPDES/SDS Permit Discharge Monitoring Reports, 2001 through mid-2003.)

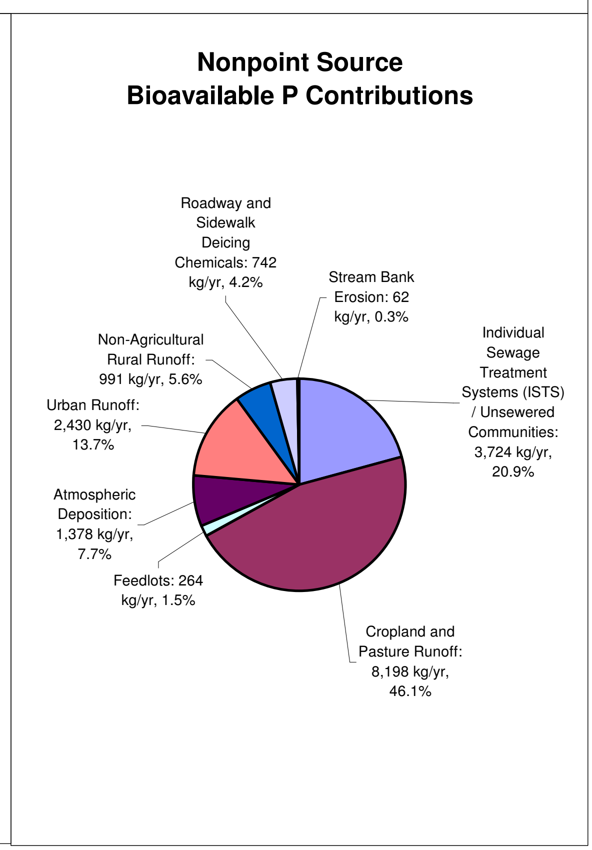
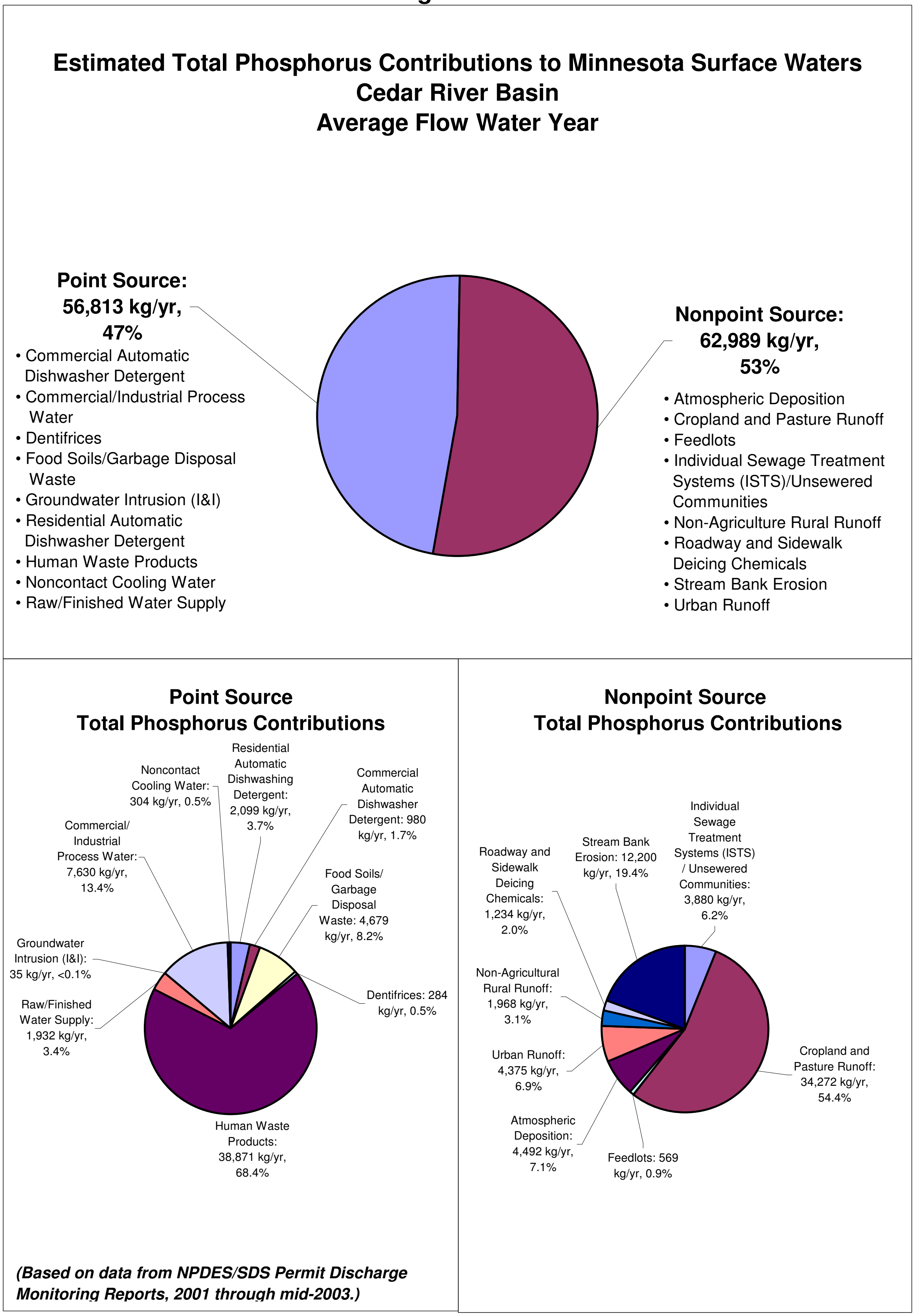


Figure 3-65


Estimated Total Phosphorus Contributions to Minnesota Surface Waters
Cedar River Basin
Average Flow Water Year
Point Source: 56,813 kg/yr, 47%
• Commercial Automatic Dishwasher Detergent
• Commercial/Industrial Process Water
• Dentifrices
• Food Soils/Garbage Disposal Waste
• Groundwater Intrusion (I&I)
• Residential Automatic Dishwasher Detergent
• Human Waste Products
• Noncontact Cooling Water
• Raw/Finished Water Supply
Nonpoint Source: 62,989 kg/yr, 53%
• Atmospheric Deposition
• Cropland and Pasture Runoff
• Feedlots
• Individual Sewage Treatment Systems (ISTS)/Unsewered Communities
• Non-Agriculture Rural Runoff
• Roadway and Sidewalk Deicing Chemicals
• Stream Bank Erosion
• Urban Runoff
Point Source
Total Phosphorus Contributions
Residential Automatic Dishwashing Detergent: 2,099 kg/yr, 3.7%
Noncontact Cooling Water: 304 kg/yr, 0.5%
Commercial Automatic Dishwasher Detergent: 980 kg/yr, 1.7%
Commercial/ Industrial Process Water: 7,630 kg/yr, 13.4%
Food Soils/ Garbage Disposal Waste: 4,679 kg/yr, 8.2%
Groundwater Intrusion (I&I): 35 kg/yr, <0.1%
Dentifrices: 284 kg/yr, 0.5%
Raw/Finished Water Supply: 1,932 kg/yr, 3.4%
Human Waste Products: 38,871 kg/yr, 68.4%
(Based on data from NPDES/SDS Permit Discharge Monitoring Reports, 2001 through mid-2003.)
Nonpoint Source
Total Phosphorus Contributions
Individual Sewage Treatment Systems (ISTS) / Unsewered Communities: 3,880 kg/yr, 6.2%
Stream Bank Erosion: 12,200 kg/yr, 19.4%
Roadway and Sidewalk Deicing Chemicals: 1,234 kg/yr, 2.0%
Non-Agricultural Rural Runoff: 1,968 kg/yr, 3.1%
Urban Runoff: 4,375 kg/yr, 6.9%
Cropland and Pasture Runoff: 34,272 kg/yr, 54.4%
Atmospheric Deposition: 4,492 kg/yr, 7.1%
Feedlots: 569 kg/yr, 0.9%

3.4.10.2.2 Bioavailable Phosphorus

Under average flow conditions, Figure 3-66 shows that the bioavailable point source phosphorus contribution drops to 60 percent, compared to 75 percent for the loadings to surface waters under low flow conditions. As presented in Figure 3-66, cropland and pasture runoff, streambank erosion and ISTS/unsewered communities represent 56, 15, and 10 percent, respectively, of the nonpoint source bioavailable phosphorus loadings, with the remaining nonpoint source contributions below 8 percent. Compared to low flow conditions (Figure 3-64), Figure 3-66 shows that the relative nonpoint source contributions of bioavailable phosphorus increased significantly for streambank erosion and decreased significantly for urban runoff, ISTS/unsewered communities and atmospheric deposition.

3.4.10.3 Wet Condition (High Flow)

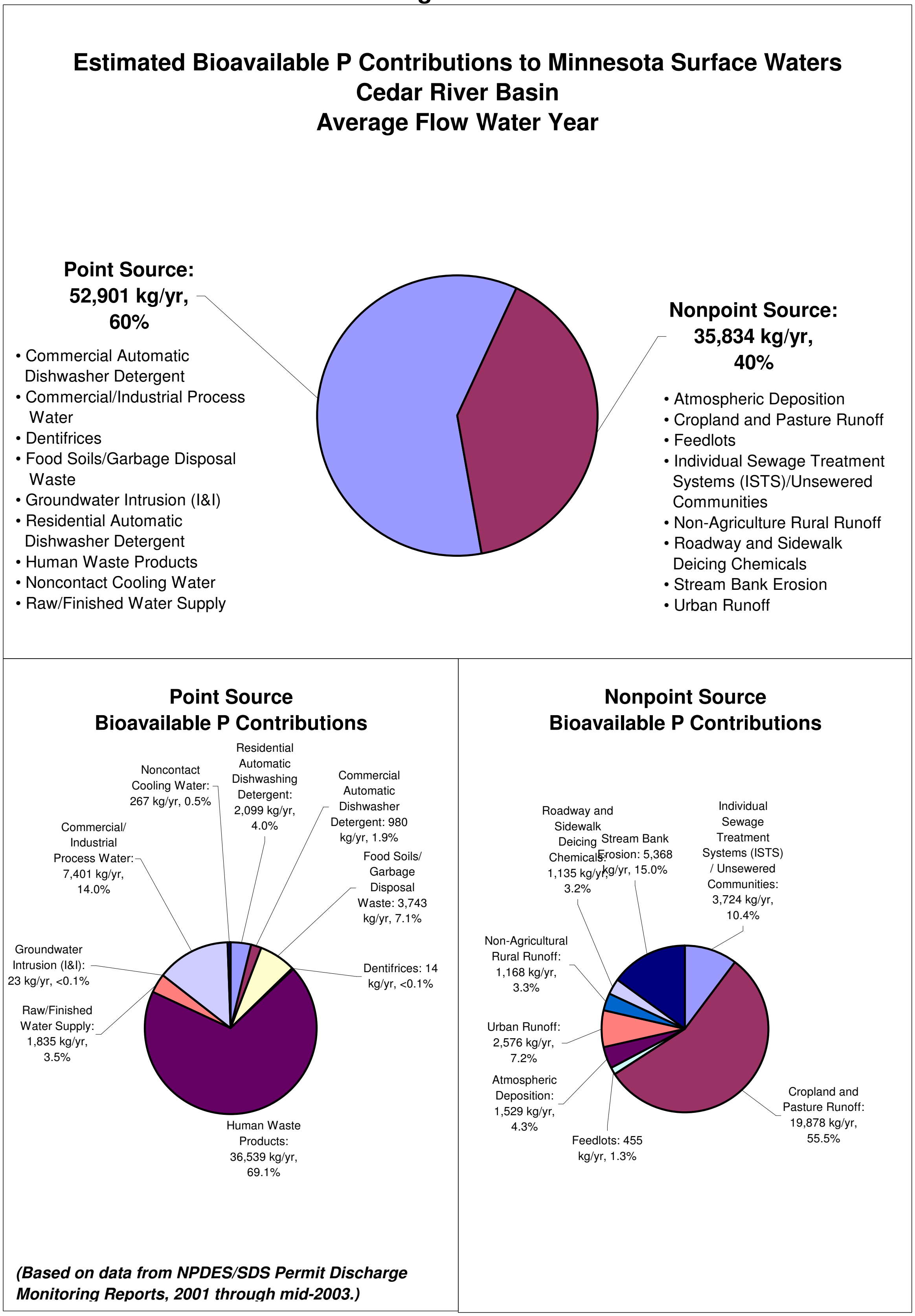
3.4.10.3.1 Total Phosphorus

Under high flow conditions, Figure 3-67 shows that the total point source phosphorus contribution drops to 32 percent, compared to 47 and 66 percent for the loadings to surface waters under average and low flow conditions, respectively. As presented in Figure 3-67, streambank erosion and cropland and pasture runoff represent 49 and 36 percent, respectively, of the nonpoint source total phosphorus loadings, with the remaining nonpoint source contributions below 5 percent. Compared to average flow conditions (Figure 3-65), Figure 3-67 shows that the relative statewide nonpoint source contributions of total phosphorus increased significantly for streambank erosion and decreased significantly for all of the remaining source categories.

3.4.10.3.2 Bioavailable Phosphorus

Under high flow conditions, Figure 3-68 shows that the bioavailable point source phosphorus contribution drops to 45 percent, compared to 60 and 75 percent for the loadings to surface waters under average and low flow conditions, respectively. As presented in Figure 3-68, cropland and pasture runoff and streambank erosion represent 40 and 41 percent, respectively, of the nonpoint source bioavailable phosphorus loadings, with the remaining nonpoint source contributions below 6 percent. Compared to average flow conditions (Figure 3-66), Figure 3-68 shows that the relative nonpoint source contributions of bioavailable phosphorus increased significantly for streambank erosion and decreased significantly for all of the remaining source categories, except feedlots.

Figure 3-66



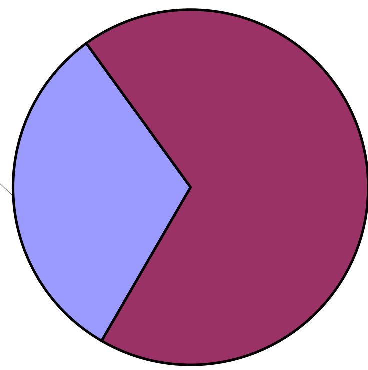
Estimated Bioavailable P Contributions to Minnesota Surface Waters
Cedar River Basin
Average Flow Water Year
Point Source: 52,901 kg/yr, 60%
• Commercial Automatic Dishwasher Detergent
• Commercial/Industrial Process Water
• Dentifrices
• Food Soils/Garbage Disposal Waste
• Groundwater Intrusion (I&I)
• Residential Automatic Dishwasher Detergent
• Human Waste Products
• Noncontact Cooling Water
• Raw/Finished Water Supply
Nonpoint Source: 35,834 kg/yr, 40%
• Atmospheric Deposition
• Cropland and Pasture Runoff
• Feedlots
• Individual Sewage Treatment Systems (ISTS)/Unsewered Communities
• Non-Agriculture Rural Runoff
• Roadway and Sidewalk Deicing Chemicals
• Stream Bank Erosion
• Urban Runoff
Point Source
Bioavailable P Contributions
Residential Automatic Dishwashing Detergent: 2,099 kg/yr, 4.0%
Noncontact Cooling Water: 267 kg/yr, 0.5%
Commercial Automatic Dishwasher Detergent: 980 kg/yr, 1.9%
Commercial/ Industrial Process Water: 7,401 kg/yr, 14.0%
Food Soils/ Garbage Disposal Waste: 3,743 kg/yr, 7.1%
Groundwater Intrusion (I&I): 23 kg/yr, <0.1%
Dentifrices: 14 kg/yr, <0.1%
Raw/Finished Water Supply: 1,835 kg/yr, 3.5%
Human Waste Products: 36,539 kg/yr, 69.1%
(Based on data from NPDES/SDS Permit Discharge Monitoring Reports, 2001 through mid-2003.)
Nonpoint Source
Bioavailable P Contributions
Roadway and Sidewalk Deicing Chemicals: 1,135 kg/yr, 3.2%
Stream Bank Erosion: 5,368 kg/yr, 15.0%
Individual Sewage Treatment Systems (ISTS) / Unsewered Communities: 3,724 kg/yr, 10.4%
Non-Agricultural Rural Runoff: 1,168 kg/yr, 3.3%
Urban Runoff: 2,576 kg/yr, 7.2%
Atmospheric Deposition: 1,529 kg/yr, 4.3%
Feedlots: 455 kg/yr, 1.3%
Cropland and Pasture Runoff: 19,878 kg/yr, 55.5%

Figure 3-67

Estimated Total Phosphorus Contributions to Minnesota Surface Waters
Cedar River Basin
Wet, High Flow Water Year

Point Source: 56,813 kg/yr, 32%

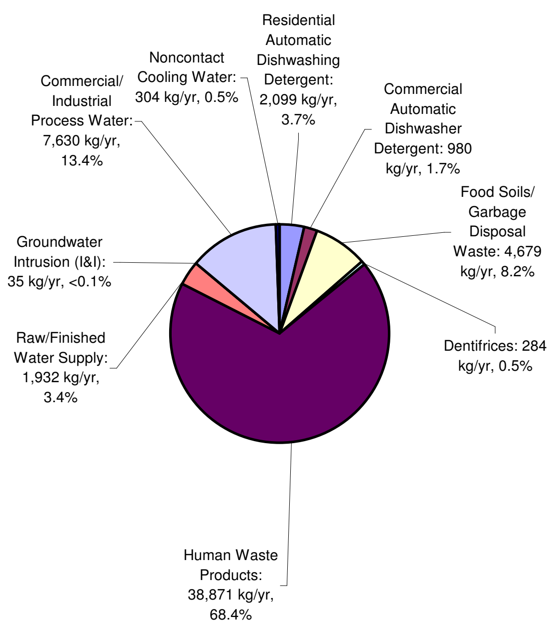
- Commercial Automatic Dishwasher Detergent
- Commercial/Industrial Process Water
- Dentifrices
- Food Soils/Garbage Disposal Waste
- Groundwater Intrusion (I&I)
- Residential Automatic Dishwasher Detergent
- Human Waste Products
- Noncontact Cooling Water
- Raw/Finished Water Supply



Nonpoint Source: 121,927 kg/yr, 68%

- Atmospheric Deposition
- Cropland and Pasture Runoff
- Feedlots
- Individual Sewage Treatment Systems (ISTS)/Unsewered Communities
- Non-Agriculture Rural Runoff
- Roadway and Sidewalk Deicing Chemicals
- Stream Bank Erosion
- Urban Runoff

Point Source Total Phosphorus Contributions



(Based on data from NPDES/SDS Permit Discharge Monitoring Reports, 2001 through mid-2003.)

Nonpoint Source Total Phosphorus Contributions

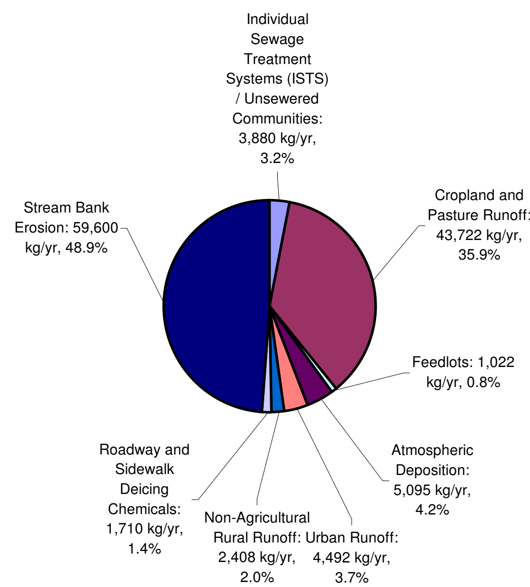
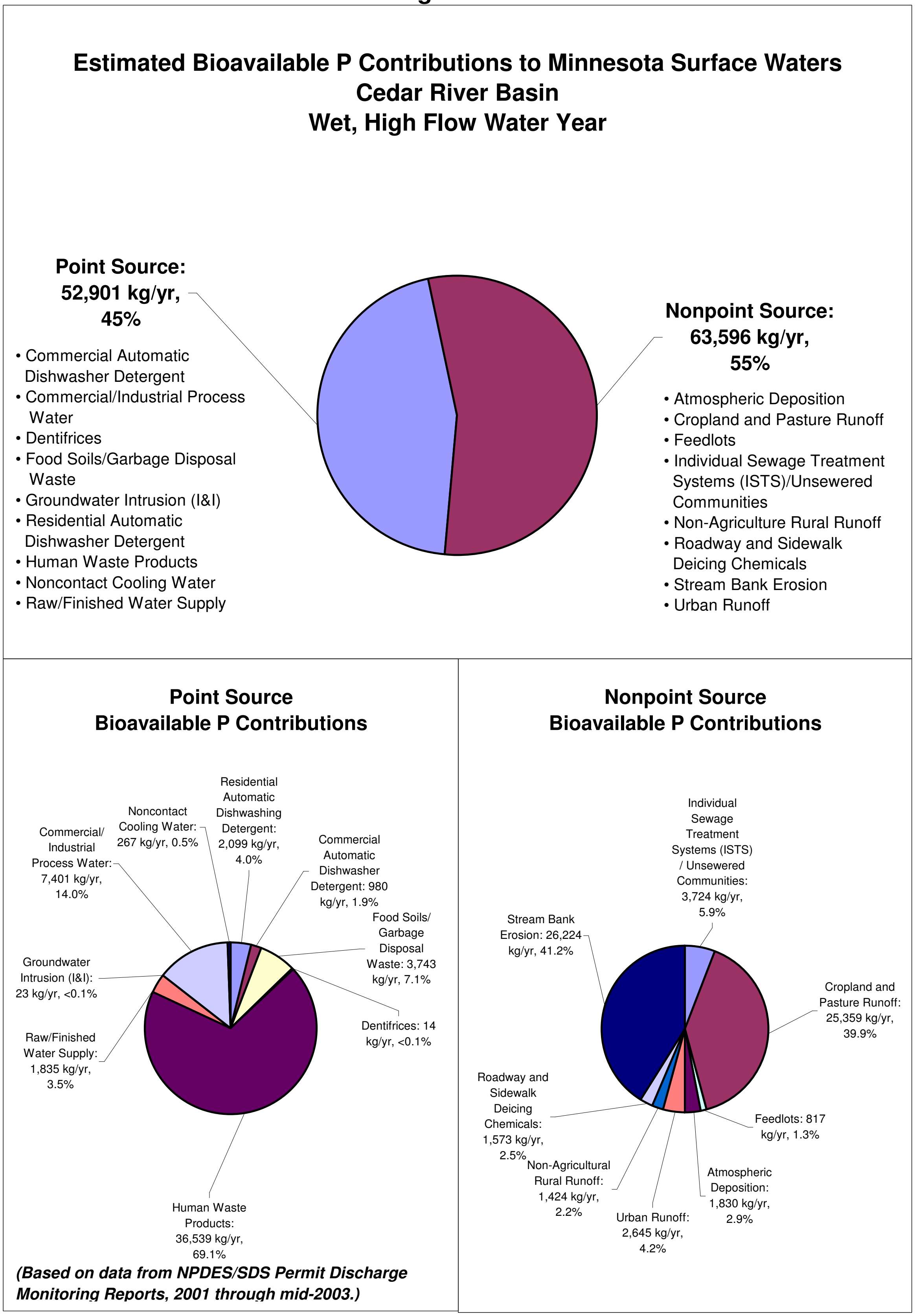


Figure 3-68



Estimated Bioavailable P Contributions to Minnesota Surface Waters
Cedar River Basin
Wet, High Flow Water Year
Point Source: 52,901 kg/yr, 45%
• Commercial Automatic Dishwasher Detergent
• Commercial/Industrial Process Water
• Dentifrices
• Food Soils/Garbage Disposal Waste
• Groundwater Intrusion (I&I)
• Residential Automatic Dishwasher Detergent
• Human Waste Products
• Noncontact Cooling Water
• Raw/Finished Water Supply
Nonpoint Source: 63,596 kg/yr, 55%
• Atmospheric Deposition
• Cropland and Pasture Runoff
• Feedlots
• Individual Sewage Treatment Systems (ISTS)/Unsewered Communities
• Non-Agriculture Rural Runoff
• Roadway and Sidewalk Deicing Chemicals
• Stream Bank Erosion
• Urban Runoff
Point Source Bioavailable P Contributions
Residential Automatic Dishwashing Detergent: 2,099 kg/yr, 4.0%
Noncontact Cooling Water: 267 kg/yr, 0.5%
Commercial/ Industrial Process Water: 7,401 kg/yr, 14.0%
Commercial Automatic Dishwasher Detergent: 980 kg/yr, 1.9%
Food Soils/ Garbage Disposal Waste: 3,743 kg/yr, 7.1%
Groundwater Intrusion (I&I): 23 kg/yr, <0.1%
Dentifrices: 14 kg/yr, <0.1%
Raw/Finished Water Supply: 1,835 kg/yr, 3.5%
Human Waste Products: 36,539 kg/yr, 69.1%
(Based on data from NPDES/SDS Permit Discharge Monitoring Reports, 2001 through mid-2003.)
Nonpoint Source Bioavailable P Contributions
Individual Sewage Treatment Systems (ISTS) / Unsewered Communities: 3,724 kg/yr, 5.9%
Stream Bank Erosion: 26,224 kg/yr, 41.2%
Cropland and Pasture Runoff: 25,359 kg/yr, 39.9%
Roadway and Sidewalk Deicing Chemicals: 1,573 kg/yr, 2.5%
Feedlots: 817 kg/yr, 1.3%
Non-Agricultural Rural Runoff: 1,424 kg/yr, 2.2%
Atmospheric Deposition: 1,830 kg/yr, 2.9%
Urban Runoff: 2,645 kg/yr, 4.2%

3.4.11 Des Moines River Basin

3.4.11.1 Dry Conditions (Low Flow)

3.4.11.1.1 Total Phosphorus

Figure 3-69 shows that, under low flow conditions, the total point source phosphorus contribution represents 60 percent, while nonpoint sources of phosphorus represent 40 percent of the loadings to surface waters in the Des Moines River basin. Figure 3-69 also shows that human waste products and commercial/industrial process water represent 14 and 80 percent, respectively, of the point source total phosphorus contributions. The remaining point source categories contribute less than 3 percent of the point source loadings. The combination of residential and commercial automatic dishwasher detergent represents approximately 2 percent of the point source total phosphorus contributions. As shown in Figure 3-69, cropland and pasture runoff and atmospheric deposition represent 67 and 13 percent, respectively, of the nonpoint source total phosphorus loadings, with the remaining nonpoint source contributions below 8 percent.

3.4.11.1.2 Bioavailable Phosphorus

Figure 3-70 shows that, under low flow conditions, the bioavailable point source phosphorus contribution represents 71 percent of the loadings to surface waters. Figure 3-70 also shows that human waste products and commercial/industrial process water represent 13 and 81 percent, respectively, of the point source bioavailable phosphorus contributions. The remaining point source categories contribute less than 3 percent of the point source loadings. The combination of residential and commercial automatic dishwasher detergent represents approximately 2 percent of the point source bioavailable phosphorus contributions. As shown in Figure 3-70, cropland and pasture runoff represents approximately 66 percent of the nonpoint source bioavailable phosphorus loadings, with the remaining nonpoint source contributions below 9 percent.

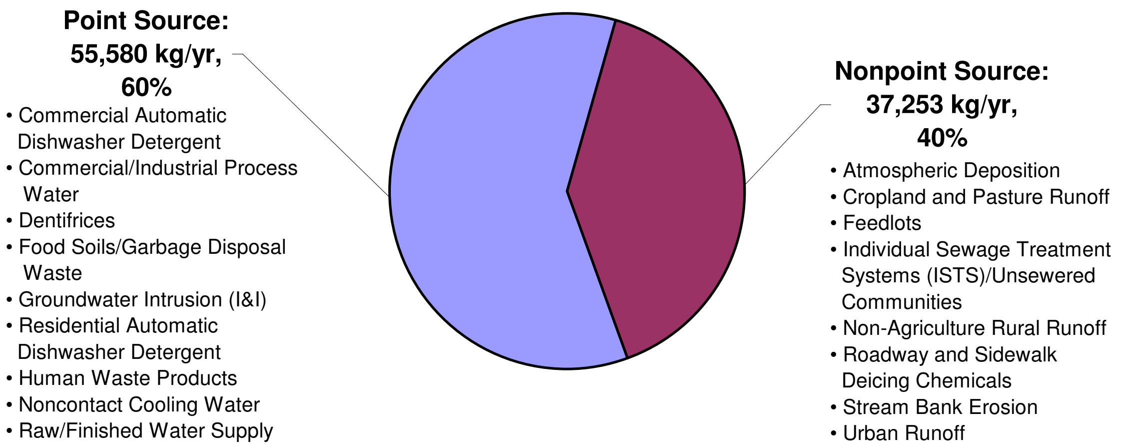
3.4.11.2 Average Condition

3.4.11.2.1 Total Phosphorus

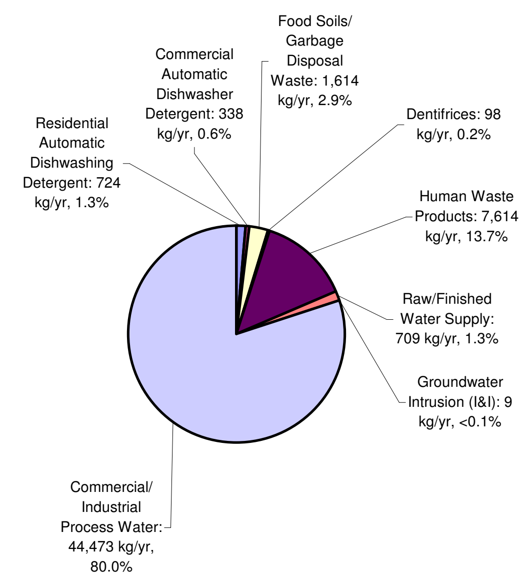
Under average flow conditions, Figure 3-71 shows that the total point source phosphorus contribution drops to 48 percent, compared to 60 percent for the loadings to surface waters under low flow conditions. As presented in Figure 3-71, cropland and pasture runoff and streambank erosion represent 62 and 12 percent, respectively, of the nonpoint source total phosphorus loadings, with the remaining nonpoint source contributions below 10 percent. Compared to low flow conditions (Figure 3-69), Figure 3-71 shows that the relative nonpoint source contributions of total phosphorus increased significantly for feedlots and streambank erosion, and decreased significantly for urban runoff, ISTS/unsewered communities and atmospheric deposition.

Figure 3-69

Estimated Total Phosphorus Contributions to Minnesota Surface Waters
Des Moines River Basin
Dry, Low Flow Water Year



Point Source Total Phosphorus Contributions



(Based on data from NPDES/SDS Permit Discharge Monitoring Reports, 2001 through mid-2003.)

Nonpoint Source Total Phosphorus Contributions

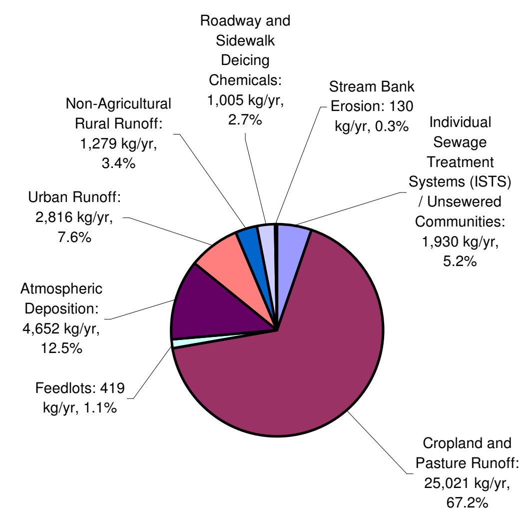
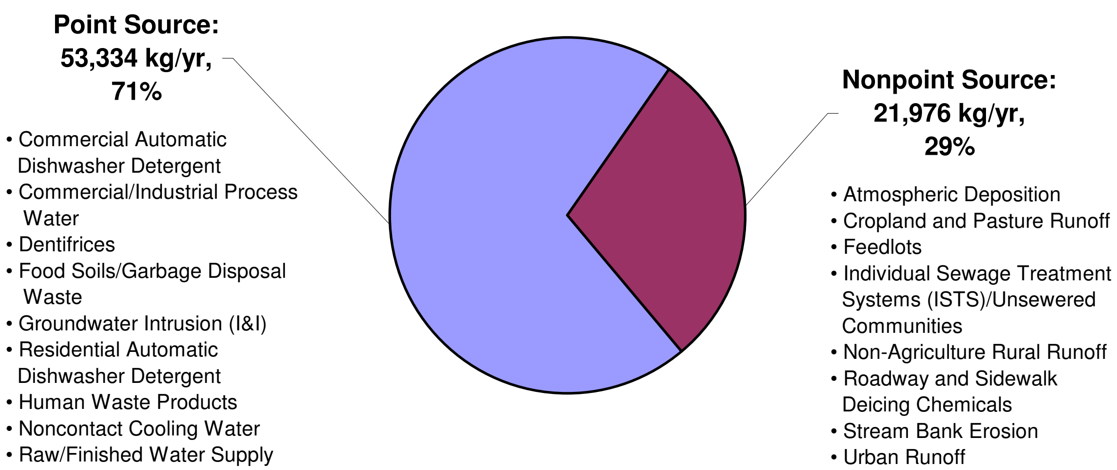
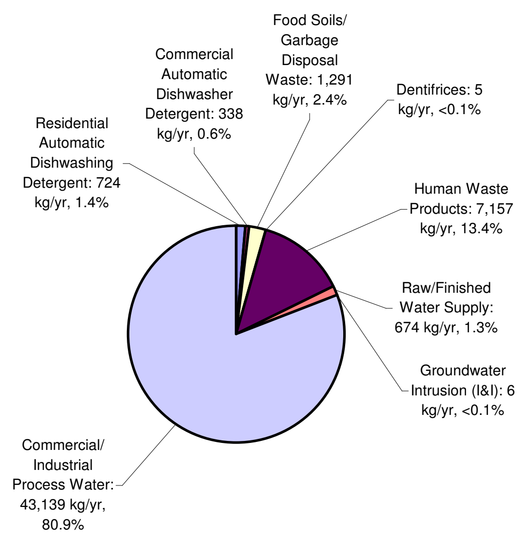


Figure 3-70

Estimated Bioavailable P Contributions to Minnesota Surface Waters
Des Moines River Basin
Dry, Low Flow Water Year



Point Source Bioavailable P Contributions



(Based on data from NPDES/SDS Permit Discharge Monitoring Reports, 2001 through mid-2003.)

Nonpoint Source Bioavailable P Contributions

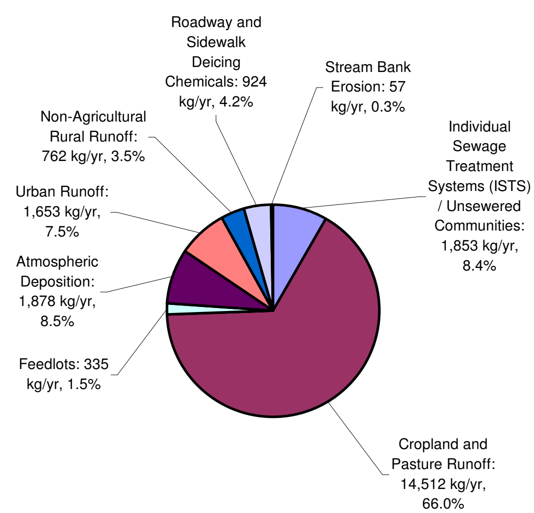
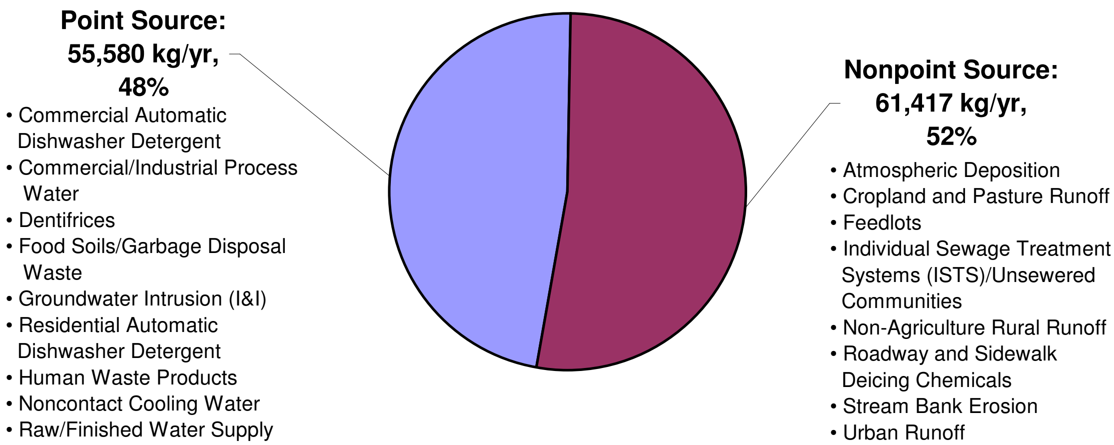
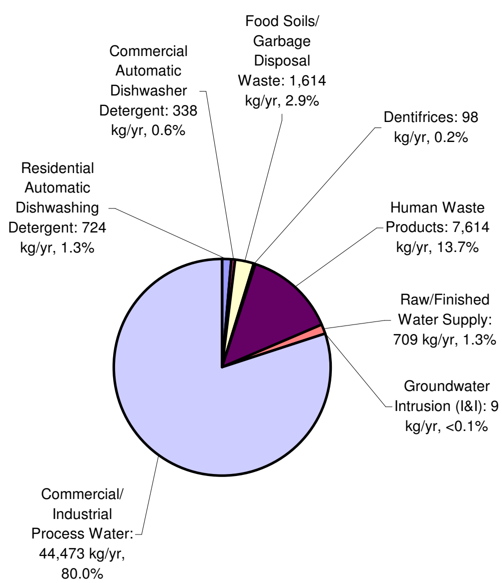


Figure 3-71

Estimated Total Phosphorus Contributions to Minnesota Surface Waters
Des Moines River Basin
Average Flow Water Year

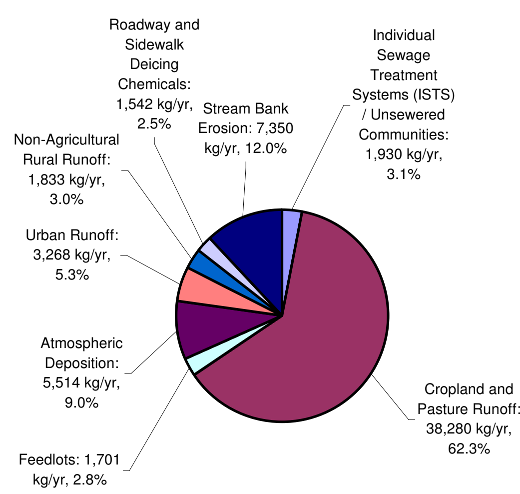


Point Source Total Phosphorus Contributions



(Based on data from NPDES/SDS Permit Discharge Monitoring Reports, 2001 through mid-2003.)

Nonpoint Source Total Phosphorus Contributions



3.4.11.2.2 Bioavailable Phosphorus

Under average flow conditions, Figure 3-72 shows that the bioavailable point source phosphorus contribution drops to 60 percent, compared to 71 percent for the loadings to surface waters under low flow conditions. As presented in Figure 3-72, cropland and pasture runoff and streambank erosion represent 63 and 9 percent, respectively, of the nonpoint source bioavailable phosphorus loadings, with the remaining nonpoint source contributions below 7 percent. Compared to low flow conditions (Figure 3-70), Figure 3-72 shows that the relative nonpoint source contributions of bioavailable phosphorus increased significantly for feedlots and streambank erosion, and decreased significantly for urban runoff, ISTS/unsewered communities and atmospheric deposition.

3.4.11.3 Wet Condition (High Flow)

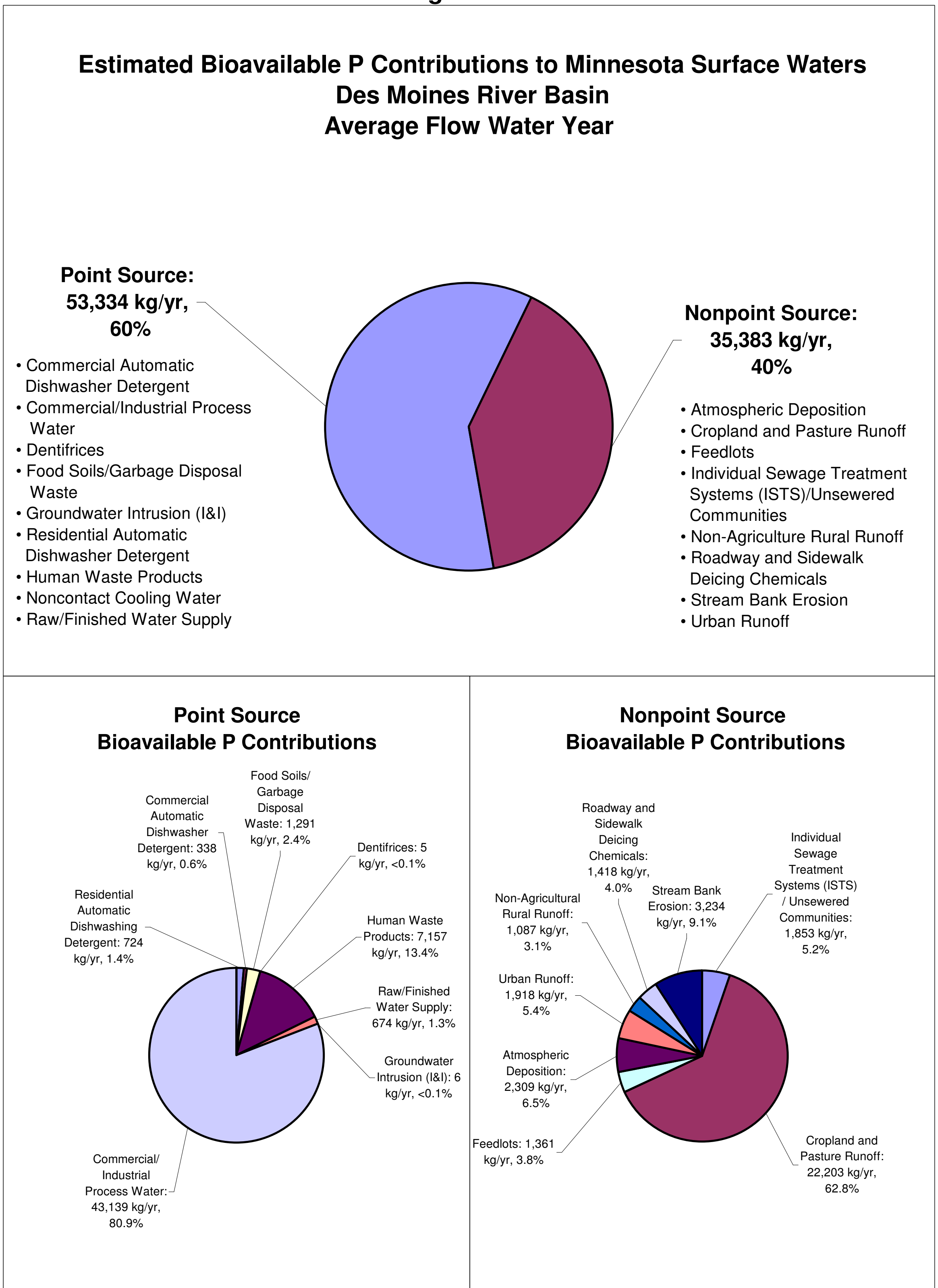
3.4.11.3.1 Total Phosphorus

Under high flow conditions, Figure 3-73 shows that the total point source phosphorus contribution drops to 28 percent, compared to 48 and 60 percent for the loadings to surface waters under average and low flow conditions, respectively. As presented in Figure 3-73, streambank erosion and cropland and pasture runoff represent 33 and 52 percent, respectively, of the nonpoint source total phosphorus loadings, with the remaining nonpoint source contributions below 5 percent. Compared to average flow conditions (Figure 3-71), Figure 3-73 shows that the relative statewide nonpoint source contributions of total phosphorus increased significantly for streambank erosion and decreased significantly for all of the remaining source categories except feedlots.

3.4.11.3.2 Bioavailable Phosphorus

Under high flow conditions, Figure 3-74 shows that the bioavailable point source phosphorus contribution drops to 41 percent, compared to 60 and 71 percent for the loadings to surface waters under average and low flow conditions, respectively. As presented in Figure 3-74, cropland and pasture runoff and streambank erosion represent 55 and 27 percent, respectively, of the nonpoint source bioavailable phosphorus loadings, with the remaining nonpoint source contributions below 5 percent. Compared to average flow conditions (Figure 3-72), Figure 3-74 shows that the relative nonpoint source contributions of bioavailable phosphorus increased significantly for streambank erosion and decreased significantly for all of the remaining source categories, except feedlots.

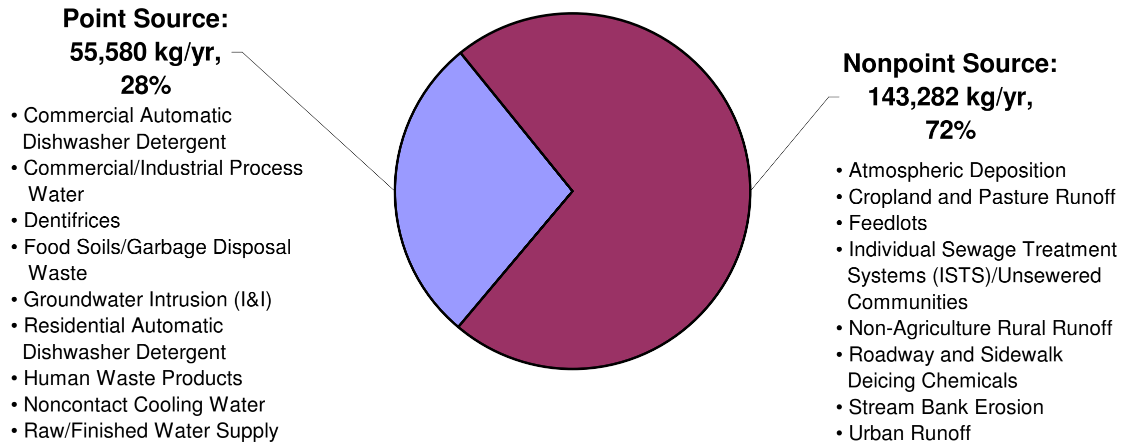
Figure 3-72



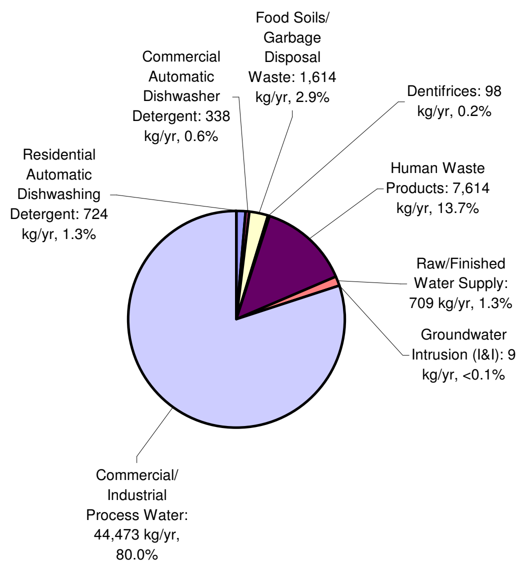
(Based on data from NPDES/SDS Permit Discharge Monitoring Reports, 2001 through mid-2003.)

Figure 3-73

Estimated Total Phosphorus Contributions to Minnesota Surface Waters
Des Moines River Basin
Wet, High Flow Water Year



Point Source Total Phosphorus Contributions



(Based on data from NPDES/SDS Permit Discharge Monitoring Reports, 2001 through mid-2003.)

Nonpoint Source Total Phosphorus Contributions

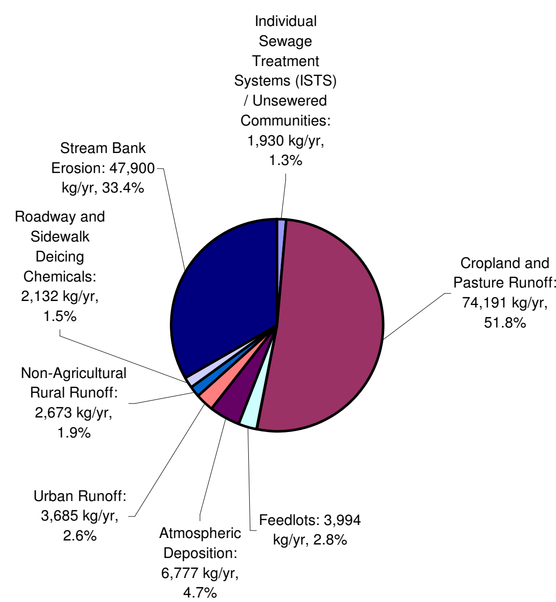
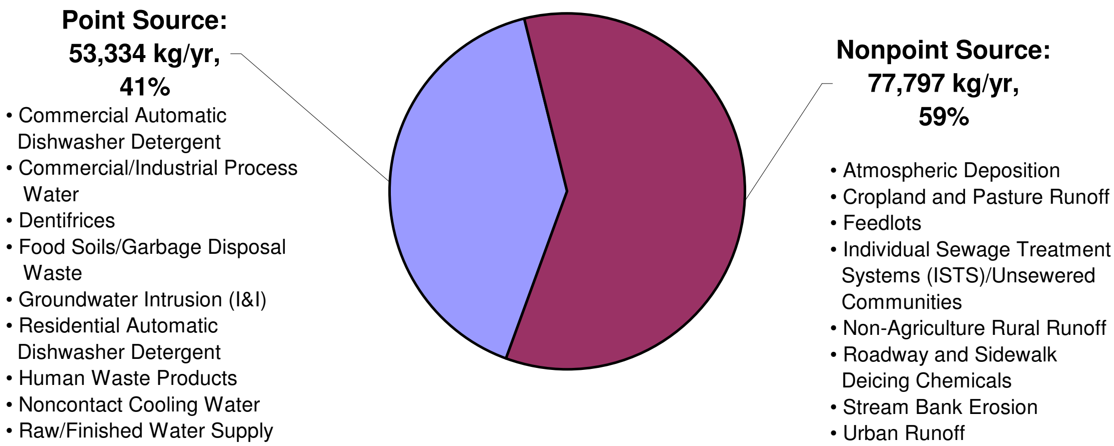
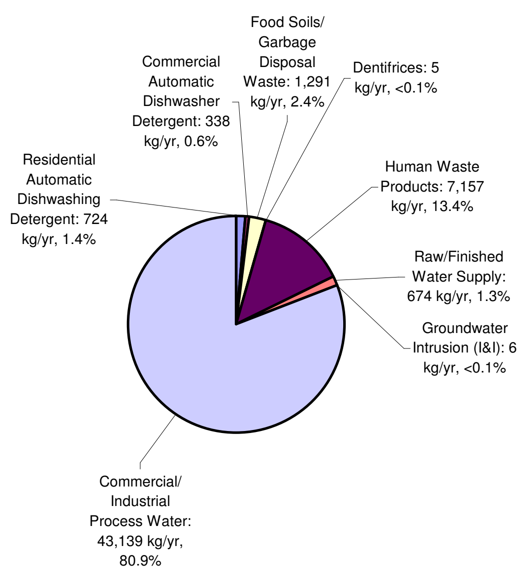


Figure 3-74

Estimated Bioavailable P Contributions to Minnesota Surface Waters
Des Moines River Basin
Wet, High Flow Water Year

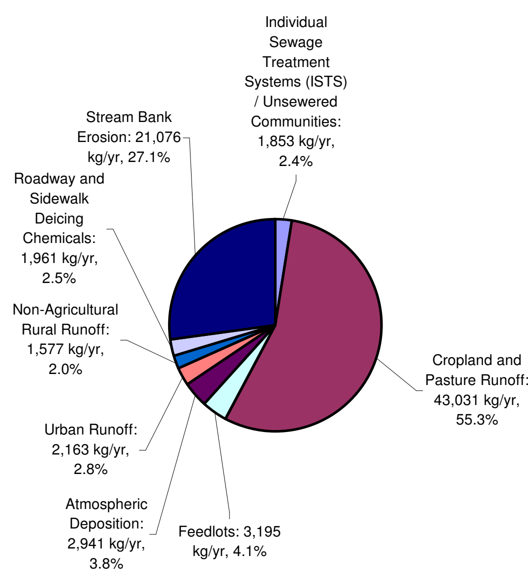


Point Source Bioavailable P Contributions



(Based on data from NPDES/SDS Permit Discharge Monitoring Reports, 2001 through mid-2003.)

Nonpoint Source Bioavailable P Contributions



3.5 Comparison of Total Phosphorus Loadings from All Sources With Monitored Loadings in Minnesota and Upper Mississippi River Basins

The estimates of phosphorus loadings to surface waters, with the best estimates for each flow condition presented in Sections 3.2 through 3.4, were independently determined for each source category. This section is intended to provide a comparison between the total phosphorus loadings from all sources with the major basins that have no upstream basins and their watershed area primarily within Minnesota as a way of validating that the combined estimates for all of the source categories are appropriate. Also the published phosphorus loading estimates were compared with the basin loading estimates in Appendix K, completed for this study. The following discussion provides a review of monitored loads compared to loads to surface waters for the Upper Mississippi River and Minnesota Basins.

Phosphorus loads were given in the National Water-Quality Assessment Program (NWQAP) report (USGS, 2002) for the Minnesota River at Jordan and the Mississippi River at Anoka for water years 1997 and 1998 which were assumed to represent wet and average years, respectively. Loads were converted to metric tons per year and prorated to the basin total with the basin gaged area multiplier (total Minnesota basin area divided by monitored basin area; 0.992 in the Minnesota River, 1.052 in the Mississippi River). The values were compared to the water year loads listed in Appendix K as follows:

<u>Upper Mississippi River Total Phosphorus Loads, metric tons/yr.</u>

	1997	1998
NWQAP (USGS, 2003)	1,010	662
Appendix K	1,273	997 (average of average flow year)

<u>Minnesota River Total Phosphorus Loads, metric tons/yr.</u>

	1997	1998
NWQAP (USGS, 2003)	2,686	1,252
Appendix K	2,275	1,254 (average of average flow year)

The following discussion presents total estimated phosphorus loads to surface waters from all of the sources evaluated in this study for the Mississippi and Minnesota River basins. Significant downstream point source loading estimates have been subtracted from those loads so values can be compared to the loads at the basin monitoring location.

	Upper Mississippi River Basin		
	Dry	Average	Wet
Load to Surface Waters	1,082	1,446	2,280
Outlet Monitored Load	508	997	1,545
	Minnesota River Basin		
	Dry	Average	Wet
Load to Surface Waters	795	1,291	2,290
Outlet Monitored Load	475	1,291	2,290
units metric tons/yr.			

Comparing the USGS monitored loads to the sum of the source loadings, from this study, indicates that there is general agreement in both of the major basins. Some of the differences may be the result of water year versus calendar year and calculation method differences. The sum of the total phosphorus source loadings to surface waters in the Upper Mississippi River basin is significantly higher than the monitored load for the basin. This is likely because a significant portion of the phosphorus is retained or taken up by the lakes, wetlands and rivers present in the Upper Mississippi River basin's aquatic system. Unlike the Upper Mississippi River basin, the sum of the total phosphorus source loadings to surface waters in the Minnesota River basin is approximately the same as the monitored load for the basin. This may be due to any or all of the following factors:

- There is considerably less phosphorus retention available in the Minnesota River basin aquatic system, compared to the Upper Mississippi River basin
- Variability and differences associated with the load estimation methods and difference between water and calendar year comparisons
- Degree to which monitored loads are representative of each flow condition
- Residence time and amount of phosphorus present in aquatic system prior to monitored water year

3.6 Effluent Total Phosphorus Reduction Efforts by Wastewater Treatment Plants

As discussed in Section 2.2.4, several WWTPs were contacted regarding phosphorus treatment methods at their plant. The WWTPs were asked to identify the total flow into the plant, unit operations at the plant, phosphorus treatment method, influent and effluent phosphorus concentrations, estimated costs for phosphorus treatment, and methods used for limiting phosphorus input to the WWTPs. The WWTPs ranged in size (0.7 to 24 million gallons per day), treatment methods (chemical and/or biological phosphorus removal), and phosphorus discharge requirements (0.07 mg/L to 2.41 mg/L). All of the WWTPs surveyed were activated sludge plants. This section summarizes the findings of the WWTP surveys, for a more detailed description of each WWTP see Appendix L. Phosphorus removal performance data for each of the WWTPs surveyed are presented in Table 3-20. Average wet weather design flow (AWWDF) and additional information regarding significant industrial users (SIUs) are included in Table 3-20 and Appendix L, respectively. Pond systems were not evaluated for this study, but it should be noted that pond systems are capable of removing phosphorus by batch chemical treatment prior to controlled discharges.

Four of the eight WWTPs used chemical treatment only for phosphorus removal. The chemicals used were either alum or ferric chloride. The WWTPs are described below in order from the lowest total phosphorus discharge requirement (0.3 mg/L, Bemidji, MN) to the highest (2.41 mg/L, Mankato, MN):

- The Bemidji WWTP is the first WWTP discharge into the Mississippi River, just upstream of Lake Bemidji. A phosphorus effluent limit of 0.3 mg/L total phosphorus or less is required as part of the NPDES permit. To meet the NPDES requirements, the WWTP uses alum for phosphorus precipitation and polymer for suspended solids precipitation. The alum and polymer are added after the activated sludge aeration basin but before the secondary clarifier. The average total phosphorus concentration entering the plant is 7 mg/L and the average total phosphorus concentration discharging from the plant is 0.15 mg/L. Bemidji does not have any significant industrial users, so the phosphorus entering the plant is primarily from domestic sources. This system has an average flow of 1.15 MGD. Costs for phosphorus removal were based solely on alum costs. A treatment cost of $3.25 per pound of total phosphorus removed was calculated using the average influent and effluent total phosphorus concentrations, the average flow, and alum costs for a year.

- The St. Croix Valley WWTP discharges into the St. Croix River/Lake St. Croix at Oak Park Heights, Minnesota and is one of the WWTPs operated by the Metropolitan Council. A phosphorus effluent limit of 0.8 mg/L total phosphorus or less is required as part of the NPDES permit. To reach the NPDES requirements, the WWTP uses alum for phosphorus precipitation. The alum is added at the inlet to the primary clarifier. The average total phosphorus concentration entering the plant is 4.8 mg/L and the average total phosphorus concentration discharging from the plant is 0.45 mg/L. This system has an average flow of 3.4 MGD. Costs for phosphorus removal were based solely on alum costs. A treatment cost of $0.96 per pound of total phosphorus removed was calculated using the average influent and effluent total phosphorus concentrations, the average flow, and alum costs for a year.

- The Rochester WWTP discharges into the Zumbro River upstream of Lake Zumbro. A phosphorus effluent limit of 1 mg/L total phosphorus or less is required as part of the NPDES permit. To reach the NPDES requirements, the WWTP uses ferric chloride and alum for phosphorus precipitation and polymer for suspended solids precipitation. The ferric chloride is added to the primary clarifier and alum and polymer are added to the secondary clarifier. The average total phosphorus concentration entering the plant is 7.5 mg/L and the average total phosphorus concentration discharging from the plant is 0.7 mg/L. Rochester has several significant industrial users that discharge to the WWTP. Daily maximum and monthly average total phosphorus limits are set for significant industrial users to limit the phosphorus discharged to the WWTP by industry. This system has an average flow of 14 MGD. A treatment cost of $1.76 per pound of phosphorus removed was given by the Rochester Environmental Coordinator. Since no further description of the treatment costs was given, it was assumed that treatment costs were based solely on chemical costs.

- The Mankato WWTP discharges to the Minnesota River at Mankato. A phosphorus discharge cap of 20,000 kg/yr (2.41 mg/L at 6 MGD) of total phosphorus is required as part of the NPDES permit, with a phosphorus discharge goal of 15,700 kg/yr (1.89 mg/L at 6 MGD). To achieve the NPDES effluent limits, the WWTP uses ferric chloride for phosphorus precipitation and polymer for suspended solids precipitation. The ferric chloride is added at the influent of the WWTP and is settled out in the primary clarifier. Polymer is added to the secondary clarifier for solids precipitation. The average total phosphorus concentration entering the plant is 8.0 mg/L and the average total phosphorus concentration discharging from the plant is 1.88 mg/L. This system has an average flow of 6 MGD. Mankato has several significant industrial users (SIUs) that discharge to the WWTP. SIUs are allowed to discharge 1 kg/day of total phosphorus, which is averaged on an annual basis, at no charge. Any discharge above this loading is charged a fee. The fee is based on the treatment costs and phosphorus treatment efficiency for the year and includes chemical costs, biosolids disposal, maintenance, utilities, and lab analysis. Capital costs are not included. The treatment cost is approximately $1.70 per pound of phosphorus removed ($3.75 per kg). In comparison, the cost for phosphorus removal using chemical costs alone was $0.70 per pound of phosphorus removed. The all-inclusive costs are 2.3 times greater than the chemical only costs. This was the only facility in the survey that provided more inclusive costs for chemical phosphorus removal.

Four of the eight WWTPs used enhanced biological phosphorus removal (EBPR). In addition to EBPR, three of the four plants surveyed also use chemical treatment to meet total phosphorus discharge requirements below 1 mg/L. The WWTPs are described in order from the lowest total phosphorus discharge requirement (0.07 mg/L, Durham and Rock Creek WWTPs, Oregon) to the greatest (monitoring only, St. Cloud). Listed below is a brief description of the WWTPs that used EBPR:

- The Rock Creek and Durham WWTPs are located just west of Portland, Oregon in the Tualatin Watershed and have one of the lowest phosphorus discharge requirements in the United States of approximately 0.07 mg/L total phosphorus. The average flow for the Durham WWTP is approximately 20 MGD and the Rock Creek WWTP is 24 MGD. The average total phosphorus influent concentration is 7 mg/L for both plants. Each WWTP has a mass-based monthly median total phosphorus discharge of 9 lb/day (0.07 mg/L total phosphorus based on the average flow rate for each plant) during the summer (May – October). The Rock Creek and Durham WWTPs use EBPR and two-point alum addition to meet the stringent 0.07 mg/L total phosphorus discharge requirement. Pilot testing and full scale system modifications were required to reach the high level of phosphorus removal achieved by these plants. Alum is added to the primary clarifier prior to EBPR, total phosphorus concentrations after alum treatment in the primary clarifier and EBPR are approximately 0.5 mg/L. After the first alum treatment and EBPR, alum is added to the secondary clarifier; the effluent from the secondary clarifier is then filtered for an average total phosphorus effluent concentration of 0.05 mg/L. Prior to implementing EBPR, the Durham facility only used chemical treatment (alum) for phosphorus removal. Significant cost savings were observed once enhanced biological phosphorus removal was implemented at the Durham facility (i.e., the chemical costs for alum were cut by one third). Chemical costs for the facility are now approximately $0.47 per pound of total phosphorus removed. The pilot test and plant modifications to achieve EBPR at the Durham facility cost approximately $900,000. Because of the public awareness of phosphorus discharge into this sensitive watershed, industries have voluntarily reduced phosphorus discharges.

- The Ely WWTP discharges into Shagawa Lake. The NPDES discharge requirement is 0.3 mg/L total phosphorus. EBPR and chemical addition of alum are used to meet the NPDES discharge requirements. The average annual flow into the WWTP is approximately 0.7 MGD. Lime had originally been used at the Ely plant for chemical precipitation, but because of the high cost associated with lime treatment, the plant switched to alum. When EBPR does not meet the discharge requirement alum is added to the mixing zone of the secondary clarifier. The secondary clarifier effluent is then passed through sand filters; the final total phosphorus average effluent discharge concentration is 0.2 mg/L. For short periods of time, the WWTP has been able to achieve 0.05 mg/L total phosphorus discharge concentrations. It was estimated by the WWTP superintendent that the costs associated with phosphorus removal are approximately 25% of the annual operating budget. Therefore, the estimated cost for phosphorus treatment is approximately $20 per pound of phosphorus removed. This WWTP does not have any significant industrial users discharging to the WWTP; therefore, the phosphorus source is primarily from domestic dischargers. Phosphorus influent to the plant was significantly reduced in the early 1980's by educating the public on limiting the use of phosphorus in detergents. As estimated by the WWTP superintendent, the total phosphorus influent to the WWTP was reduced from 12 to 15 mg/L prior to public education to approximately 5 mg/L after public education.

- The St. Cloud WWTP uses EBPR for phosphorus removal. The discharge from this WWTP is into the Mississippi River at St. Cloud. This WWTP was not initially designed for EBPR. In 1996 the City of St. Cloud modified the existing wastewater treatment plant to improve energy efficiency by replacing the coarse air diffusers in the aeration basin with fine air diffusers. In addition to the energy efficiency improvements, the WWTP was modified for EBPR by installing an anaerobic zone in the first pass of each aeration tank. The average flow into the WWTP in 2002 was 10.6 MGD and the average total phosphorus influent in 2002 was 5.0 mg/L; after EBPR the average effluent total phosphorus is 0.93 mg/L. The St. Cloud WWTP NPDES discharge permit requires monitoring of effluent total phosphorus and development and implementation of a phosphorus management plan. The City of St. Cloud implemented a Phosphorus Management Plan (PMP) in 2001, with a primary goal of limiting the amount of phosphorus coming into the facility by means of pollution prevention and public outreach. The goal of the pollution prevention program is to assist non-domestic nutrient contributors (NDNC) in developing phosphorus reduction strategies that will reduce the amount of phosphorus that enters the wastewater collection system and eliminate phosphorus slug loads. The city works with industrial users to keep phosphorus discharges to the WWTP below 6 mg/L. This method is effective at reducing spike loads and the average influent phosphorus concentrations. Comparing the 95% confidence limits of the average influent phosphorus concentrations prior to implementation of the PMP (7.72 mg/L ± 1.22 mg/L, 2000) to the 95% confidence limits of the average influent phosphorus concentrations after implementation of the PMP (5.03 mg/L ± 0.14 mg/L, 2002), there has been a significant reduction and less variability in the average phosphorus influent concentration. The lowering and stabilization of the influent total phosphorus concentration is also credited in decreasing the average total phosphorus effluent concentration from 2.01 mg/L in 2000 to 0.93 mg/L in 2002.

The following discussion summarizes the conclusions of the aforementioned survey done to evaluate phosphorus reduction efforts by wastewater treatment plants:

- The cities implementing source reduction programs all achieved significant reduction in phosphorus loading on their WWTPs using a variety of methods: public outreach, phosphorus bans, surcharges for phosphorus treatment, and maximum limits on SIU phosphorus discharges.

- The St. Cloud WWTP showed that a reduction in influent phosphorus loading and phosphorus slug loads lead to a reduction in effluent phosphorus concentration.

- Chemical treatment is capable of reaching the lowest phosphorus effluent concentrations.

- The cost per unit of total phosphorus removed varied from $0.96 to $20.00 per pound of total phosphorus removed. Some of this variation appears to be the result of various cost calculation techniques. The cost of treating phosphorus chemically appeared to show an economy of scale.

- The cost for chemical treatment was lower for those WWTPs that used a combination of EBPR and chemical treatment.

- EBPR alone is generally effective at achieving 0.5 mg/L to 1 mg/L effluent phosphorus concentrations. Chemical addition is necessary to achieve effluent phosphorus concentrations less than 0.5 mg/L. One of the best available bio/chemical treatment facilities (Durham WWTP, OR) was able to achieve an average effluent phosphorus concentration of 0.05 mg/L. To reach this low effluent concentration, significant pilot testing was required and phosphorus removal efficiency was dependent upon wastewater characteristics.

- Once the initial capital improvements are made there are no additional costs associated with phosphorus removal using EBPR.

- In some cases EBPR can be implemented with simple process modifications (e.g., St Cloud aeration modifications) that achieve reductions in effluent phosphorus concentrations. St Cloud was able to achieve an effluent phosphorus concentration of 0.93 mg/L with this approach.

It should also be noted that the data used for this study is from the years 2001, 2002 and the first half of 2003. During that time period many POTWs (Blue Lake, Seneca and quite a few other cities) have implemented phosphorus removal or will begin to implement it in the future.

As population growth occurs, and POTW flows increase, if effluent concentrations remain constant there will be corresponding increases in total phosphorus loadings.

Table 3-20 Wastewater Treatment Plant Phosphorus Removal Summary

Treatment Plant	Treatment Method	Average WWDF (MGD)	Average Flow (MGD)	TP Influent (mg/L)	Average TP Effluent (mg/L)	Treatment Cost	Total Phosphorus NPDES Requirement
Ely	EBPR and alum after activated sludge and before secondary clarifier when necessary and sand filtration	3	0.7	5	0.2	$20/lb All inclusive	0.3 mg/L
Bemidji	Alum & polymer after activated sludge and before secondary clarifier	2.5	1.15	7	0.15	$3.25/lb TP Chemical only	0.3 mg/L
St. Croix Valley	Alum in primary clarifier inlet	5.8	3.4	4.8	0.45	$0.96/lb TP Chemical only	0.8 mg/L
Mankato	Ferric chloride at influent and polymer at belt filter for sludge dewatering	11.25	6	8	1.88	$1.70/lb TP all inclusive $0.74/lb Chemical only	20,000 kg/yr (cap) = 2.41 mg/L TP at 6 MGD and 15,700 kg/yr (goal) = 1.89 mg/L at 6 MGD
St. Cloud	EBPR	26	10.6	5.03	0.93	NA	ND
Rochester	Ferric chloride in primary; alum & polymer in secondary	19.1	14	7.5	0.7	$1.76/lb TP Chemical only	1 mg/L
Durham WWTP (Tigard, OR)	Alum in primary, EBPR, alum in tertiary, and filtration	NA	20	7	0.05	$0.47/lb TP Chemical only	9 lb/day monthly median = approx. 0.07 mg/L at current flow
Rock Creek (Hillsboro, OR)	Alum in primary, EBPR, alum in tertiary, and filtration	NA	24	7	0.05	$0.47/lb TP Chemical only	9 lb/day monthly median = approx. 0.07 mg/L at current flow

Key:
EBPR = Enhanced Biological Phosphorus Removal
NA = Not Available
MGD = Million Gallons per Day
TP = Total Phosphorus
ND = Not Determined

4.0 Recommendations

4.1 Recommendations for Lowering Phosphorus and Associated Water Quality Benefits

This section provides recommendations for lowering phosphorus loadings to surface waters from each source category, along with general discussions about the associated water quality benefits, where appropriate.

4.1.1 Point Sources

The recommendations for lowering the phosphorus export are presented in two parts. The first part discusses recommendations for lowering phosphorus amounts discharged to POTWs and the second part discusses recommendations for lowering the point source phosphorus amounts discharged to basins and statewide. A more detailed discussion is included in Appendix B.

4.1.1.1 Phosphorus Loading to POTWs

The results of this study are intended to assist the MPCA in complying with MN Laws 2003, Chap. 128 Art. 1, Sec. 122., as follows:

The state goal for reducing phosphorus from non-ingested sources entering municipal wastewater treatment systems is at least a 50 percent reduction developed by the commissioner under section 166, and a reasonable estimate of the amount of phosphorus from non-ingested sources entering municipal wastewater treatment systems in calendar year 2003.

For purposes of complying with this legislation, this study has estimated that the current non-ingested phosphorus load entering POTWs is 2,573,000 kg/yr. A 50 percent reduction would require decreasing the phosphorus discharged to POTWs by least 1,286,000 kg/yr. The applicability of reduction tactics for each of the non-ingested sources entering POTWs are discussed in descending rank order, by component, below:

- Next to human wastes, a variety of industrial and commercial dischargers contribute the most phosphorus to POTW influent streams. The contribution of phosphorus from these commercial and industrial sources accounts for approximately 46 percent of the non-ingested phosphorus load discharged into POTWs. Total removal of phosphorus from commercial and industrial wastewater is not expected to be feasible. In most cases, reduction would have to come from resource/product substitution, waste minimization through recycling and reuse, improvements in technology, and through pretreatment of wastewater prior to discharge to the POTW. Reducing the commercial and industrial phosphorus contribution to POTWs by one half would reduce the total non-ingested phosphorus discharged to POTWs by almost 23 percent. Excise taxes and/or effluent strength charges may be useful in reducing this influent source of phosphorus.

- Food soils and garbage disposal wastes account for approximately 28 percent (725,000 kg/yr) of the non-ingested phosphorus discharged to POTWs. This is a substantial amount, but it is unlikely amenable to direct modification (e.g. product modification), or prohibiting discharge of food wastes into the sewer systems. Approximately 25 percent of the phosphorus from this source is discharged into the sewer system as garbage disposal waste. Garbage disposal waste could be sent elsewhere (trash, compost, etc.) but it would be more difficult to manage the phosphorus from dish rinsing and dish washing. Short of inducing the food product industries to reduce their use of phosphates or eliminating garbage disposals and discharge of food wastes down the drain, relatively little appears possible for reducing this phosphorus load to POTWs. Public education may be the best option to reduce discharge of food wastes down the drain.

- Residential ADWD detergent contributes approximately 7.3 percent or 326,000 kg/yr to the total influent phosphorus load discharged into POTWs and almost 13 percent of the non-ingested phosphorus load. Eliminating all phosphorus from residential ADWD detergents would reduce the non-ingested phosphorus load discharged to POTWs by almost 13 percent. Although there has been a slight decline in the consumption of phosphorus for residential ADWD detergents, SRI states that it is unlikely that detergents with much lower phosphorus contents will be available in the near future. Currently, at least one brand of ADWD does not contain phosphorus; the phosphorus content of other brands varies significantly. Advertising and prominent content labeling would help reduce this source by aiding consumers in choosing low phosphorus products. Public education about the use of ADWD based on hardness and the availability of no- and low-phosphorus content products should be encouraged.

- Commercial and institutional ADWD detergent contributes a statewide average of approximately 6 percent (152,000 kg/yr) of the influent non-ingested phosphorus load discharged into POTWs. Public education about the use of ADWD based on hardness and the availability of no- and low-phosphorus content products should be encouraged.

- The influent phosphorus loads to POTWs from water supply chemicals were estimated to average approximately 5.5 percent of the non-ingested phosphorus load to POTWs statewide. Use of phosphorus for sequestration of metals typically is an aesthetics issue. On the other hand, corrosion control of lead and copper is a human health issue and is required by law for those communities that do not pass the state corrosion tests. One option would be to substitute alternative water treatment chemicals in place of those with phosphorus.

- Dentifrices account for less than two percent of the total non-ingested phosphorus load to POTWs. Because the phosphorus load from this source is so minimal, it does not warrant major steps to reduce phosphorus discharges from toothpastes and denture cleaners.

- The results of this study indicate that inflow and infiltration contribute a negligible amount of phosphorus to POTW influent. There are reasons to limit inflow and infiltration into sewer systems, such as to prevent hydraulic overloading of treatment facilities, but the reduction of influent phosphorus is not one of them.

Given that food soils would be very difficult to reduce, and that dentifrices and I & I contribute so little to the influent phosphorus load discharged to POTWs, it is recommended that reduction efforts focus on residential ADWD, commercial and industrial process wastewater, commercial and institutional ADWD, and water treatment chemicals. A summary of the phosphorus load discharged to POTWs and the reduction potential is presented in Table 4-1.

Table 4-1 Reduction Potential for Phosphorus Loads to POTW

Summary		**Portion of Total Load to POTW**
Total Phosphorus Load Discharged to POTWs	4,468,000 kg/yr	
Human Waste	1,900,000 kg/yr	43
Non-ingested Waste	2,573,000 kg/yr	57
Phosphorus Source	**% Reduction to Non-Ingested Phosphorus Load (%)**	**Cumulative Reduction to Non-Ingested Phosphorus Load (%)**
Residential ADWD reduced to 0	13	13
Commercial ADWD reduced to 0	6	19
Commercial and Industrial reduced by one half	23	42
Total Reduction		**42**

If residential and commercial/institutional ADWD and water treatment chemicals were eliminated completely, the required commercial and industrial process wastewater reduction is estimated to be more than 64 percent. Given that it will be difficult to completely eliminate commercial/institutional ADWD and water treatment chemicals and reduce the commercial and industrial process wastewater loading by more than 64 percent, a 50 percent reduction in the total non-ingested phosphorus contribution to POTWs appears to be an ambitious goal.

4.1.1.2 Phosphorus Loading to Surface Waters

Phosphorus effluent from POTWs represents, on average, more than 80 percent of the total point source loads to waters of the state. The largest source of phosphorus is from large (> 1.0 mgd) POTWs and phosphorus reduction efforts should begin at these facilities. As discussed previously, many POTWs have implemented phosphorus removal and others will begin to implement it in the near future. The lowest effluent limits to date have been 1 mg/L with two exceptions, the Bemidji and Ely WWTPs are treating to levels at or below 0.3 mg/L.

Privately owned wastewater treatment systems account for less than 0.5 percent of the total point source phosphorus discharged to the basins and increased phosphorus removal at these facilities will not have a large impact on the statewide point source phosphorus load.

Commercial and industrial dischargers to the basins constitute approximately 18 percent of the point source phosphorus load. It was not within the scope of this study to categorize the phosphorus loading data by NAICS code number or to determine which industries are the largest contributors. However, it is recommended that industrial dischargers that make major contributions to the phosphorus loadings be evaluated in further detail.

4.1.2 Cropland and Pasture Runoff

Four alternative agricultural management scenarios were investigated and compared to a baseline scenario involving an average climatic year and existing rates of adoption of conservation tillage and existing rates of phosphorus fertilizer applications.

The potential future impacts of improved phosphorus fertilizer management can be quite significant. Reductions in phosphorus fertilizer usage could occur if University of Minnesota recommendations were followed more consistently. For instance, phosphorus fertilizer and manure is spread on significant areas of land in the Minnesota River basin even if soil test phosphorus levels exceed the threshold set by the University above which crops do not respond to additional fertilizer. This is because recommendations made by the fertilizer industry are often based on the concept of fertilizing at a rate equivalent to crop removal, if soil test phosphorus levels are above 21 ppm. Excess applications in the past were considered cheap forms of insurance for crop yield needs and since even high soil phosphorus levels were wrongly perceived not to be released from soils the environmental impact was considered minimal. In the Minnesota River basin, reductions in the rate of phosphorus fertilizer and manure application could potentially reduce phosphorus losses to surface waters by about 81,000 kg/yr as compared to existing conditions, for a 16% reduction. Comparable levels of reduction could occur with improved phosphorus fertilizer management in the Red River, and the Upper and Lower Mississippi River basins.

The potential impact of improved manure application methods is significant in the Red River basin. Phosphorus loads to surface waters reduction estimates are about 75,000 kg/yr, for a 20% reduction in the Red River basin. Reductions are estimated to be much smaller in other basins with significant phosphorus loads from agricultural land. Improved manure application methods are estimated to reduce phosphorus loads to surface waters by 12%, 7% and 7% in the Upper Mississippi, Lower Mississippi, and Minnesota River basins. In general, the effects on phosphorus loads of improvements in method of manure application are greatest for basins that have large numbers of beef cattle, and least for basins with large numbers of hogs.

The last scenario involves decreasing or increasing the area of cropland within 100 m of surface waterbodies. Decreases in area of cropland could correspond to land retirement programs such as those promoted in the Conservation Reserve and Conservation Reserve Enhancement Programs. Increases in cropland area would correspond to putting grass or forest riparian areas into production, alternatively this could be viewed as increasing the amount for cropland areas that contribute phosphorus to surface waters. The results from this scenario indicate that retiring land in close proximity to surface waters would decrease the phosphorus loadings as expected. Retiring land farther away has diminishing returns as the distance from surface waters increases. It should be noted that throughout most of Minnesota, we believe that the risks of phosphorus transport to surface waters are greatest in the contributing corridor within about 100 m from surface waterbodies. Due to topographic variations along surface waterbodies, in some areas phosphorus contributions from overland runoff and erosion may occur from as far away as several hundreds of meters. In contrast, where berms are present along waterbodies it may be unlikely for a significant amount of surface runoff or erosion to enter surface water. Thus, the 100 m contributing corridor should be viewed as a regional average for contributions of P to surface waters from runoff and erosion on adjacent cropland.

4.1.3 Atmospheric Deposition

Soil dust is expected to be the largest source of atmospheric phosphorus. Therefore, reducing soil dust, particularly from agricultural fields, through the application of best management practices (shelterbelts, no till planting, use of cover crops, etc.) would seem to be a high priority. Another potential activity on a much smaller and local scale to reduce soil dust might include the periodic wetting of exposed soil at large construction sites during dry periods to minimize soil dust being entrained into the air due to wind erosion.

4.1.4 Deicing Agents

Efforts currently underway, as part of MnDOT's road weather information system (RWIS), use timely and accurate weather and road data in deicing application decisions to optimize the use of deicing materials. The Minnesota Legislative Auditor (1995) reported that "(M)ost counties (93 percent), cities providing their own service (91 percent), and townships providing their own service (59 percent) rely on television or radio weather reports, including the National Weather Service reports via telephone, for weather information." More accurate weather information could lead to reduced usage of deicing agents. The use of brines can also improve the effectiveness of deicing agents and thereby reduce the overall use of deicers.

The high phosphorus content of many of the agriculturally derived alternatives to road salt is noteworthy. In most cases the high phosphorus content for these alternatives is due to the corrosion inhibitor portion of the mixtures. Since concern for the environmental impacts of chlorides has increased, additional emphasis may be placed on the use of these alternatives. While this analysis does not make any attempt to quantify what those impacts would be, a review of the literature shows that many of these products have phosphorus concentrations 100 to 10,000 times greater than road salt or sand.

4.1.5 Streambank Erosion

There is the potential for substantial water quality benefits associated with lowering phosphorus export from streambank erosion; including reduced eutrophication, reduced sedimentation and improved biological habitat within reservoirs, lakes and wetlands, along with the river systems themselves. Careful land use planning that considers the potential adverse impacts associated with increased runoff volumes; well-designed stream road crossings that consider the potential hydrodynamic changes to the system; exclusion or controlled access of pastured animals and preservation of riparian vegetation; and rotational grazing. There are opportunities to reduce streambank erosion in watersheds that have experienced flow volume increases from land use changes.

4.1.6 Individual Sewage Treatment Systems/Unsewered Communities

Many of the counties are delegated to implement the Minnesota Rules (Chapter 7080) for ISTS, which require conformance with state standards for new construction and disclosure of the state of the existing ISTS when a property transfers ownership. Several counties require ISTS upgrades at property transfer. Lack of knowledge is thought to be a major impediment to making more rapid progress toward goals and objectives for ISTS and undersewered communities (MPCA, 2003b). This includes a lack of awareness of compliance requirements, management and operational requirements, and the environmental consequences of widespread system failure. The complexity of addressing undersewered community issues tends to discourage county compliance activity in this area. The availability of financial assistance, particularly low-interest loans, is thought to be an essential catalyst to accelerating fixes of nonconforming ISTS. This and other forms of financial assistance are needed to accelerate progress with undersewered communities (MPCA, 2003b).

Owners of ISTS that pose an "Imminent Public Health Threat," through direct discharge to tile lines or surface ditches or systems seeping to the ground surface should be identified through a statewide survey to help residents determine whether their ISTS are adequately treating and disposing of sewage below grade. Programs proposed to follow up on specific problems include homeowner education on compliance requirements and financial assistance to owners needing new systems. Residents of unsewered communities should be targeted to help them understand the need for wastewater treatment and assist them through each phase of the community decision-making process, while building the capacity of local and regional government staff to provide such assistance to other communities in the future (MPCA, 2003b). LUG ISTS permitting and inspection programs should be targeted with MPCA audits to determine adequacy of performance in a number of key areas, including spot checks on conformance on new ISTS installations, level of effort on ISTS inspections and follow-through on replacement of noncompliant systems, and dealing with problem ISTS professionals (MPCA, 2003b).

Since septic system failure is a widespread problem, a basinwide approach to addressing nonconforming systems with potential for high delivery of pollutants to public waters, such as straight pipe discharges and other types of ITPHS should be given priority attention. The LUGs should work with the MPCA to develop, populate and maintain a database, similar to MPCA's feedlot database that shows where each of the nonconforming systems, especially straight pipe discharges and other types of ITPHS are located. LUG personnel should be provided with an incentive to inventory all systems within their jurisdiction, and track system performance and maintenance.

4.1.7 Non-Agricultural Rural Runoff

The protection of natural areas is needed to insure they retain the hydrologic and ecologic functions that keep surface runoff volumes low, nutrient export low and groundwater recharge rates high. Many natural areas are under stress due to development pressures, invasion by exotic species and increased nutrient loading from adjacent land uses. While the statewide percentage of land cover represented by these natural plant communities is only 23%, they provide valuable ecologic and hydrologic value. All land use decisions should consider the loss of these functions, and provision of economic mechanisms that allow landowners to retain these functions.

Conservation easements, such as CREP and RIM, provide additional opportunities for reducing phosphorus export from contributory watershed areas. The impact of these easements on phosphorus export from converted agricultural lands is evaluated in greater detail as part of the analysis discussed in Appendix C.

4.1.8 Urban Runoff

The design, construction and maintenance of watershed BMPs will help reduce pollutant loads to surface waters. However, the current dependence of watershed managers and regulators upon "NURP-type" ponds will not prevent the degradation of surface water resources due to increased phosphorus loadings. While the NURP-style ponds can remove particulate phosphorus, they are relatively ineffective at removing soluble phosphorus (which can comprise up to 50% of the phosphorus in urban runoff). The phosphorus removal efficiency of ponds are also only in the 40 to 50 percent range, so that in many urban developments, the phosphorus load increase exceeds the removal efficiency of ponds. The ponds required by regulators to mediate the increased runoff therefore do not fully mitigate the increases in runoff loads. In essence the BMP treatment, whether ponds or otherwise, never keeps the post-development loadings at pre-development levels once impervious area surpasses 40 – 50% (Schueler, 1995). Another problem is that many urban planners assume that urban turf grass is an effective infiltrator of runoff, when in reality, most urban turf grows on highly compacted soils and can have a runoff rate of up to 45% during large storm events (Schueler, 1996a, 1996b; Legg, *et al*, 1996). Urban soils need to be protected from compaction during development/construction activities and likewise need to be actively managed to reduce compaction and increase infiltration over the long term. Water quality protection requires that all urban development design use a water budget approach, where the preservation of the infiltration and evapotranspiration components of the hydrologic cycle are primary considerations. Site planning that reduces impervious surface area and preserves infiltration will help attain water quality protection. Caraco, et al (1998) recommends that site design in urban areas create urban spaces that:

- Reduce impervious cover
- Spread runoff over pervious areas
- Utilize open channel drainage
- Conserve forests and natural areas
- Reduce the amount of managed turf and lawn
- Create more effective stream buffers and riparian areas

A number of stormwater management and urban best management practices manuals are available that provide design guidance for controlling the impacts of urban runoff and promoting infiltration (Metropolitan Council, 2001; Schueler, 1995; Brach, 1989; US EPA. 2001).

The National Pollutant Discharge Elimination System (NPDES) permit administered by the MPCA regulates runoff from construction sites, industrial facilities and municipal separate storm sewer systems (MS4s) to reduce the pollution and ecological damage. Phase I focused on large construction sites, 11 categories of industrial facilities, and major metropolitan MS4s. Phase II broadened the program to include smaller construction sites, small municipalities (populations of less than 100,000) that were exempted from Phase I regulations, industrial activity, and MS4s. At a minimum, compliance with the stormwater pollution prevention planning requirements of this permit program is critical to minimize the phosphorus loadings associated with urban runoff.

4.2 Recommendations for Reducing Uncertainty and Error Terms in Future Refinements

This section provides recommendations for reducing uncertainty and error in the estimated phosphorus loadings to surface waters from each source category, as part of any future refinements that may be made to this analysis.

4.2.1 Point Sources

The variability and uncertainty associated with the point source data sources has been discussed throughout this report. The following paragraphs provide a discussion of the variability and uncertainty associated with each data source and recommendations for future refinements. A more detailed discussion is included in Appendix B.

Each station under each permit in the Delta database is coded to list the type of discharge: surface water, land application, spray irrigation, internal waste stream, etc. Because this information is submitted by permitees for entry into Delta by MPCA staff, there may be some error due to interpretation and it is possible that some discharge stations may have been miscategorized.

There are several areas of uncertainty associated with the influent and effluent phosphorus loading estimates. These estimates are based on the flow data discussed above and the average annual phosphorus concentration. In many cases, phosphorus concentration data was limited to a few data points or not available at all. It was necessary to estimate the phosphorus concentration for many of the permitees. In addition, there was some variability among the phosphorus data for a permit when it was available. This identified a need for good laboratory analysis of phosphorus and reporting of quality assurance data. The study used annual average flowrates multiplied by the average annual phosphorus concentration to estimate the annual phosphorus load. The load could also have been calculated on a daily basis or monthly basis and then the average annual load calculated, resulting in different values.

Many of the influent phosphorus sources are based on per capita values and there is some uncertainty associated with the available population data. Approximately 230 of the 576 POTW and privately owned treatment facilities had population data listed in the Delta database. An attempt was made to validate some of the data, but due to the number of permits, it was not possible to verify all of the population data received.

Data was collected on commercial and industrial dischargers to the MCES system and several out-state POTWs. However, not all of these facilities had phosphorus monitoring data. The phosphorus data that was available was often based on a limited number of sampling events and there was some variability between industries with similar NAICS code numbers. For the unmonitored facilities, most of the commercial and industrial process wastewater phosphorus values were estimates based on the data set collected from industrial dischargers to the MCES system and to the other communities that monitored for phosphorus. Given the limited data set, there is likely a high level of uncertainty associated with the estimates for this source.

The information on the phosphorus contribution from water supply chemicals in municipal water treatment was based on information from the MDH. While the information received is likely valid, it was not complete. Phosphorus concentrations were provided for only 120 of the 360 facilities noted as adding phosphorus. The phosphorus residual in the remaining 240 water treatment facilities was based on an estimate using the average phosphorus concentration in the other 120 communities.

The phosphorus loading from residential ADWD detergents has some uncertainty associated with it due mainly to the population estimates. While the annual consumption of phosphorus in ADWD detergents reported (SRI, 2002) is likely an accurate number, the loading to the Minnesota basins was estimated based on a per capita value calculated from this national total. Because this estimate also relied on population data, there is some additional uncertainty associated with it due to the uncertainty in the population data discussed in a previous paragraph. The uncertainties associated with commercial and institutional ADWD detergents are similar to those discussed for the residential ADWD detergents.

The per capita value used to determine the food soils and garbage disposal waste contribution to the influent phosphorus loading to POTWs and privately owned treatment facilities was based on the average of three values obtained from studies conducted in the 1970s and 1980s, but they were in fairly good agreement. These data are more than 20 to 30 years old, which may introduce some uncertainty, since there has been a significant increase in the use of phosphorus in the food and beverage market. It follows then that there may be more phosphorus in the food disposed of down the drain. What is unknown is the trend in the amount of food and beverages disposed of down the drain. Also, because the food soils and garbage disposal wastes were based on per capita values, the loadings discharged to the treatment facilities are also based on the population served.

The method used to determine the dentifrice contribution to the influent phosphorus load to treatment facilities was based on a per capita value calculated from annual consumption in the U.S. This method assumes that Minnesota’s dentifrice use is equivalent to that as the U.S. as a whole and because this is a per capita value and there is some uncertainty due to the population data.

The inflow and infiltration flow values were obtained from MCES and are estimates based on a few data points for each of their facilities. However, because the groundwater phosphorus concentration is quite low, even large variability in the flow values will not have a large impact on the total phosphorus to the POTWs from this source.

The phosphorus loading from human waste was calculated by difference. That is, all other estimated sources of phosphorus were subtracted from the total influent phosphorus load for each facility. This method of estimating the human waste phosphorus contribution leaves some uncertainty since it is based on all of the other source estimates. Therefore, the phosphorus contribution from human waste obtained by difference was compared to literature values. Literature values for phosphorus in human waste ranged from 1.6 g/p·d (*Siegrist et al.*, 1976) to 2 g/p·d (*Strauss*, 2000). The statewide flow weighted average for phosphorus in human waste was 1.53 g/p·d.

The following recommendations are made to improve the estimates of phosphorus point source loading to the basins in Minnesota:

1. Since the commercial and industrial loadings are a significant portion of the phosphorus load, additional monitoring of industrial effluent discharged to POTWs would improve the precision of estimates presented in this component.

2. It was not within the scope of this study to present or discuss the phosphorus contribution from individual industrial contributors of phosphorus to POTWs. It is recommended that this study be expanded to determine the specific industries that constitute the major phosphorus contributors.

3. This study assumed that the influent components of the POTW's and privately owned treatment plant's phosphorus from various sources were in the effluent in the same proportions as in the influent. A study on the percentage removal for the various sources at the different type of treatment plants would provide a more accurate estimate of the source of phosphorus loads to the waters of the state.

4. Many of the phosphorus sources discharge to POTWs were based on per capita estimates. Improving the population served data for each of the POTWs would improve the accuracy of these estimates.

5. Phosphorus data were not available for all permits. Increased phosphorus monitoring (both influent and effluent) would improve loading estimates. Good laboratory analysis of phosphorus and good quality assurance procedures would insure more accurate load calculations.

6. Calculation of phosphorus loads on a monthly basis and then totaled rather than on an annual basis would improve the estimates.

4.2.2 Agricultural Runoff

4.2.2.1 Cropland and Pasture Runoff

There are many possible sources of uncertainty in the estimated phosphorus loadings. These can be divided into errors in input data, errors in converting phosphorus index values to phosphorus export coefficients, errors in estimating the proportion of cropland that contributes to phosphorus loadings, and errors due to a lack of consideration for impacts of surface and subsurface drainage, wind erosion or snowmelt runoff on phosphorus loadings. The primary sources of errors in input data include those due to spatial variations in farm management practices at scales smaller than watersheds or agroecoregions, errors in estimating slope length for erosion calculations, and errors due to out of date landuse information (all cropland estimates in the contributing corridor around surface water bodies are based on 1992 landuse data). Appendix C provides a more detailed discussion about uncertainties in these phosphorus loading estimates.

The assumption made about the contributing corridor represents a source of uncertainty. In most of Minnesota, it its believed that the risks of phosphorus transport to surface waters are greatest in the contributing corridor within about 100 m from surface waterbodies. This is consistent with research results from across the country, and with recommendations of the primary group of soil scientists conducting research on phosphorus transport to surface waters (the SERA-17 group). Due to topographic variations along surface waterbodies, in some areas phosphorus contributions from overland runoff and erosion may occur from as far away as several hundreds of meters. In contrast, where berms are present along waterbodies it may be unlikely for significant surface runoff or erosion to enter surface water. Thus, the 100 m contributing corridor should be viewed as a regional average for contributions of P to surface waters from runoff and erosion on adjacent cropland. Errors can also arise from improperly estimating the area of cropland within 100 m of surface water bodies. Also, the area of cropland within 100 m of surface water bodies was not varied when computing basin scale phosphorus loadings for dry, average, and wet years.

Our primary method of estimation does not consider the influence that surface tile intakes farther than 100 m may have on phosphorus loadings. To include the effects of surface tile intakes we would need to know the number of tile intakes per unit area, the area of cropland contributing to tile intake flow, and the phosphorus export coefficients for surface tile intakes. These data are not available for Minnesota in enough detail to be confident about their representativeness. Similarly, our primary method does not consider the influence of subsurface tile drainage on phosphorus export to surface waters. Surface and subsurface tile drainage load was estimated in the Minnesota River basin, but as concluded in Appendix B, more research is needed to accurately define the mean and range in phosphorus loading from subsurface drainage tiles. Other than the Minnesota River basin, subsurface drainage phosphorus loads were not estimated. The load from other basins would be much smaller, because tile drainage is of limited extent in basins other than the Minnesota River basin. In addition, not enough research data are available to reliably estimate the phosphorus loadings from surface tile intakes or subsurface tile drains to surface waters in the Minnesota River basin during dry or wet climatic years. As described above, this approach could substantially overestimate the phosphorus loadings in dry years.

Finally, we do not explicitly account for the effects of wind erosion or snowmelt runoff on phosphorus loadings to surface waters. Wind erosion may be particularly important in the Red River basin. It is not expected that wind erosion estimates, which represents a portion of the atmospheric deposition loadings completed for this study, would adequately account for "low level" wind blown soil deposited in drainageways. Snowmelt erosion is indirectly accounted for in the regional phosphorus index through the runoff factor, as well as in the method of manure application factor, so this error may not be large.

This study provides a broad overview of the impacts of agricultural lands on phosphorus loadings to surface waters. There are many detailed questions remaining that should be studied in further detail. Some of these are listed below:

- Comparison of watershed based phosphorus loadings with agroecoregion based phosphorus loadings at the scale of major watersheds

- Development of phosphorus delivery ratios for agricultural as well as non-agricultural sources of phosphorus as a function of area of contributing watershed, area of lake and wetland storage in the watershed, and landscape characteristics

- Investigation of the impacts that farm scale variability has on estimated phosphorus loadings within watersheds

- Further study of the distance from surface waters within which the majority of phosphorus losses from cropland to surface waters originate

- Further investigation of the variable source area concept as applied to phosphorus transport during dry, average and wet climatic years

- Further investigation of the contribution of surface tile intakes and subsurface drainage to phosphorus loads

- Study of the impact that wind erosion has on phosphorus loading to surface waters

4.2.2.2 Feedlot Runoff

There are several possible sources of uncertainty in the estimated phosphorus loadings from feedlot runoff. These sources of uncertainty are discussed in more detail in Appendix D. In addition, not all potential avenues of phosphorus transport to waters from feedlots were included in this analysis. This analysis did not include runoff from:

- Manure application sites (i.e. from spreading onto cropland) and pastures. This is handled in the report under the category agricultural runoff;

- Silage leachate runoff, which has high concentrations of phosphorus, but relatively low volumes;

- Milkhouse wastewater discharges;

- Open lots that are not included in the MPCA feedlots data base, including those feedlots that have not yet registered or those feedlots that are too small to require registration (i.e. under 50 animal units outside of shoreland). This would include many small farms with horses and livestock.

- Feedlots that do not have open lots; incidental runoff from total confinement operations is considered negligible.

- Poultry facilities and field stockpiles associated with poultry operations. Most poultry are raised in total confinement, and the relatively small number raised outside or the runoff from poultry manure stockpiles was considered negligible for basin-wide analysis.

- Runoff from pasturing animals, including animals with direct access to surface waters.

The following areas of uncertainty and variability exist in this analysis:

- **Uncertainties about animal units at open lots** - The data base used to obtain the information is incomplete. While 29,122 feedlots exist in the data base, incomplete information is available from several counties, and also many smaller feedlots were not required to register. It is possible that the actual number of all feedlots could be several thousand more than indicated in the data base. Additionally, information about the presence of open lots at 11,574 was not available. Since the missing feedlots are mostly small lots, the added phosphorus loading would not be expected to be more than 25% greater than our current estimates.

- **Uncertainties about manure P generation** – The amount of phosphorus generated by each animal type was provided from average values based on research in the Midwest. The actual P generated is increasingly being reduced through dietary measures. However, this source of variability and uncertainty is considered to be relatively minor.

- **Uncertainties about the fraction of feedlots that contribute P to surface waters** – Areas with steeper slopes and a more pronounced drainage system will have a higher percentage of open lots with runoff problems. Unpublished county-specific information used to develop the statewide average (MDA, 2003), indicates that the percentage of open lots that may contribute runoff P to surface waters varies significantly from the statewide average for several basins, but this variability was not accounted for in the analysis. Due to a lack of basin-specific information, it was decided to use the 35 percent figure statewide. It is likely that some phosphorus is delivered to waters from feedlots that are in compliance with state feedlots rules. No feedlot runoff was accounted for from feedlots that were considered to be in compliance with state feedlot rules. Also, it was assumed that all of the animals in feedlots with open lots contribute manure to the open lot. We did not have information that would allow us to differentiate which animals used the open lot and which were kept in total confinement.

- **Uncertainties about phosphorus delivery** – The FLEval model used to estimate the fraction of phosphorus delivery to waters is currently being upgraded by the University of Minnesota to improve estimates of annual phosphorus loading. Several assumptions were made for the FLEval modeling exercise that affected the estimated loading. The P loading results could be either half as much or twice as much as the study results, depending on modeling assumptions about the feedlot size (square feet per animal unit), the effect of downslope vegetation and cropland, and other model inputs. Another uncertainty is the effect that holding animals in the barns or pastures will have on reducing the fraction of P delivery to waters. Where animals are held in barns or pasture for a long enough time during the day so that less than 100 percent of the feedlot area has manure on the surface, then the phosphorus loadings would be reduced. In the model we assumed that each animal unit contributed to 200 square feet of feedlot surface that was covered with 100 percent manure. Both of these assumptions are variable and affect the modeling results, causing an overestimate of P loading for this part of the loading calculation.

Based on the primary uncertainties in this analysis we see that some are expected to result in overestimates of phosphorus loading from feedlots and others contributed to underestimates of phosphorus loadings from feedlots, as summarized below:

1. *Incomplete feedlot data base*, resulting in underestimates by roughly 10 to 25 percent;
2. *Not including milkhouse wastewater, silage leachate and spills*, resulting in underestimates of P loading by roughly 5 to 20 percent;
3. *Not including P from feedlots in compliance with feedlot runoff regulations*, resulting in underestimates of roughly 1 to 10 percent;
4. *Uncertainties in percent of open lots that contribute P to surface waters*, potentially resulting in the Lower Mississippi basin underestimates by as much as 100 percent and overestimates in the Missouri, Des Moines basins by roughly 100 percent, with other basins being closer to statewide averages.
5. *Uncertainties about FLEval modeling of annual loading*, with unknown effects; and
6. *Uncertainties about how much time the livestock at feedlots with open lots spent in the barn or on pasture*, resulting in overestimates of roughly 10 to 30 percent.

Future refinements can be made when the MPCA data base is improved to more clearly indicate whether an open lot exists at each feedlot and when better basin-specific information can be provided about how many feedlots are out of compliance with state feedlot runoff rules and regulations. Additionally, the results can be refined after the FLEval model upgrades are completed by the University of Minnesota and when better information is available about average downslope buffer conditions at non-compliant feedlots. Also, future analyses should incorporate estimates of how livestock time in barns or pastures may reduce the overall fraction of manure P that is delivered to waters.

4.2.3 Atmospheric Deposition

The following recommendations are made to minimize uncertainty and improve the estimates of atmospheric (wet and dry) phosphorus deposition:

1. Additional one to two years of monitoring for [P] and [Ca] in precipitation to improve the ability to extrapolate the findings from the research sites to other locations in the state

2. Additional sites should be included in the wet deposition monitoring network, particularly in southwest and western Minnesota, to identify significant regional differences in the [P] and [Ca] relationship, and further improve the ability to extrapolate the findings to other locations

3. Assess the variability in annual dry deposition in relation to changes in annual precipitation to determine the significance of this project assuming dry deposition is constant for low, average, and high precipitation years

4. Determine the phosphorus deposition rate of the collected PM10 filters and verify the assumption that the [P] to [Ca] ratio in dry depositon is the same as that in precipitation

5. Additional particulate monitoring (TSP, P, PM10) in other areas of the state should be conducted, with a particular emphasis on rural areas, to determine whether extrapolation of the particulate filter data to larger regions or river basins is appropriate

6. A source apportionment study, using chemical mass balance or similar approach, for phosphorus should be conducted to determine if sources other than soil are significant, or could be significant, for phosphorus deposition

4.2.4 Deicing Agents

All of the loading estimates prepared for phosphorus from deicing agents were based upon information reported by road maintenance agencies whenever possible (see Appendix F for more discussion). MnDOT and other agencies readily acknowledge that better record keeping is needed and better measurements are needed to document the actual usage numbers. While MnDOT data is of relatively high quality, the near absence of local road agency data for use in this analysis creates concern for the accuracy of the final numbers beyond those for state maintained roads, given the amount of variability that currently exists due to year-to-year weather patterns and the resulting deicer usage patterns. To further evaluate the uncertainty, the actual MnDOT usage data was confined to the 1996 – 2003 time period, as it includes MnDOT operations since the start of implementation for the Salt Solutions study recommendations and most accurately represents current deicer use trends for the state highway system (Vasek, 2003).

A state-wide sum of salt and sand usage for MnDOT maintained roads and the reported state-wide deicer use data from MnDOT allowed for an analysis of the loading estimate uncertainty against actual application information. The estimation methods were assessed against actual MnDOT usage levels and the results were summarized for the wet, average and dry years based upon a comparison to actual application quantities for similar years. The usage estimation for sand and salt usage, and thus the phosphorus load estimates from MnDOT uses for the three scenarios were reasonable given the limitations of the data (+/- 22%). The MnDOT salt usage estimate for the "average" year, i.e., for those years of data upon which the other scenario estimates were constructed has a smaller error than for the sand and brine. The error for Brine is about 30%, but the phosphorus loading due to brine is less than 0.001% of the total phosphorus load and thus is insignificant. Without further data for other road agencies the accuracy of the other estimates can only be assumed to be similar.

Much of the phosphorus content analysis for these deicing agents has been collected from widespread sources having differing and sometime poorly documented analysis methods. The limited number of studies and the ongoing citation of a few early studies by current investigators suggest that more analytical studies on deicing agents and phosphorus should be completed. The summary statistics for the data on salt and sand gleaned from the literature highlight the relative lack of data on the subject and the variability of concentrations. A data set that is confined to deicing agents used in Minnesota would provide a more accurate estimate of the loads.

4.2.5 Streambank Erosion

The variability and uncertainty of the phosphorus loading computations done for this analysis can be attributed to each of the following sources of error (described in more detail in Appendix G):

- The natural variability associated with the published streambank erosion and sediment yield data
- The uncertainty that is introduced in this analysis as a result of extrapolating the monitored sediment yield data to the unmonitored areas for each ecoregion
- The variation in sediment yield within each ecoregion

- The assumptions that the Simon and Hupp (1986) model of channel evolution applied to Minnesota streams and the slope of the suspended-sediment rating relationship could be used to characterize stable versus unstable streams, based on data published in Simon (1989a)
- The standard error in the regression between the slope of the suspended-sediment rating relationship and the sediment yield
- The assumption that the probability plot of Blue Earth River streambank erosion rates from Sekely et al. (2002) could be utilized to estimate the variation of streambank erosion during low and high flow conditions for the remaining streams in the state
- The variation in the total phosphorus concentration of the sediment eroding from streambank escarpments throughout the state

Many areas of the State have not been adequately sampled for definition of sediment-transport characteristics. Only a few or no sediment samples (with corresponding discharges) have been collected from most of the streams in northern and central Minnesota, with almost no samples present for the Northern Minnesota Wetlands Ecoregion (Tornes, 1986; Simon et al., 2003). Some rivers in west-central Minnesota, parts of the Red River of the North, the Rock River, and the Pomme de Terre River drain areas underlain by clayey or loess soils may have sediment yields that are similar to those in the southeast part of the State (Tornes, 1986). In addition, no sediment-transport curves or erosion assessments have been published for streams in the St. Croix River basin. The current lack of sediment-transport data and erosion assessments throughout the state make it difficult to adequately ascertain the impacts of streambank erosion, especially as it pertains to impaired biota. Collecting more data for streambank erosion assessments can be used to further refine this analysis, reduce the current level of uncertainty, and improve the understanding of the linkage between sediment and phosphorus loadings with biological impairments.

The MPCA should install continuous flow monitoring equipment, and begin developing stage-discharge-sediment transport curves, as a means of assessing erosion within some of the existing State milestone monitoring watersheds, that are not currently being monitored by the USGS. Additional streambank erosion assessments should be done in conjunction with stream water quality and biological monitoring, and channel evolution stage determinations, to develop and refine empirical models and provide a better understanding of the impacts of streambank erosion throughout the State. One such assessment, recently completed by the MPCA, was done to evaluate the relationship between suspended sediment transport, stream classification and fish index of biological integrity (IBI) scores (Magner et al., 2003). All of these assessments should also be done to evaluate streambank erosion during low and high flow conditions and address the variability and uncertainty associated with the estimates presented here. Also, more total phosphorus data should be collected from eroding streambanks across the state to further evaluate how much of the phosphorus loading is entering the streams from upland sources versus fluvial processes. Additionally, the connection of streambank erosion with land use changes causing hydromodifications needs to be better documented.

4.2.6 Individual Sewage Treatment Systems/Unsewered Communities

The primary sources (and estimated magnitudes) of variability and uncertainty in the total phosphorus loading computations done for this assessment (see Appendix H) include:

- Percentage of phosphorus attenuation in soil absorption field for permanent and seasonal residences—(these percentages are likely to vary by 50 percent or more, depending on the proximity to surface water, soils and water table characteristics, etc.; if the all of the conforming systems from the remaining ISTS category removed 100% of the P load produced, the 140,510 kg total P load discharged to surface waters would be reduced by approximately 30%)

- Portion of undersewered communities receiving various levels of treatment, more or less than septic tank removals (as assumed)—(these percentages are likely to vary by 50 percent or more, as some of the undersewered communities may be receiving good treatment with soil absorption, while others may not even receive treatment from septic tanks)

- Population of undersewered communities—(population figures may vary significantly within each basin depending on each counties ability to determine, report or verify and update the presence and population of undersewered communities)

- Population served and portion of direct-to-tile ISTS receiving various levels of treatment, more or less than septic tank removals (as assumed)—(these values are likely to vary by 100 percent or more, as the number of systems and population served are extrapolated from a small subset of areas studied in the MRAP which may or may not have already been counted with the ITPHS percentages, and some of the direct-to-tile ISTS may not even receive treatment from septic tanks)

- Population served and per capita P loadings for permanent versus seasonal residences—(the current P loading estimates assume that all of the population served by seasonal residences

[2.1 people per seasonal residence for 4 months each year] is in addition to all of the P loadings generated by the current permanent residents of Minnesota, which may overestimate the P load from permanent Minnesota residents that maintain seasonal residences, but helps to offset both the fact that seasonal residences may be under-represented in the databases and the fact that people from other states maintain seasonal residences; in addition, the per capita loadings for dishwashing detergents and dentifrices are based on actual nationwide consumption, while the per capita loadings for human waste and food soils are based on monitoring of permanent residences)

The following refinements are recommended to reduce the error terms or uncertainty of the phosphorus loading estimates:

- LUGs should work with the MPCA to develop, populate and maintain a geographic database, similar to MPCA's feedlot database that shows where each of the failing systems, straight pipe discharges and other types of ITPHS are located
- LUG personnel should be trained to assess the proper functioning of each type of system and be provided with an incentive to inventory all systems within their jurisdiction, and track system performance and maintenance
- The estimates for population served by conforming and nonconforming systems, as well as unsewered communities and direct-to-tile ISTS, should be refined, updated and linked to a geographic database
- Additional analyses should be done to study the treatment effectiveness of conforming and nonconforming treatment systems, throughout the state, to evaluate the variability of the estimated phosphorus loadings to surface waters under various settings

4.2.7 Non-Agricultural Rural Runoff

The variability and uncertainty of these phosphorus loading computations and assessment is currently difficult to assess due to the lack of monitoring data that would allow a rigorous evaluation of the application of the concepts of contributory area and the use of the basin runoff factor (see Section 2.2.2.6 and Appendix I).

Refinement of the application of export coefficients to Minnesota watershed will require further monitoring and research into the development and application of transmission coefficients. This work will require more detail investigation into the relationships that exist between phosphorus-flux coefficients, land use export coefficients, and transmission factors and their impact on the effective contributory area for large watersheds. As was seen in the literature review, many of the export coefficients for natural vegetation were developed on very small sites. Larger scale studies, comparable to the work by Sartz and others in the driftless area should be undertaken.

The width of the effective contributory area has major implications for water quality management. Much of the research conducted on buffer systems provides some insight into contributory watershed area functions. However, refinement of the interactions of soil type, topography and vegetative cover on the transmission of phosphorus to surface waters needs further research. Research and monitoring efforts on this topic should include GIS modeling efforts to help define these relationships and allow for state-wide spatial database development.

4.2.8 Urban Runoff

In an effort to define the accuracy of the pollutant loading estimates derived from the regression equations (see Section 2.2.2.7 and Appendix J), a comparison was completed using FLUX calculated loads for the Minneapolis Chain of Lakes watershed. This assessment was completed on the residential watersheds that had direct storm water flow from the 1991 monitoring stations. All of the sites had continuous flow measurement and flow-composite runoff samples; the data was reduced to a flow-weighted mean concentration using FLUX (MPRB, 1993; Walker, 1986). Not all of the watersheds assessed in the Chain of Lakes project were included in the assessment, as a number of them had upstream wetlands or large areas of natural land cover that attenuated the phosphorus loadings.

For purposes of this loading variability and uncertainty discussion, the loading regression equation developed for this assessment was used to calculate loads to the eight watersheds. All of the load estimates were calculated using the 1991 monitored flow volumes. The 1991 FLUX-derived loadings based upon FWMC concentrations were considered the baseline loadings. Annual loadings were also estimated using the mean 1991 EMC for each specific watershed, using a national EMC for residential watersheds of 320 µg/L (Center for Watershed Protection, 2003), and the regression equation result of 326 µg/L. The loads calculated with the national EMC for residential watersheds and the regression equation were 100.6% and 102.5% of the FLUX model loadings, respectively. The results of the regression equation are very similar to the monitored loads.

The regression equation developed for the urban land use loads estimation explains 19% of the variance for stormwater using precipitation and impervious percentage, which shows that there is considerable variability in the water quality of urban runoff due to several factors. Refinement of the load estimate for phosphorus in urban runoff will require that additional, long-term monitoring sites be established across the state. Most of the long-term monitoring locations used for the regression equation development were located within the Twin Cities metropolitan area or other large cities. There were some out-state sites but most lacked multiple years of data or were quite old and therefore were not appropriate for this assessment.

5.0 Overall Conclusions

The results of this assessment indicate that the estimated amounts of total and bioavailable phosphorus entering surface waters within each major basin and the state vary significantly, both by source category and by flow condition. The phosphorus loadings associated with several point and nonpoint source categories can be controlled to various levels, resulting in significant water quality improvements, depending on the water resource and flow condition. The following discussion provides some overall conclusions from this assessment:

- Because of the general nature of this analysis, it can be true that sources of phosphorus which are deemed minor at the basin scale, may actually contribute the majority of phosphorus to specific surface water bodies, at a localized scale. For example, point sources typically contribute little or no phosphorus to Twin Cities Metropolitan and most outstate lakes, but can represent a significant portion of the total phosphorus load to rivers under low flow conditions. Because of this, there is still a need to complete individual assessments of specific watersheds to evaluate specific loading conditions.

- Under average conditions, the point source total phosphorus contribution represents 31 percent of the loadings to surface waters, statewide, whereas nonpoint sources contribute 69 percent. Of these nonpoint sources, cropland and pasture runoff, atmospheric deposition, streambank erosion, human waste products, and commercial/industrial process water each represent between 10 and 30 percent of the total phosphorus loading. All of the remaining source category contributions are below 6 percent. The combination of household and commercial automatic dishwasher detergent represents approximately 3 percent of the total phosphorus contributions to surface waters in the state, during an average year.

- Under low flow conditions, the total point source phosphorus contribution represents 45 percent, compared to 31 and 19 percent for the statewide loadings to surface waters under average and high flow conditions, respectively. The bioavailable low flow point source phosphorus contribution represents 57 percent of the statewide loadings, confirming that point sources of phosphorus are more bioavailable than nonpoint sources. Comparing high flow to average and low flow conditions, the relative statewide nonpoint source contributions of total phosphorus increased significantly for streambank erosion, decreased somewhat for urban runoff, and decreased significantly for atmospheric deposition and ISTS/unsewered communities.

- Nonpoint source phosphorus loadings nearly double from low to average flow conditions, and again from average to high flow conditions.

- Human waste products represent a significant portion of the total and bioavailable phosphorus loadings in the Upper Mississippi and Cedar River basins under each flow condition; and on a statewide basis, for the low and to a lesser extent average flow conditions. During low flow conditions, human waste products contribute between 10 and 20 percent of the bioavailable phosphorus loadings in the Lake Superior and St. Croix, Lower Mississippi, Red, Missouri, and Minnesota River basins.

- Commercial/industrial process water represents a significant portion of the total and bioavailable phosphorus loadings in the Upper Mississippi, Lower Mississippi, Minnesota, and Des Moines River basins under each flow condition, and on a statewide basis, for the low and to a lesser extent average flow conditions.

- Phosphorus contributions from ISTS/unsewered communities are of relative importance in the St. Croix River basin.

- Cropland and pasture runoff represents a significant portion of the total and bioavailable phosphorus loadings in the St. Croix, Lower Mississippi, Red, Missouri, Minnesota, Cedar and Des Moines River basins, and on a statewide basis, under all flow conditions. The phosphorus contribution from cropland and pasture runoff is also significant in the Upper Mississippi River basin for the average and high flow conditions.

- Atmospheric deposition represents a significant portion of the phosphorus loadings in the Lake Superior, St. Croix, Red, and Rainy River basins for each flow condition.

- Non-agricultural rural runoff contributes a significant portion of the phosphorus loadings in the Lake Superior and Rainy River basins for each flow condition, although the typical rate of total phosphorus export from each acre of non-agricultural land is approximately four times lower than the corresponding load from each acre of contributing cropland and pasture runoff.

- Streambank erosion is an important source of phosphorus under high flow conditions for all of the basins, and is fairly significant in the Lake Superior, Lower Mississippi, Rainy and Missouri River basins under average flow conditions. Streambank erosion can also contribute somewhat significant amounts of total phosphorus statewide and to the Minnesota and Cedar River basins under average flow conditions.

- The concepts for lowering the phosphorus export from point sources address possible reductions of phosphorus discharged to POTWs as well as phosphorus discharged to the surface waters in each basin. Food soils would be very difficult to reduce, and dentifrices, noncontact cooling water and I & I contribute little to the influent phosphorus load discharged to POTWs. If residential and commercial/institutional ADWD and water treatment chemicals were eliminated completely, commercial and industrial process wastewater would still need to be reduced more than 64 percent to attain a 50 percent reduction in the total non-ingested phosphorus contribution to POTWs (the goal established in MN Laws 2003, Chap. 128 Art. 1, Sec. 122). Given the difficulties in completely eliminating phosphorus from commercial/institutional ADWD and water treatment chemicals, and reducing the commercial and industrial process wastewater loading by more than 64 percent, a 50 percent reduction of non-ingested influent phosphorus appears to be an ambitious goal. In addition, a 50 percent reduction in influent may not mean a 50 percent reduction in the effluent depending upon the type of wastewater treatment processes used.

- A large portion of the influent phosphorus load to POTWs is from human waste products and/or is largely uncontrollable. Continued implementation of enhanced biological phosphorus removal (EBPR) will significantly reduce effluent phosphorus concentrations.

- Public education about the use of ADWD based on hardness and the availability of no- and low-phosphorus content products should be encouraged.

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Northern one-half to one-third of MN:	15 $kg/km^2 \cdot yr^{-1}$
Central:	30+ $kg/km^2 \cdot yr^{-1}$
Southern part of MN with wind erosion:	30 – 40 $kg/km^2 \cdot yr^{-1}$

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Detailed Assessment

of

Phosphorus Sources

to

Minnesota Watersheds

Volume 2: Appendices

Prepared by Barr Engineering Company
February 2004

Technical Memorandum

To: Marvin Hora, Doug Hall and Mark Tomasek, Minnesota Pollution Control Agency
From: Tim Anderson, Barr Engineering Co.
Subject: Final Basin Hydrology Technical Memorandum
Date: December 17, 2003
Project: 23/62-853 BASN 008
c: Greg Wilson, Hal Runke

Overview and Introduction to Basin Hydrology

The objective of the Detailed Phosphorus Assessment Study is to estimate the sources of phosphorus for the 10 major basins for three flow scenarios within the State of Minnesota. These basins are shown in Figure 1. The flow scenarios are:

- Dry year
- Average year
- Wet year

The estimate of phosphorus loading, especially from non-point sources, requires the estimate of flows and rainfall that correspond to each of the three flow scenarios. The identification of three flow conditions will allow for the comparison of point and non-point phosphorus sources during the varied climatic and flow conditions that occur across Minnesota. The mass of phosphorus from non-point sources is generally higher during high runoff years than for average or dry years. Therefore, the proportion of the total phosphorus mass in the drainage system originating from point sources (e.g. waste water treatment plants) should be lower in wet years due to greater mass originating from non-point sources.

The Basin Hydrology portion of this study has two objectives:

- The identification of dry, average and wet years conditions for each basin, including the estimation of flow and precipitation
- Selecting years that are representative of these conditions

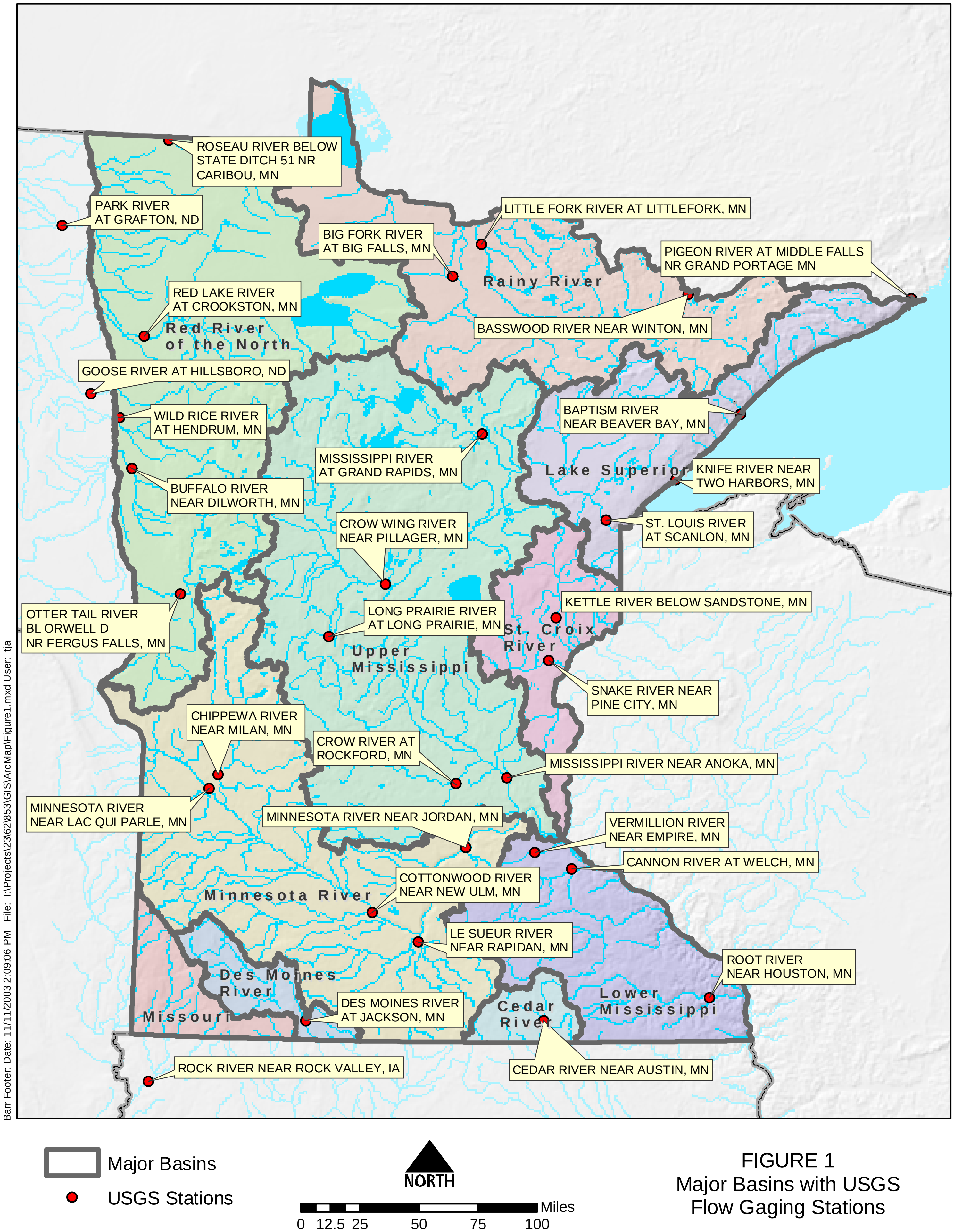


FIGURE 1
Major Basins with USGS Flow Gaging Stations

The methods used for each of these objectives are discussed below.

Watershed Basin Characteristics

The ten major drainage basins within Minnesota vary greatly in their characteristics. Table 1 provides a summary of some of the characteristics of each basin. As shown in the table, there is a significant variability of runoff and precipitation across the state. There is also a significant difference in land cover between basins, particularly between the southwest and northeast parts of the state. Each basin is described in more detail below.

Cedar River

The Cedar River basin in Minnesota consists of approximately 1000 square miles and is drained by the Winnebago, Shell Rock and Cedar Rivers, all of which flow into the State of Iowa and ultimately to the Mississippi River. The major cities in this Basin are Albert Lea and Austin and the dominate land use is tilled agriculture. The USGS gage near Austin, on the Cedar River measures flow for 399 square miles of this Basin.

Des Moines River

The Des Moines River Basin consists of the headwater areas of both the East and West Fork of the Des Moines River in southwest Minnesota. The Basin is about 1500 square miles, mostly made up of row crops. The cities of Jackson and Windom are within this Basin along with the northern ½ of the City of Worthington. The USGS gage at Jackson, on the West Fork of the Des Moines River, measures flow for 1250 square miles of this Basin.

Lake Superior

The Lake Superior Basin drains about 6,150 square miles of northeast Minnesota. Approximately 3646 square miles of the basin drain to the St. Louis River, which enters Lake Superior at Duluth. The Nemadji River drains 278 square miles of Minnesota, south of Duluth before it enters Wisconsin and ultimately reaches Lake Superior at Superior, Wisconsin. The remaining 2,226 square miles of the Minnesota's Lake Superior Basin drains via many small streams and rivers along the North Shore of Lake Superior. The major land cover types within this basin are forest, lakes and wetlands. Duluth, Two Harbors, and many of the Iron Range cities are located in this Basin. The Lake Superior Basin produces the most runoff (12.44 inches annually, on average) even though three of

TABLE 1
Basin Characteristics

Basin	Area (Sq Miles)*	Average Precipitation (1979-2002)	Average Runoff (1979-2002)	Land Cover Percentages** Urban	Forested	Tilled Agricultural	Pasture/ Grassland	Wetland/Open Water	Other
Cedar River	1,028	32.06	9.80	3.4%	3.3%	83.4%	6.2%	3.7%	0.0%
Des Moines River	1,535	27.98	5.68	1.8%	1.8%	79.9%	11.0%	5.5%	0.0%
Lake Superior	6,149	29.11	12.44	1.4%	57.1%	2.6%	3.5%	33.3%	2.1%
Lower Mississippi	6,317	33.29	10.28	2.4%	15.4%	52.2%	24.8%	5.1%	0.1%
Minnesota River	14,943	28.14	5.61	2.2%	4.6%	72.7%	12.6%	7.8%	0.1%
Missouri	1,782	27.16	5.25	1.5%	1.0%	78.9%	16.0%	2.6%	0.0%
Rainy River	11,236	26.20	8.01	0.4%	41.4%	2.0%	2.3%	52.5%	1.3%
Red River	17,741	23.29	3.42	0.7%	12.0%	54.6%	8.8%	23.8%	0.2%
St. Croix River	3,528	30.61	9.71	1.3%	36.8%	10.8%	20.6%	30.1%	0.2%
Upper Mississippi	20,100	28.07	6.87	3.5%	29.1%	20.2%	16.7%	29.7%	0.7%
State Wide	**79,202**	**27.39**	**6.83**	**1.9%**	**22.7%**	**38.1%**	**12.0%**	**24.7%**	**0.6%**

*Drainage area within Minnesota
**Based on USGS National Land Cover Database (1992)

the other basins receive more precipitation. Flow data from four USGS gage locations were used to assess runoff from this area.

Lower Mississippi

The Lower Mississippi consists of approximately 6,300 square miles of area draining to the Mississippi River below the River's confluence with the St. Croix River. The Lower Mississippi is the only non-headwaters basin. The Upper Mississippi, Minnesota and St. Croix Basins flow into the Mississippi River above the Lower Mississippi. Rivers that drain the Lower Mississippi Basin include the Zumbro, Root, Cannon and Vermillion Rivers. The major land cover is agricultural, although there are significant forest areas in the hilly bluff lands along the major river systems. The Cities of Rochester, Winona, Owatonna, Faribault and Red Wing are in this Basin. The southern suburbs of the Metropolitan area, including most of Lakeville are also in this Basin. This Basin receives the greatest annual average precipitation. During the period of 1979-2002, the basin received an average 33.3 inches annually. Flow data from three USGS gage locations were used to assess direct runoff from this area.

Minnesota River

The Minnesota River Basin is composed of 16,950 square miles, of which 1,668 are in South Dakota, 5 in North Dakota and 338 are in Iowa. The USGS gage near Jordan measures flow from about 16,200 square miles (or 96 percent) of the Basin. The Minnesota River drains into the Mississippi River upstream of St. Paul. Major tributaries of the Minnesota include the Pomme De Terre, Chippewa, Lac Qui Parle, Yellow Medicine, Redwood, Cottonwood, Watonwan, Blue Earth and Le Sueur Rivers. The vast majority of the land is in agricultural land uses. Cities included in this basin are Mankato, Redwood Falls, St. Peter, Morris, Marshall, Fairmont and the southwest suburbs of the Twin Cities. Flow data from five USGS gage locations were use to assess runoff from this area.

Missouri River

The Missouri River Basin is composed of 1,782 square miles in extreme southwestern Minnesota. The main rivers draining this Basin are the Little Sioux, Rock, and Pipestone. These river systems flow into Iowa and South Dakota. The only long term gaging record in this watershed is on the Rock River near Rock Valley, Iowa. Approximately 95 percent of this basin has agricultural land uses. Cities within this basin include Pipestone, Luverne and part of Worthington.

Rainy River

The Rainy River Basin consists of approximately 11,240 square miles of area in Minnesota draining to the Rainy River and Lake of the Woods on the Canadian border. Much of the Boundary Waters Canoe Area Wilderness is within this Basin. A significant part of the area tributary to Rainy River and Lake of the Woods are in Canada. Major land cover types within this basin include forest, lakes and wetlands. Rivers that drain this basin include the Little Fork, Big Fork and Basswood Rivers. Cities within this basin include Ely, International Falls, Warroad and Baudette. Flow data from three USGS gage locations were used to assess runoff from this area.

Red River of the North

The Red River of the North Basin in Minnesota consists of 17,741 square miles of area. The Red River of the North Basin receives the least amount of rainfall on average and also produces the least runoff of the ten basins. The Red River of the North flows north along the western boundary of the state. Approxmately one-half of the watershed area to the Red River of the North at the Canadian border is in North Dakota.

Major river systems that flow to the Red River in Minnesota include the Bois De Sioux, Ottertail, Buffalo, Wild Rice, Sandhill, Red Lake, Snake, Tamarac and Roseau Rivers. The land cover of the eastern portions of the basin includes significant lake, wetland and forested areas while the western portion is mostly tilled farm land. Cities in the basin include Moorhead, East Grand Forks, Crookston, Roseau, Detroit Lakes, Fergus Falls and Thief River Falls. Flow data from seven USGS gage locations were used to assess runoff from this area.

St. Croix River

The St. Croix River Basin in Minnesota drains a 3,528 square mile area of mixed land use in the east central part of the state. An additional 4,200 square miles of watershed to the St. Croix River is in Wisconsin. Rivers that drain this basin include the Kettle, Snake and Sunrise Rivers. The St. Croix watershed includes the extreme eastern portions of the Twin City area. Other cites in this basin include Moose Lake, Sandstone, Hinckley, North Branch, Taylors Falls and Stillwater. Flow data from two USGS gage locations were used to assess runoff from this area.

Upper Mississippi River

The Upper Mississippi River Basin consists of the area tributary to the Mississippi River upstream of the confluence of the St. Croix River, not including the area tributary to the Minnesota River. This basin is 20,100 square miles and is a transition zone between agricultural areas to the south and west and forest and open water/wetland areas to the north. Major river systems that are tributary to the Upper Mississippi include the Crow, Sauk, Rum, Long Prairie, Red Eye, Crow Wing and Pine rivers. This basin also contains the majority of the Minneapolis-St. Paul Metropolitan area. Other cities in this basin include St. Cloud, Little Falls, Brainerd, Hutchinson, Alexandria, Grand Rapids and Bemidji. Flow data from five USGS gage locations were used to assess runoff from this area.

Available River Discharge and Precipitation Data

Precipitation and river discharge data were collected and analyzed as part of this portion of the project.

River Discharge Data

Mean monthly discharge data were collected from the USGS for 32 gaging stations across Minnesota and neighboring states. Figure 1 shows the location of the gages where data was collected. The stations were selected based on their length of record and the location of the gage within each of the ten basins. The Mississippi River near Anoka gage and Minnesota near Jordan gage are included in Figure 1 but were not directly used in deriving the flow values related to the dry, wet and average years. Measurements at these gages represent flow from nearly the entire Upper Mississippi and Minnesota basins, respectively. Because of the large size of these basins , USGS data from smaller watersheds within these basins were used so that regional runoff patterns could be better estimated.

Precipitation Data

Basin-wide precipitation data were made available from the State Climatology Office of the Minnesota Department of Natural Resources. The data consisted of monthly values calculated from a grid-based archive of historical monthly precipitation totals for the period of 1892 – 2002. These data consisted of estimated monthly total precipitation over each watershed, in inches, for each of the ten basins. The data were totaled by water-year (October – September) for use in this study. Data for the period of 1979 – 2002 water years were used in this study. Table 2 provides the minimum, maximum and average number of precipitation gages used to develop the grids for the 1979-2002 period. Figures 2 and 3 show the distribution of precipitation gages for the months with the minimum and maximum number, respectively, of gages used to develop the grids.

Table 2

	Cedar River	Des Moines River	Lower Miss-issippi	Minne-sota River	Mis-souri River	Rainy River	Red River of the North	St. Croix River	Lake Super-ior	Upper Miss-issippi	Total
Average	15	22	83	226	22	44	142	64	56	339	1014
Min-iumum	2	2	18	65	3	25	36	21	40	165	480
Max-imum	39	49	150	416	41	66	246	118	71	591	1632

Number of Precipitation Gages

Approach and Methodology for Calculation of Basin Runoff Volumes

The phosphorus load estimates in this study were determined for low, average and high flow conditions, for each of the ten basins. A characteristic of most of the basins is that water is received from upstream basins (such as the Lower Mississippi which receives flow from the Minnesota, St. Croix and Upper Mississippi basins) or water flows into the basin from neighboring states or provinces. Therefore, flow and phosphorus data measured at the “outlet” of the basin will include both water and phosphorus originating from outside of Minnesota or from other upstream Minnesota basins. For example, 53 percent of the watershed area of the Red River of the North (which is the border between North Dakota and Minnesota), at the Manitoba border, is in the State of North Dakota. The Lake Superior and Rainy River basins do not have a defined single outlet point at all, since both discharge from lakes that share a boundary with multiple states and/or provinces. Since this study is only concerned with phosphorus contributions from Minnesota, a methodology was developed to estimate only Minnesota’s contribution of water.

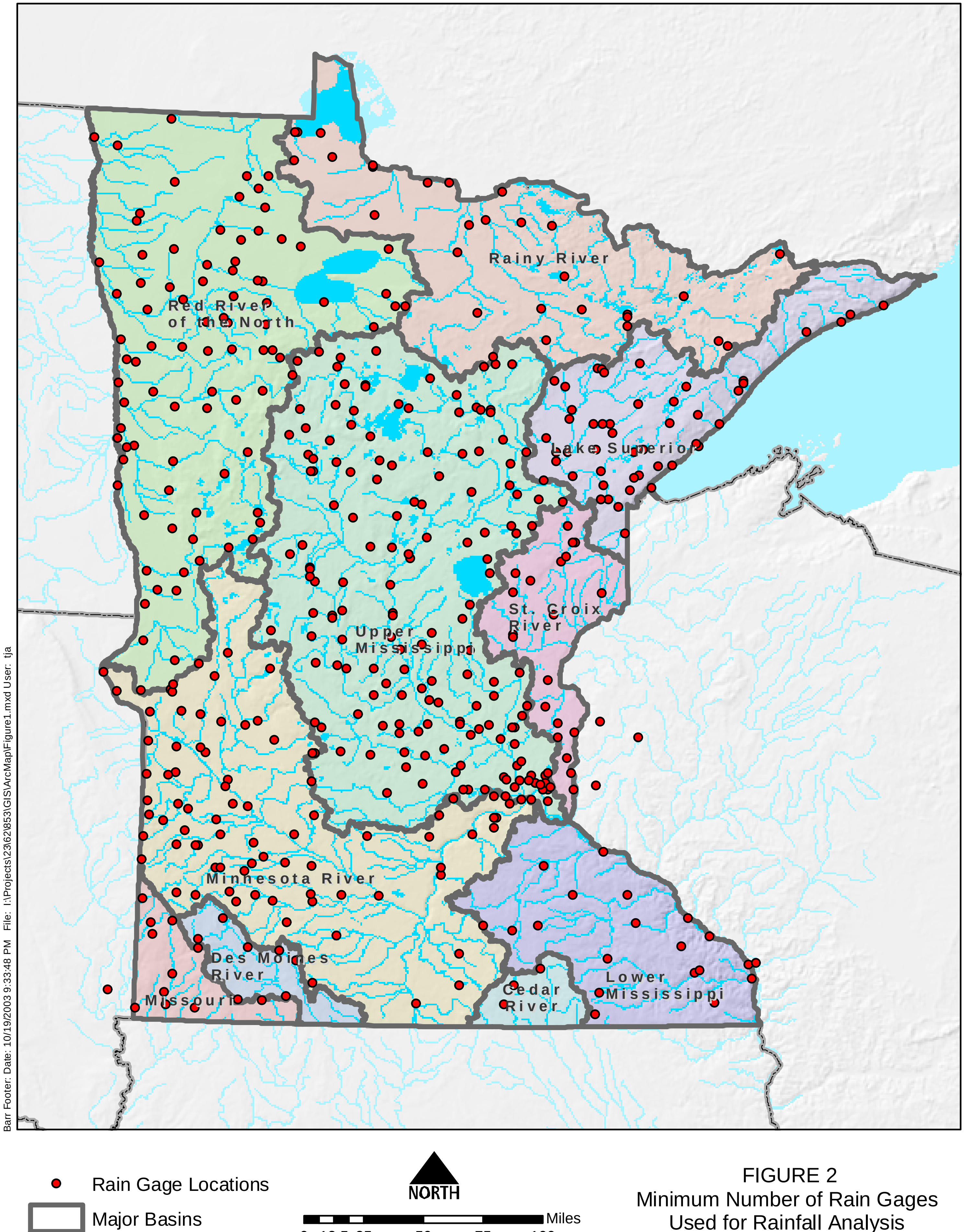
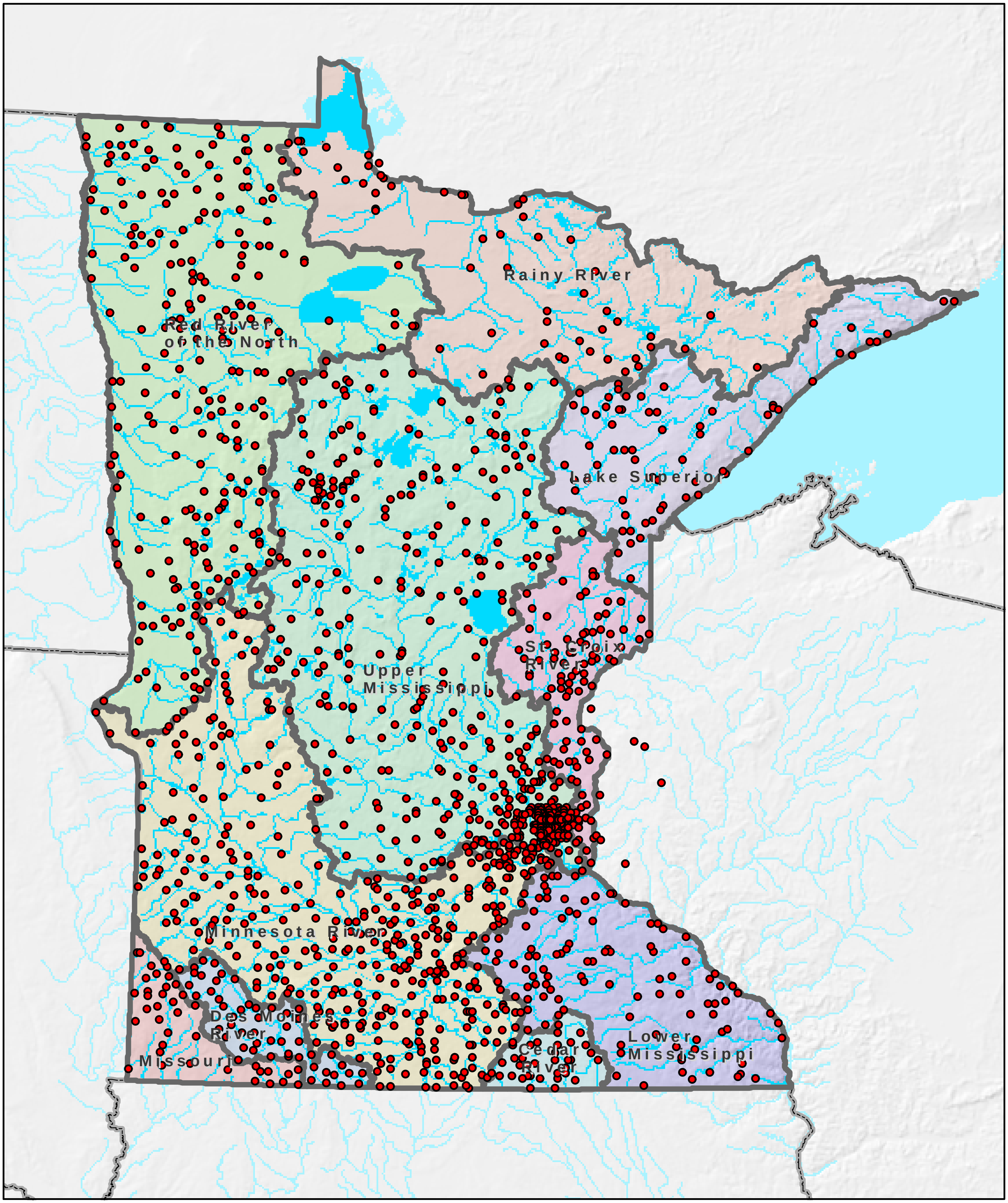


FIGURE 2
Minimum Number of Rain Gages
Used for Rainfall Analysis
(480 Total, February, 1987)



Major Basins

Rain Gage Locations

NORTH

0 12.5 25 50 75 100 Miles

FIGURE 3
Maximum Number of Rain Gages
Used for Rainfall Analysis
(1632 Total, June, 1994)

Runoff from the Minnesota portions of the ten basins were calculated using state-wide flow maps for the three flow conditions. Each map consists of a state-wide 1 km x km grid of values representing runoff in inches. The resulting maps are shown in Figures 4, 5 and 6. Using these grids, runoff averages over the basins were determined. The methods used to develop these maps are described below.

River Discharge Data

Monthly mean stream flow data were collected from the United States Geologic Survey for 27 gaging stations in Minnesota, two in North Dakota and one in Iowa for a total of 30 gages. Annual runoff in inches, for each gage was determined by summing the monthly mean flows for each water year (October – September) and dividing by the contributing watershed area to arrive at runoff in inches per year. The watershed areas were delineated using the Minnesota Department of Natural Resources Division of Waters Watershed Basin (1995) GIS Layer. This layer was developed using data from USGS 1:24,000 Quadrangle Maps. The percent of the area of the major basins that drain to the gages used are summarized in Table 3.

Development of Frequency Curves

The result of these computations was a table of annual runoff values, in inches over each of the 30 watersheds. These data were used to develop two frequency curves for each of the 30 gages and were based on these following periods of record:

1. Using all water years data were available
2. Using water years 1979 – 2002

For curve one, the time period of available flow data varied greatly. Some gages had data available for up to 100 years and others only a dozen or so years. The second curve was developed to reflect current climatic and drainage conditions. During the 1979-2002 period, a complete record of data was available for most of the gages used. This shorter period also reflected current watershed drainage characteristics and climatic trends. Because of these reasons, the 1979-2002 record was used to develop the runoff maps. Table 4 provides general statistics on the gages used, including the length of record.

The frequency curves were developed using a statistical analysis of the annual basin flows adopted from *Guidelines for Determining Flood Flow Frequency*, Bulletin #17B, U.S. Water Resources

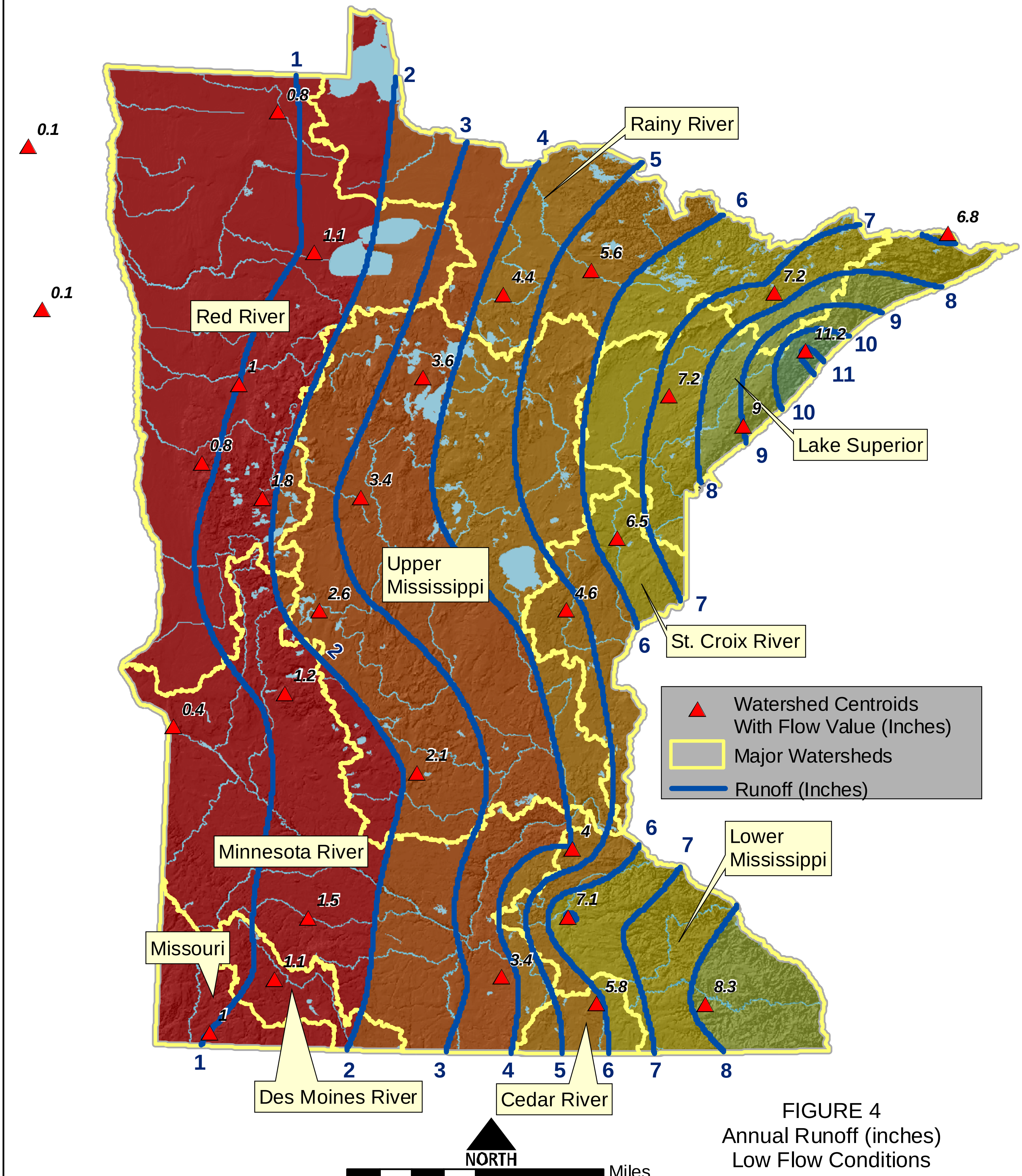


FIGURE 4
Annual Runoff (inches)
Low Flow Conditions
Based on 1979-2002 USGS Data

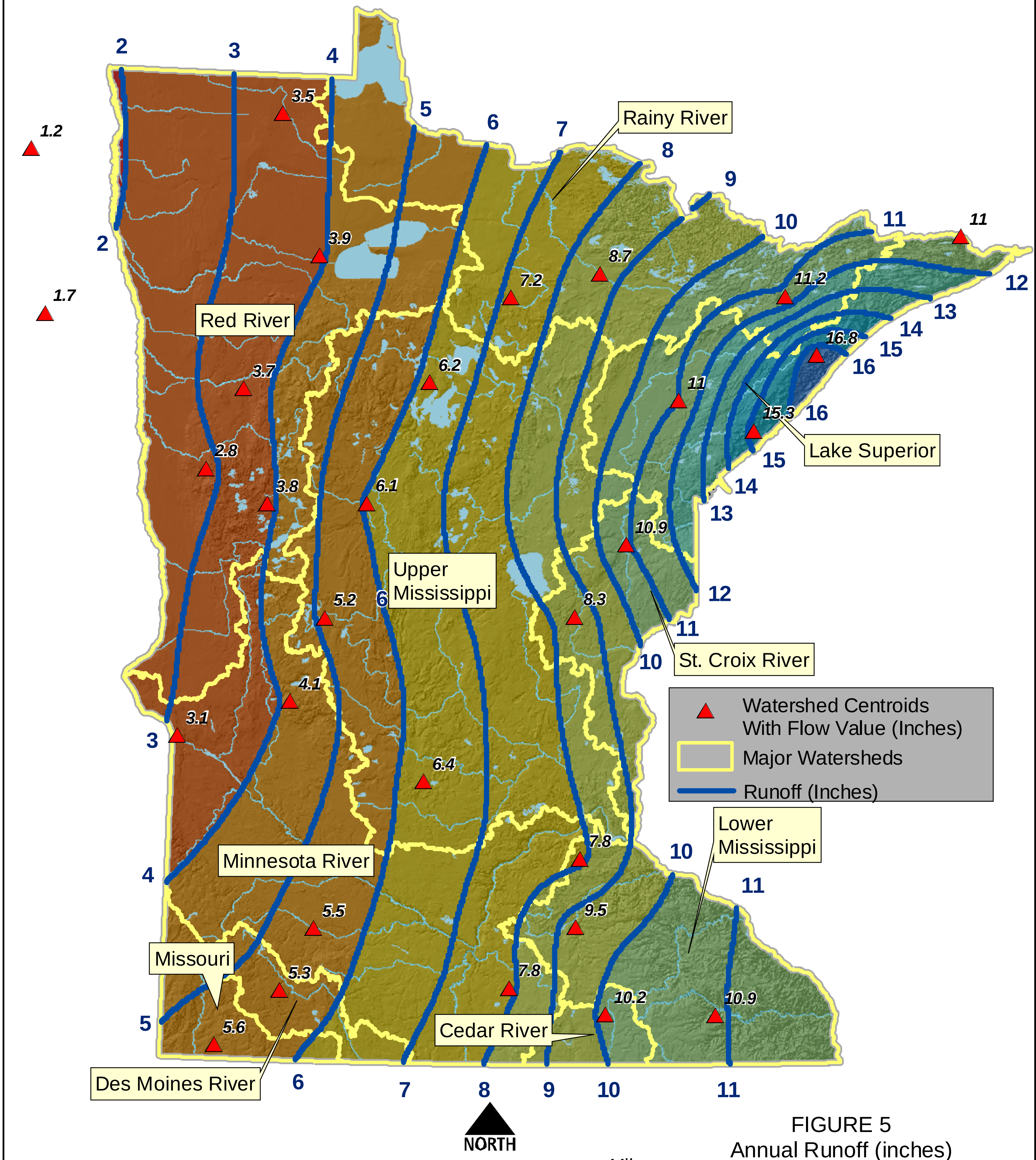


FIGURE 5
Annual Runoff (inches)
Average Conditions
Based on 1979-2002 USGS Data

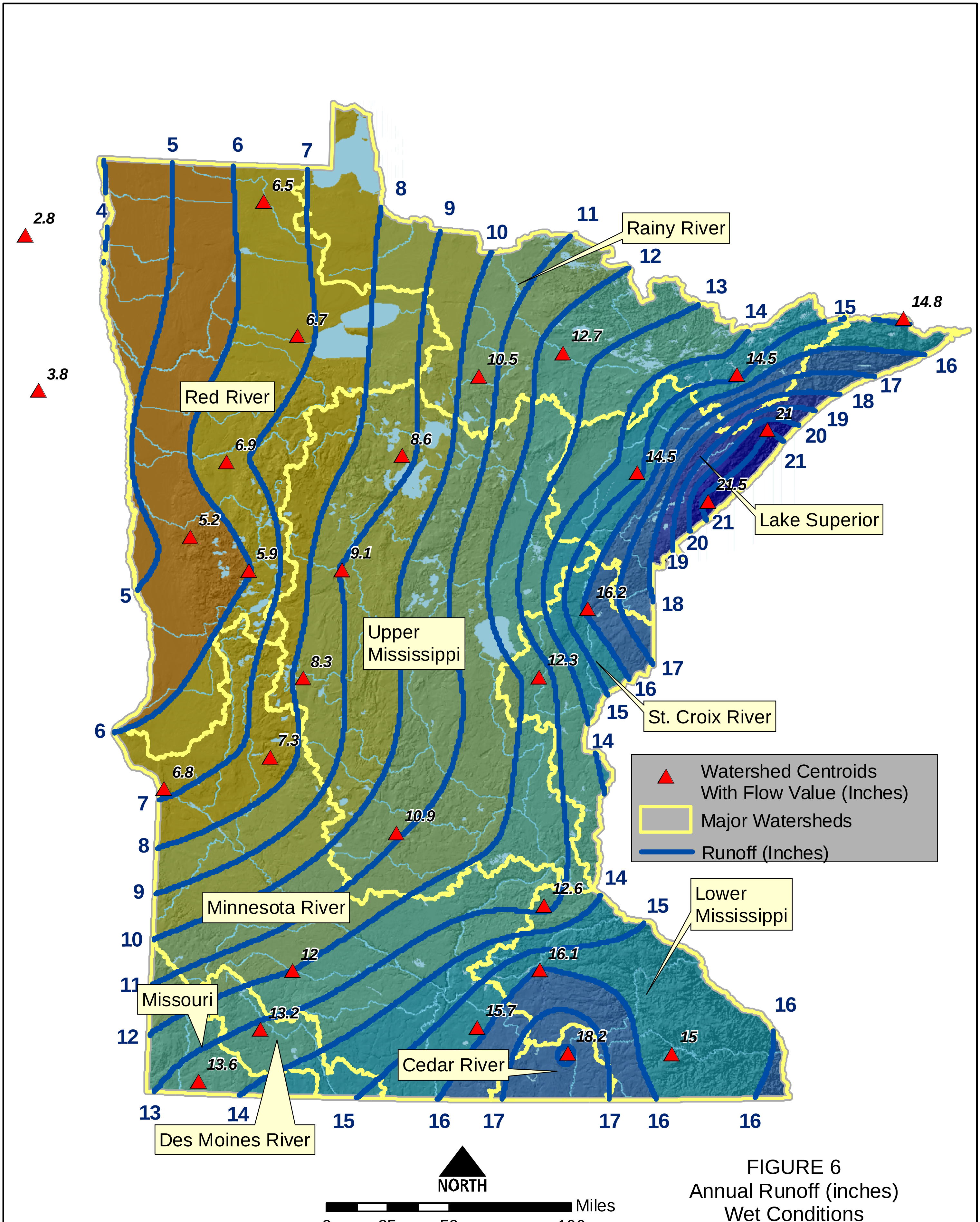


FIGURE 6
Annual Runoff (inches)
Wet Conditions
Based on 1979-2002 USGS Data

Table 3
Gage Watershed Summary

USGS Gage	Major Basin	Major Basin Area Within Minnesota (Sq. Miles)	Contributing Watershed Area Within Minnesota (Sq. Miles)	Percent of Total Basin Area
CEDAR RIVER NEAR AUSTIN	Cedar River	1,028	399	38.8%
TOTAL CEDAR RIVER BASIN GAGES		**1,028**	**399**	**38.8%**
DES MOINES RIVER AT JACKSON	Des Moines River	1,536	1,250	81.4%
TOTAL OF DES MOINES RIVER BASIN GAGES		**1,536**	**1,250**	**81.4%**
BAPTISM RIVER NEAR BEAVER BAY	Lake Superior	6,149	140	2.3%
KNIFE RIVER NEAR TWO HARBORS	Lake Superior	6,149	84	1.4%
PIGEON RIVER AT MIDDLE FALLS NR GRAND PORTA	Lake Superior*	6,149	241	3.9%
ST. LOUIS RIVER AT SCANLON	Lake Superior	6,149	3,430	55.8%
TOTAL OF LAKE SUPERIOR BASIN GAGES		6,149	3,895	63.3%
CANNON RIVER AT WELCH	Lower Mississippi	6,317	1,340	21.2%
ROOT RIVER NEAR HOUSTON	Lower Mississippi	6,317	1,250	19.8%
VERMILLION RIVER NEAR EMPIRE, MN	Lower Mississippi	6,317	129	2.0%
TOTAL OF LOWER MISSISSIPPI BASIN GAGES		**6,317**	**2,719**	**43.0%**
CHIPPEWA RIVER NEAR MILAN, MN	Minnesota River	14,933	1,880	12.6%
COTTONWOOD RIVER NEAR NEW ULM, MN	Minnesota River	14,933	1,300	8.7%
LE SUEUR RIVER NEAR RAPIDAN, MN	Minnesota River	14,933	1,110	7.4%
MINNESOTA RIVER NEAR LAC QUI PARLE, MN*	Minnesota River	14,933	2,398	16.1%
TOTAL OF MINNESOTA RIVER BASIN GAGES		**14,933**	**6,688**	**44.8%**
ROCK RIVER NEAR ROCK VALLEY, IA*	Missouri River	1,782	917	51.5%
TOTAL OF MISSOURI RIVER BASIN GAGES		**1,782**	**917**	**51.5%**
BASSWOOD RIVER NEAR WINTON	Rainy River	11,236	1,740	15.5%
BIG FORK RIVER AT BIG FALLS	Rainy River	11,236	1,480	13.2%
LITTLE FORK RIVER AT LITTLEFORK	Rainy River	11,236	1,680	15.0%
TOTAL OF RAINY RIVER BASIN GAGES		**11,236**	**4,900**	**43.6%**
BUFFALO RIVER NEAR DILWORTH	Red River of the North	17,741	975	5.5%
OTTER TAIL RIVER BL ORWELL D NR FERGUS FALLS	Red River of the North	17,741	1,740	9.8%
RED LAKE RIVER AT CROOKSTON	Red River of the North	17,741	5,270	29.7%
ROSEAU RIVER BELOW STATE DITCH 51 NR CARIBO	Red River of the North	17,741	1,420	8.0%
WILD RICE RIVER AT HENDRUM	Red River of the North	17,741	1,560	8.8%
GOOSE RIVER AT HILLSBORO, ND**	Red River of the North**	17,741	0	0.0%
PARK RIVER AT GRAFTON, ND**	Red River of the North**	17,741	0	0.0%
TOTAL OF RED RIVER OF THE NORTH BASIN GAGES		**17,741**	**10,965**	**61.8%**
KETTLE RIVER BELOW SANDSTONE	St. Croix River	3,528	868	24.6%
SNAKE RIVER NEAR PINE CITY	St. Croix River	3,528	958	27.2%
TOTAL OF ST. CROIX RIVER BASIN GAGES		**3,528**	**1,826**	**51.8%**
CROW RIVER AT ROCKFORD, MN	Upper Mississippi	20,100	2,640	13.1%
CROW WING RIVER NEAR PILLAGER, MN	Upper Mississippi	20,100	3,300	16.4%
LONG PRAIRIE RIVER AT LONG PRAIRIE, MN	Upper Mississippi	20,100	434	2.2%
MISSISSIPPI RIVER AT GRAND RAPIDS, MN	Upper Mississippi	20,100	3,370	16.8%
TOTAL OF UPPER MISSISSIPPI GAGES		**20,100**	**9,744**	**48.5%**

*Portion of Watershed is outside of Minnesota
**Watershed is not in Minnesota

Table 4
USGS Gages Used in Analysis

STATION NAME	STATION NUMBER	NUMBER OF YEARS DATA AVAILABLE	WATER YEARS FLOW DATA AVAILABLE
BAPTISM RIVER NEAR BEAVER BAY, MN	4014500	61	1931-1947, 1950-1993
BASSWOOD RIVER NEAR WINTON, MN	5127500	70	1932-1987,1939-2002
BIG FORK RIVER AT BIG FALLS, MN	5132000	67	1929-1979, 1983-1993, 1998-2002
BUFFALO RIVER NEAR DILWORTH, MN	5062000	71	1932-2002
CANNON RIVER AT WELCH, MN	5355200	53	1912-1913, 1932-1971, 1992-2002
CEDAR RIVER NEAR AUSTIN, MN	5457000	63	1910-1914, 1945-2002
CHIPPEWA RIVER NEAR MILAN, MN	5304500	65	1938-2002
COTTONWOOD RIVER NEAR NEW ULM, MN	5317000	68	1912-1913, 1936-1937, 1939-2002
CROW RIVER AT ROCKFORD, MN	5280000	76	1910-1911, 1913-1917, 1931,1935-2002
CROW WING RIVER NEAR PILLAGER, MN	5247500	33	1969-1986, 1988-2002
DES MOINES RIVER AT JACKSON, MN	5476000	67	1936-2002
GOOSE RIVER AT HILLSBORO, ND	5066500	69	1932, 1935-2002
KETTLE RIVER BELOW SANDSTONE, MN	53367000	35	1968-2002
KNIFE RIVER NEAR TWO HARBORS, MN	4015330	28	1975-2002
LE SUEUR RIVER NEAR RAPIDAN, MN	5320500	59	1940-1945, 1950-2002
LITTLE FORK RIVER AT LITTLEFORK, MN	5131500	79	1912-1916, 1929-2002
LONG PRAIRIE RIVER AT LONG PRAIRIE, MN	5245100	31	1972-2002
MINNESOTA RIVER NEAR JORDAN, MN	5330000	68	1935-2002
MINNESOTA RIVER NEAR LAC QUI PARLE, MN	5301000	56	1943-1994, 1999-2002
MISSISSIPPI RIVER AT GRAND RAPIDS, MN	52110000	105	1884-1888, 1901-1909, 1912-2002
MISSISSIPPI RIVER NEAR ANOKA, MN	5288500	71	1932-2002
OTTER TAIL RIVER BL ORWELL D NR FERGUS FALLS, MN	5046000	72	1931-2002
PARK RIVER AT GRAFTON, ND	5090000	71	1932-2002
PIGEON RIVER AT MIDDLE FALLS NR GRAND PORTAGE MN	4010500	79	1924-2002
RED LAKE RIVER AT CROOKSTON, MN	5079000	101	1902-2002
Rock River near Rock Valley, IA	6483500	54	1949-2002
ROOT RIVER NEAR HOUSTON, MN	5385000	71	1910-1917,1931-1983,1991-2000
ROSEAU RIVER BELOW STATE DITCH 51 NR CARIBOU, MN	5112000	45	1921-1930, 1933, 1937, 1941-1943, 1973-2002
SNAKE RIVER NEAR PINE CITY, MN	5338500	41	1914-1917, 1952-1981, 1992-2002
ST. LOUIS RIVER AT SCANLON, MN	4024000	94	1909-2002
VERMILLION RIVER NEAR EMPIRE, MN	5345000	30	1943, 1974-2002
WILD RICE RIVER AT HENDRUM, MN	5064000	58	1945-2002

Council, Sept. 1981. The Weibull plotting position method, described in this reference, were implemented to assign an exceedence probability (the probability of the flow being greater than or equal to a value) to every annual flow record in the time series. The probabilities were then plotted on semi-log paper to fit a trend line to the data. Different statistical equations were analyzed to determine which equation best describes the data. The frequency curves were then based on the best-fit equation, typically a Pearson Type III distribution.

Typically, frequency analysis using the methodology described above, is used for annual flood peaks rather than total annual runoff. Another statistical technique described in Bulletin #17B is the development of flow duration curves to define flow conditions. This method is commonly used in the analysis of low flow conditions. Flow duration curves are usually developed using a time step of less than a year (in this study, a year time step was used), frequently using a one day time step. A comparison between using flow-duration curves and frequency analysis was made and is shown in Table 5. The results presented in the table show only a small difference between the values derived from the two methods. Since flow-duration curves are usually fit by eye rather than a statistical distribution it was decided to use the frequency analysis which would provide objectivity in the selection of runoff values for the low, average and high runoff years.

The frequency curves for each of the watersheds are in Appendix A. The curves show that for gages in the south and west portions of the state, the period of 1979-2002 flows were consistently above the long-term period of record. The frequency curves for much of Northeast Minnesota, particularly the Rainy River, the North Shore of Lake Superior, and St. Croix River basins did not show this trend. The curves indicate that there is a general trend of decreasing runoff from east to west. Lake Superior Basin has the highest runoff in the state of Minnesota, with the Baptism River watershed having the highest values within that basin, with average runoff of 15.3 inches. Runoff in the Red River of the North Basin had the least runoff, with the Buffalo River Watershed having 2.8 inches of runoff in an average year which is lowest of the Minnesota gages used in this analysis. However, the two watersheds in the North Dakota portions of the Red River Watershed have average runoff of less than 2 inches. Decreasing runoff from east to west also occurs in southern Minnesota, but the trend is less dramatic than in the north. The Root River in extreme southeast Minnesota has nearly 11 inches of runoff for the period of 1979-2002, The Rock River in southwest Minnesota and

Table 5
Comparison of Frequency and Duration Analysis on Runoff Values

Watershed	Major Basin	Values from Frequency Plots (inches) Low Flow	Average Flow	High Flow	Values from Duration Curves (inches) Low Flow	Average Flow	High Flow	Difference (inches) Low Flow	Average Flow	High Flow
CEDAR RIVER NEAR AUSTIN	Cedar River	5.8	10.2	18.2	5.2	10.3	16.7	0.6	-0.1	1.5
DES MOINES RIVER AT JACKSON	Des Moines River	1.1	5.3	13.2	0.6	5.9	10.5	0.5	-0.6	2.7
BAPTISM RIVER NEAR BEAVER BAY	Lake Superior	11.2	16.8	21.0	10.0	17.2	20.6	1.2	-0.4	0.4
KNIFE RIVER NEAR TWO HARBORS	Lake Superior	9.0	15.3	21.5	9.0	15.8	19.7	0.0	-0.5	1.8
PIGEON RIVER AT MIDDLE FALLS NR GRAND PORTAGE MN	Lake Superior	6.8	11.0	14.8	6.5	10.9	14.3	0.3	0.1	0.5
ST. LOUIS RIVER AT SCANLON	Lake Superior	7.2	11.0	14.5	6.9	11.1	15.1	0.3	-0.1	-0.6
CANNON RIVER AT WELCH	Lower Mississippi River	7.1	9.5	16.1	7.0	9.8	13.7	0.1	-0.3	2.4
ROOT RIVER NEAR HOUSTON	Lower Mississippi River	8.3	10.9	15.0	8.8	10.5	16.5	-0.5	0.4	-1.5
VERMILLION RIVER NEAR EMPIRE, MN	Lower Mississippi River	4.0	7.8	12.6	3.9	7.5	12.0	0.1	0.3	0.6
CHIPPEWA RIVER NEAR MILAN, MN	Minnesota River	1.2	4.1	7.3	1.1	3.7	7.2	0.1	0.4	0.1
COTTONWOOD RIVER NEAR NEW ULM, MN	Minnesota River	1.5	5.5	12.0	1.1	5.4	11.1	0.4	0.1	0.9
LE SUEUR RIVER NEAR RAPIDAN, MN	Minnesota River	3.4	7.8	15.7	2.5	8.1	14.0	0.9	-0.3	1.7
MINNESOTA RIVER NEAR LAC QUI PARLE, MN	Minnesota River	0.4	3.1	6.8	0.7	2.6	7.1	-0.3	0.5	-0.3
ROCK RIVER NEAR ROCK VALLEY, IA	Missouri River	1.0	5.6	13.6	1.0	5.6	12.5	0.0	0.0	1.1
BASSWOOD RIVER NEAR WINTON	Rainy River	7.2	11.2	14.5	6.5	11.2	14.0	0.7	0.0	0.5
BIG FORK RIVER AT BIG FALLS	Rainy River	4.4	7.2	10.5	4.3	6.8	10.9	0.1	0.4	-0.4
LITTLE FORK RIVER AT LITTLEFORK	Rainy River	5.6	8.7	12.7	5.6	8.8	12.5	0.0	-0.1	0.2
BUFFALO RIVER NEAR DILWORTH	Red River of the North	0.8	2.8	5.2	0.9	2.5	5.2	-0.1	0.3	0.0
GOOSE RIVER AT HILLSBORO, ND	Red River of the North	0.1	1.7	3.8	0.1	1.3	3.9	0.0	0.4	-0.1
OTTER TAIL RIVER BL ORWELL D NR FERGUS F	Red River of the North	1.8	3.8	5.9	1.8	3.9	5.9	0.0	-0.1	0.0
PARK RIVER AT GRAFTON, ND	Red River of the North	0.1	1.2	2.8	0.1	1.1	2.7	0.0	0.1	0.1
RED LAKE RIVER AT CROOKSTON	Red River of the North	1.1	3.9	6.7	0.7	4.1	6.6	0.4	-0.2	0.1
ROSEAU RIVER BELOW STATE DITCH 51 NR CARIBOU, MN	Red River of the North	0.8	3.5	6.5	0.7	3.5	6.4	0.1	0.0	0.1
WILD RICE RIVER AT HENDRUM	Red River of the North	1.0	3.7	6.9	1.0	3.5	7.4	0.0	0.2	-0.5
KETTLE RIVER BELOW SANDSTONE	St. Croix River	6.5	10.9	16.2	6.0	11.2	15.1	0.5	-0.3	1.1
SNAKE RIVER NEAR PINE CITY	St. Croix River	4.6	8.3	12.3	4.3	7.5	12.3	0.3	0.8	0.0
CROW WING RIVER NEAR PILLAGER, MN	Upper Mississippi River	3.4	6.1	9.1	3.3	6.0	9.0	0.1	0.1	0.1
CROW RIVER AT ROCKFORD, MN	Upper Mississippi River	2.1	6.4	10.9	1.1	7.0	10.4	1.0	-0.6	0.5
LONG PRAIRIE RIVER AT LONG PRAIRIE, MN	Upper Mississippi River	2.6	5.2	8.3	2.3	5.2	8.2	0.3	0.0	0.1
MISSISSIPPI RIVER AT GRAND RAPIDS, MN	Upper Mississippi River	3.6	6.2	8.6	3.2	5.6	8.7	0.4	0.6	-0.1
Average		**3.8**	**7.2**	**11.4**	**3.5**	**7.1**	**11.0**	**0.250**	**0.037**	**0.433**
Standard Deviation								**0.370**	**0.352**	**0.901**

Northwest Iowa has an average runoff of 5.6 inches. Increases in runoff are more dramatic moving south as flows approach high flow conditions.

From the frequency curves developed for the 1979-2002 water year period, runoff values from the 90 (dry year), 50 (average year) and 10 (wet year) percent probability were determined. The 90 percent value means that, on average, 90 percent of the years will have runoff exceeding this value. The 50 percent value shows the runoff amount that would be exceeded one-half the years on average. The 10 percent value is the flow which would be exceeded only 10 percent of the years. The 90 and 10 percent probabilities were selected because they do not represent extreme events; rather they represent typical dry and wet periods for the basins (a 1 in 10 chance of occurring on any given year).

Development of Runoff Maps from Frequency Data

The centroid of the watershed for each of the 30 USGS gages was determined. The resulting X and Y coordinates of the centroid (in UTM Coordinates) were determined and were assigned the runoff values for the watershed. The centroid (essentially, the center of the watershed) was used rather than the gage location since the centroid best represents the average characteristics of the watershed. The gage is most often at an extreme point in the watershed and its location would not necessarily best represent the watershed upstream.

A table was constructed with the UTM coordinates and ruoff values. This table was imported into Surfer Software and interpolated using the Kriging routine to create three state-wide 1 kilometer x 1 kilometer grids representing the dry, average and wet condition runoff values. The resulting Surfer grid files were imported into ArcView Spatial Analyst extension and were overlain with the boundaries of the major basins. The result was an estimation of the wet, average and dry condition flow volumes based on the 10, 50 and 90 percentile frequencies, respectively.

One of the benefits of using runoff grids is that average runoff for smaller ungaged watersheds within each of the larger basins could be estimated. Runoff from smaller watersheds is a necessary input for some of the non-point source phosphorus computations. Because of the differences in rainfall and land cover across Minnesota, runoff characteristics are likely to be different for smaller watersheds compared to runoff recorded for the larger basin gages.

Precipitation Frequency Curves

Frequency curves were also developed for the basin-wide precipitation data. The data were summarized by water year and the same methodology used to develop the flow – frequency curves were also used for the precipitation. The curves are shown in Appendix B.

Results of Flow and Precipitation Computations

Maps showing the state-wide runoff values are shown in Figures 4, 5 and 6. Table 6 shows the 10 basin-wide averages develop from these maps for the wet, average and dry conditions. The averages were estimated by using ArcView Spatial Analyst to overlay the basin boundaries with the runoff grids discussed in the previous section. The average of the grid (cell) values within each basin was used as the basin-wide average for each condition. Table 6 also provides a summary of basin wide average precipitation for the wet, average and dry years based on the frequency determinations. Also shown in Table 6 is the percent runoff calculated using the ratio of runoff to rainfall.

Note that, in general, the year in which the 10^{th} percentile wet year flow volume occurred will not necessary coincide with the year in which the 10^{th} percentile wet year precipitation amount was observed. River discharge is not only a function of precipitation, but is affected by a number of hydrologic conditions such as drought and floods occurring in preceding years. For example, if the preceding year was much dryer than normal, much of the current year's rainfall (even though above average) may be used in refilling lake and wetland basins and replenishing soil moisture. The intensity of rainfall is another factor in the generation of runoff. For a given amount of precipitation, more of it will runoff if the precipitation occurs during a heavy thunderstorms rather than rain falling during a gentle day-long shower.

Therefore, there may be below-normal flow in years where precipitation is above-average. In this study it was assumed that the 10^{th} percentile flow does occur in the same year that the 10 percentile rainfall occurs. The same assumption was made for the 50 and 90th percentile years. This simplifying assumption had to be made to facilitate a direct comparison between the three flow scenarios examined.

TABLE 6
Basin-Wide Runoff and Precipitation

	Dry Conditions			Average Conditions			Wet Conditions		
Basin	Rainfall (inches)	Runoff (inches)	Percent Runoff	Rainfall (inches)	Runoff (inches)	Percent Runoff	Rainfall (inches)	Runoff (inches)	Percent Runoff
Cedar River	27.5	5.6	20.4%	32.1	9.8	30.6%	41.3	17.5	42.4%
DesMoines River	22.0	1.4	6.4%	28.0	5.7	20.3%	36.8	13.4	36.4%
Lake Superior	25.5	7.9	30.8%	29.1	12.4	42.7%	35.1	16.7	47.7%
Lower Mississippi	27.0	7.1	26.5%	33.3	10.3	30.9%	39.8	15.6	39.1%
Minnesota River	22.1	1.9	8.7%	28.1	5.6	19.9%	34.8	11.2	32.2%
Missouri River	21.1	1.0	4.6%	27.2	5.3	19.3%	35.6	12.8	36.0%
Rainy River	22.4	4.8	21.4%	26.2	8.0	30.6%	32.1	11.4	35.6%
Red River	18.6	1.1	5.7%	23.3	3.4	14.7%	28.9	6.1	21.1%
St. Croix River	23.7	5.6	23.7%	30.6	9.7	31.7%	37.6	14.3	38.1%
Upper Mississippi River	22.6	3.6	15.8%	28.1	6.9	24.5%	34.3	10.4	30.5%

The representative years for low, average and high flows for each basin are summarized in Table 7. The years selected typically had annual flow volumes within ½ inch of the 90, 50 and 10th percentile frequency values for representative gages in each Basin However, there were cases, especially in the Lower Mississippi basin, where the volume differences exceed the ½ inch value. These representative years were used to select the time frame when phosphorus and TSS data collected would best reflect the wet, average and dry flow conditions.

TABLE 7

Representative Years for Low, Average and High Flow Conditions

	Representative Years		
Major Watershed	**Low Flow**	**Average Flow**	**High Flow**
Cedar River	1988, 1989, 1990, 2002	1995, 1997, 1998	1983, 1999, 2001
Des Moines River	1988, 1989, 1990, 2000	1985, 1987, 1991, 1999	1983, 1984, 1994
Lake Superior	1988, 1990, 1998	1985, 1991, 1993, 1995	1978, 1983, 1996
Lower Mississippi River	1996, 2002	1994, 1998	1973, 1974, 1993
Minnesota River	1981, 1990, 2000	1985, 1998, 1999	1986, 1997, 2001
Missouri River	1989, 1990, 1991, 2000	1980, 1987, 1992, 1999	1983, 1984, 1997
Rainy River	1977, 1980, 2002	1992, 1993, 1997	1974, 1975, 1996, 2001
Red River of the North	1988, 1989, 1990, 1991	1993, 1994, 1995, 2002	1997, 1998, 2001
St. Croix River	1980, 1987, 1988, 1998	1994, 1995, 1999	1978, 2001, 2002
Upper Mississippi	1989, 1990, 2000	1982, 1995, 2002	1985, 1997, 2001

Flow Variability and Uncertainty

As part of the frequency analysis, the 95 percent confidence intervals for the curves were developed. For example, the confidence intervals indicate that there is a 95 percent probability the 10 percent (wet year) flow falls between the range shown on the curves (see curves in Appendix A and Appendix B). In general, when the period of record is longer, the confidence interval becomes narrower.

A comparison was also made of the interpolated grid data for the three runoff conditions with actual values for the watersheds that are entirely within the state of Minnesota. This comparison is shown in Table 8.The last three columns represent the difference between the value from the frequency curves and that predicted from the grid. The difference in high flows had the highest standard deviation and also the highest absolute difference (-1.2 inches for the St. Louis River). The average flows had the best overall match. The Big Fork River Watershed had the best fit, with nearly identical values for all three flow conditions.

Recommendations for Future Refinements

One of the problems encountered when developing this flow analysis is that some of the USGS gages were discontinued. The collection of current data at some locations would provide valuable flow data for calculation of phosphorus loadings and also more accurate estimation of annual flows. Gages where reestablishment of continuous flow monitoring is recommended are listed below:

- Baptism River near Beaver Bay
- Big Fork River at Big Falls
- Root River near Houston
- Zumbro River at Zumbro Falls

It is also recommended that one or two smaller watersheds within the metropolitan area be continuously gaged. Currently only the Vermillion River in the south suburbs has a long-term, unintrupted record.

Literature Cited

USGS Surface-Water Data for the Nation Website. http://waterdata.usgs.gov/nwis/sw

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Greg Spoden; Minnesota Department of Natural Resources Division of Waters State Climatology Office.

Guidelines for Determining Flood Flow Frequency, Bulletin #17B, U.S. Water Resources Council, Sept. 1981

USGS National Land Cover Database, 1992. http://seamless.usgs.gov, http://landcover.usgs.gov/natllandcover.html

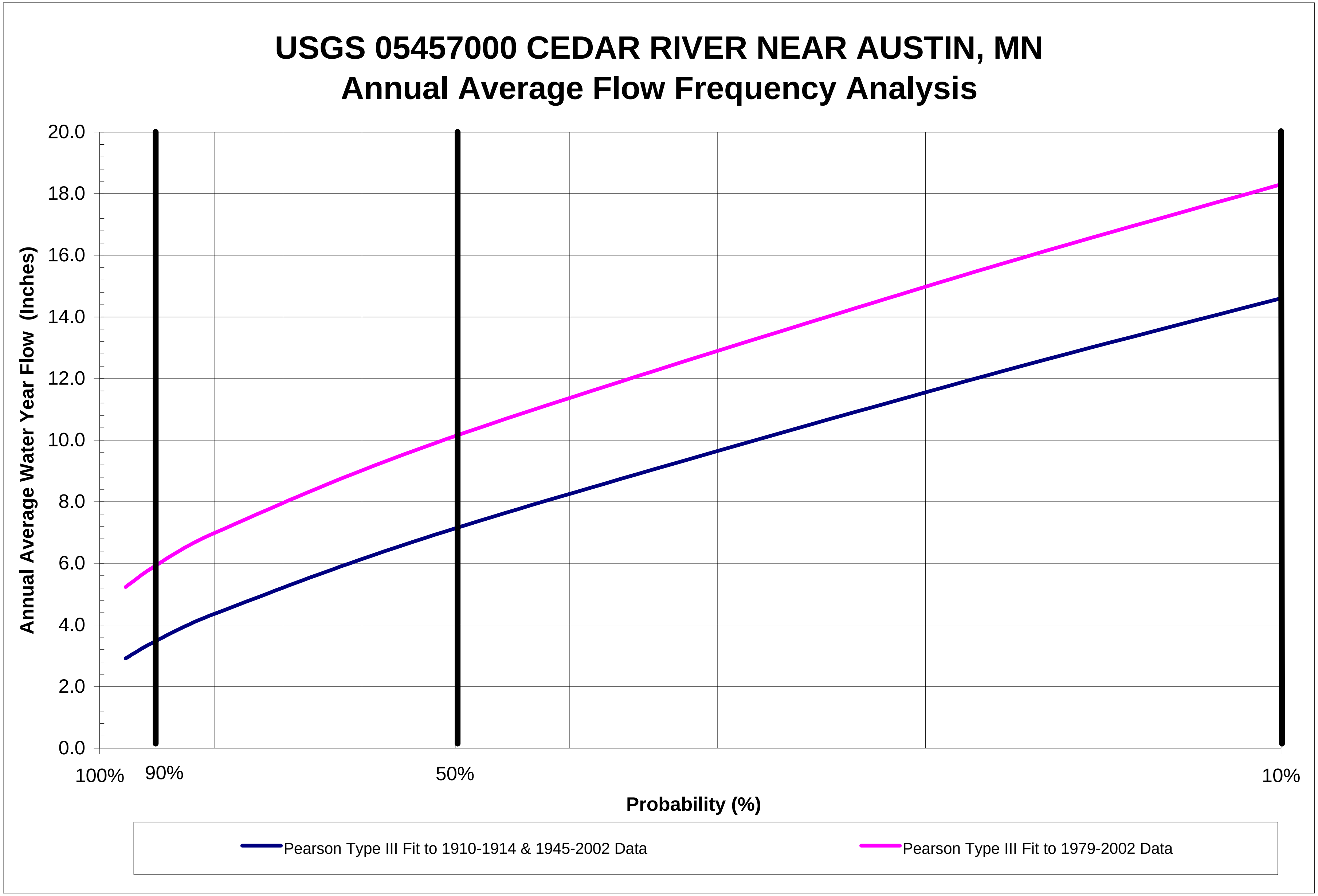
Table 8

Comparison of Runoff Calculated from State-Wide Grids and Frequency Curves for Watersheds Entirely Within Minnesota (Runoff in Inches)

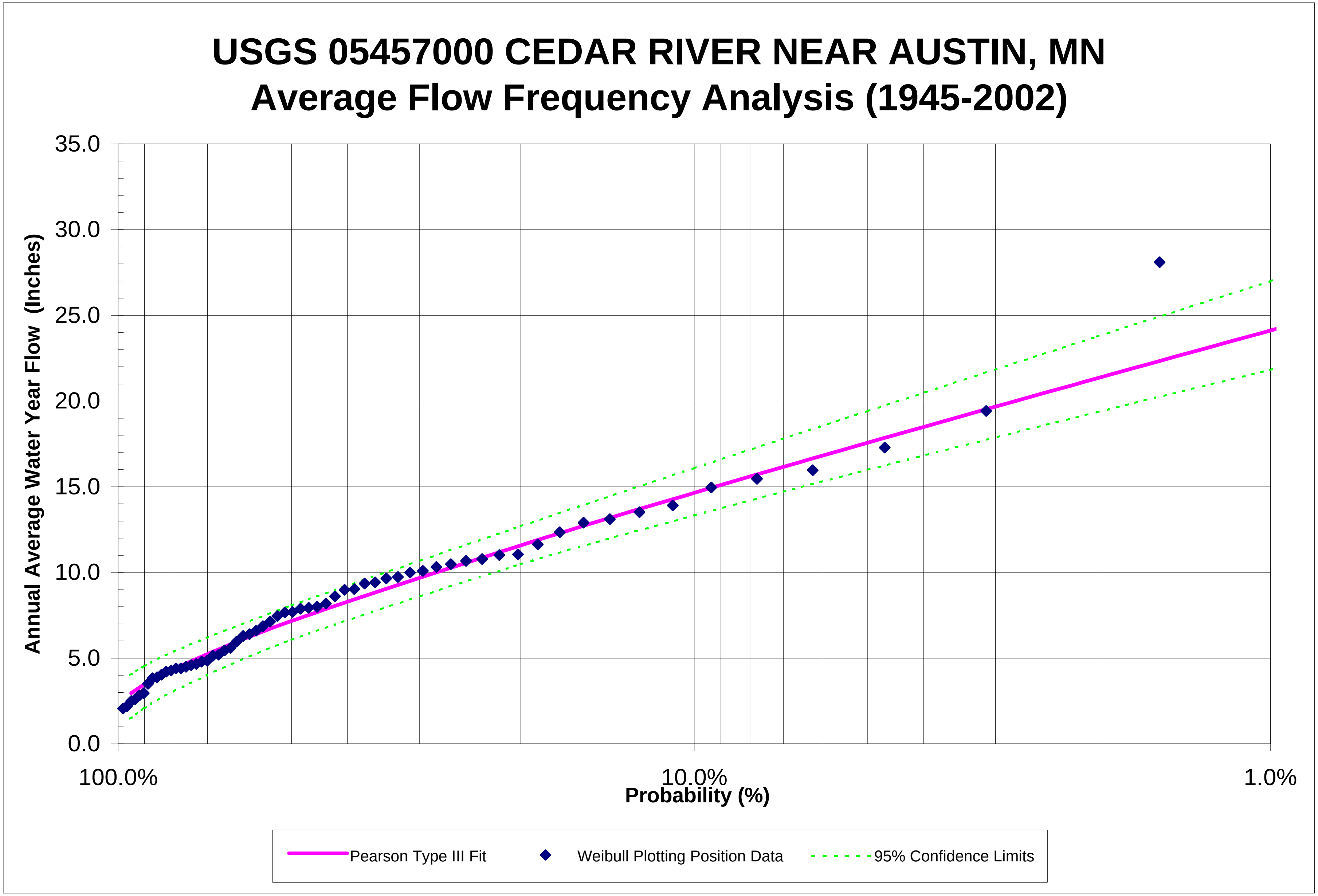
Watershed	Major Basin	Values from State-Wide Runoff Map (inches) Low Flow	Average Flow	High Flow	Values from Frequency Plots (inches) Low Flow	Average Flow	High Flow	Difference (inches) Low Flow	Average Flow	High Flow
CEDAR RIVER NEAR AUSTIN	Cedar River	5.9	10.0	17.7	5.8	10.2	18.2	-0.115	0.183	0.520
DES MOINES RIVER AT JACKSON	Des Moines River	1.2	5.5	13.1	1.1	5.3	13.2	-0.131	-0.153	0.120
BAPTISM RIVER NEAR BEAVER BAY	Lake Superior	10.7	16.2	20.5	11.2	16.8	21.0	0.470	0.608	0.535
KNIFE RIVER NEAR TWO HARBORS	Lake Superior	9.0	15.1	21.1	9.0	15.3	21.5	-0.027	0.159	0.354
ST. LOUIS RIVER AT SCANLON	Lake Superior	7.3	11.6	15.7	7.2	11.0	14.5	-0.137	-0.580	-1.235
ROOT RIVER NEAR HOUSTON	Lower Mississippi River	7.9	10.9	15.8	8.3	10.9	15.0	0.390	-0.028	-0.783
VERMILLION RIVER NEAR EMPIRE, MN	Lower Mississippi River	4.3	8.0	13.0	4.0	7.8	12.6	-0.320	-0.219	-0.374
CHIPPEWA RIVER NEAR MILAN, MN	Minnesota River	1.4	4.3	7.8	1.2	4.1	7.3	-0.191	-0.236	-0.480
COTTONWOOD RIVER NEAR NEW ULM	Minnesota River	1.5	5.5	12.1	1.5	5.5	12.0	0.037	0.018	-0.110
CROW WING RIVER NEAR PILLAGER, MN	Minnesota River	3.1	5.8	8.7	3.4	6.1	9.1	0.280	0.314	0.400
LE SUEUR RIVER NEAR RAPIDAN, MN	Minnesota River	3.8	8.0	15.8	3.4	7.8	15.7	-0.425	-0.249	-0.103
BASSWOOD RIVER NEAR WINTON	Rainy River	7.8	12.0	15.6	7.2	11.2	14.5	-0.581	-0.831	-1.098
BIG FORK RIVER AT BIG FALLS	Rainy River	4.4	7.2	10.5	4.4	7.2	10.5	0.025	-0.015	-0.018
LITTLE FORK RIVER AT LITTLEFORK	Rainy River	5.5	8.6	12.3	5.6	8.7	12.7	0.134	0.096	0.378
BUFFALO RIVER NEAR DILWORTH	Red River of the North	0.9	3.0	5.5	0.8	2.8	5.2	-0.118	-0.194	-0.293
OTTER TAIL RIVER BL ORWELL D NR FERGUS FALLS	Red River of the North	1.8	3.9	6.4	1.8	3.8	5.9	0.030	-0.148	-0.483
RED LAKE RIVER AT CROOKSTON	Red River of the North	1.5	4.1	7.0	1.1	3.9	6.7	-0.386	-0.242	-0.287
ROSEAU RIVER BELOW STATE DITCH 51 NR CARIBOU	Red River of the North	0.9	3.5	6.4	0.8	3.5	6.5	-0.120	-0.009	0.072
WILD RICE RIVER AT HENDRUM	Red River of the North	1.1	3.6	6.5	1.0	3.7	6.9	-0.109	0.098	0.415
KETTLE RIVER BELOW SANDSTONE	St. Croix River	6.4	10.7	15.7	6.5	10.9	16.2	0.138	0.229	0.515
SNAKE RIVER NEAR PINE CITY	St. Croix River	4.8	8.6	12.8	4.6	8.3	12.3	-0.209	-0.310	-0.486
CANNON RIVER AT WELCH	Upper Mississippi River	5.8	9.1	15.5	7.1	9.5	16.1	1.294	0.446	0.572
CROW RIVER AT ROCKFORD	Upper Mississippi River	2.3	6.3	10.8	2.1	6.4	10.9	-0.214	0.122	0.087
LONG PRAIRIE RIVER AT LONG PRAIRIE	Upper Mississippi River	2.4	5.1	8.2	2.6	5.2	8.3	0.157	0.103	0.128
MISSISSIPPI RIVER AT GRAND RAPIDS	Upper Mississippi River	3.6	6.3	9.1	3.6	6.2	8.6	0.048	-0.093	-0.495
MISSISSIPPI RIVER NEAR ANOKA**	Upper Mississippi River	3.5	6.8	10.4	4.4	7.0	9.9	0.862	0.198	-0.452
Average		**4.2**	**7.7**	**12.1**	**4.2**	**7.7**	**12.0**	**0.030**	**-0.028**	**-0.100**
Standard Deviation								**0.395**	**0.302**	**0.504**

**Data not used in the development of state-wide runoff maps

Appendix A: Flow – Frequency Curves



USGS 05457000 CEDAR RIVER NEAR AUSTIN, MN
Annual Average Flow Frequency Analysis
Annual Average Water Year Flow (Inches)
20.0
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
100%
90%
50%
10%
Probability (%)
Pearson Type III Fit to 1910-1914 & 1945-2002 Data
Pearson Type III Fit to 1979-2002 Data



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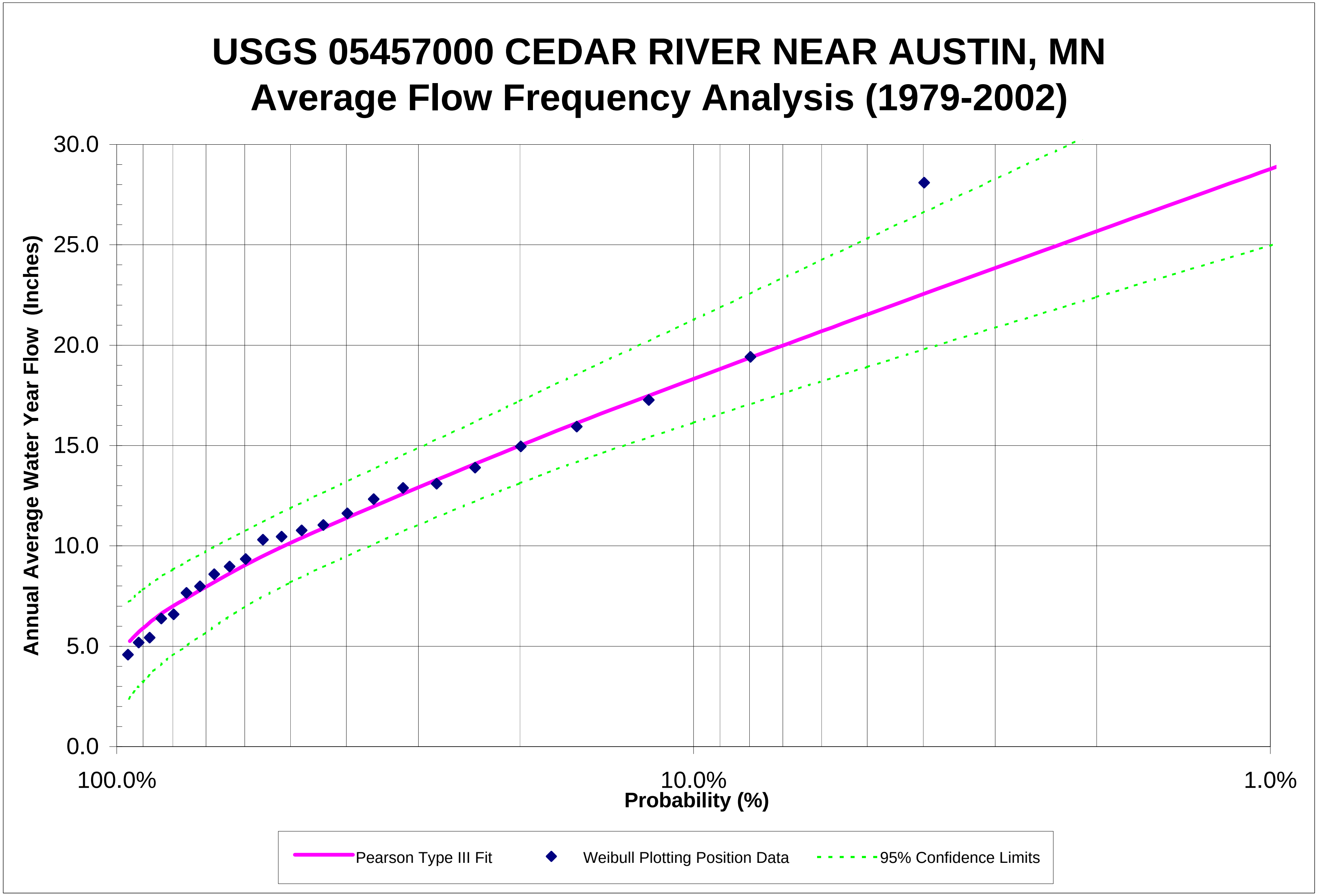
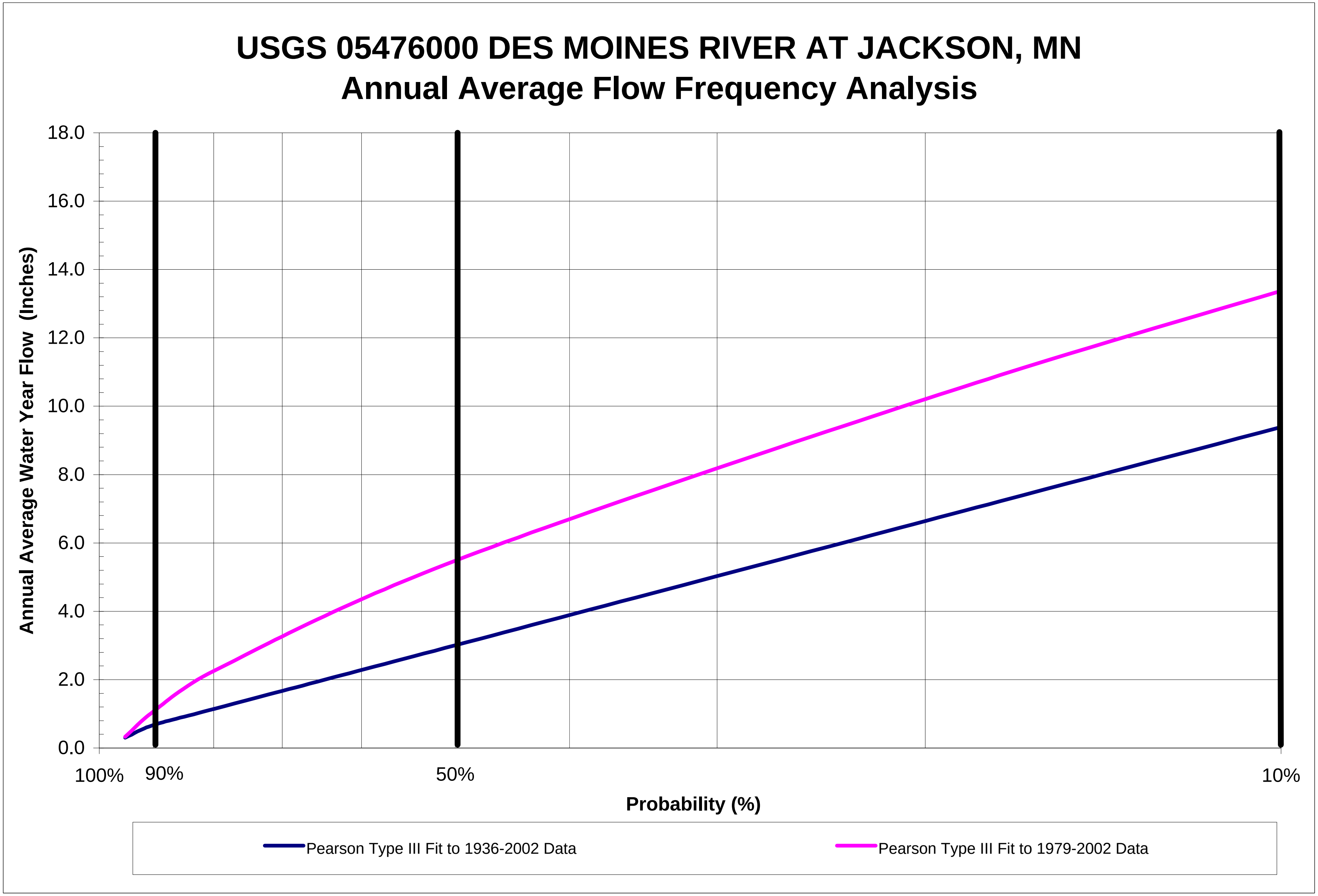


USGS 05457000 CEDAR RIVER NEAR AUSTIN, MN
Average Flow Frequency Analysis (1979-2002)
Annual Average Water Year Flow (Inches)
30.0
25.0
20.0
15.0
10.0
5.0
0.0
100.0%
10.0%
1.0%
Probability (%)
Pearson Type III Fit
Weibull Plotting Position Data
95% Confidence Limits



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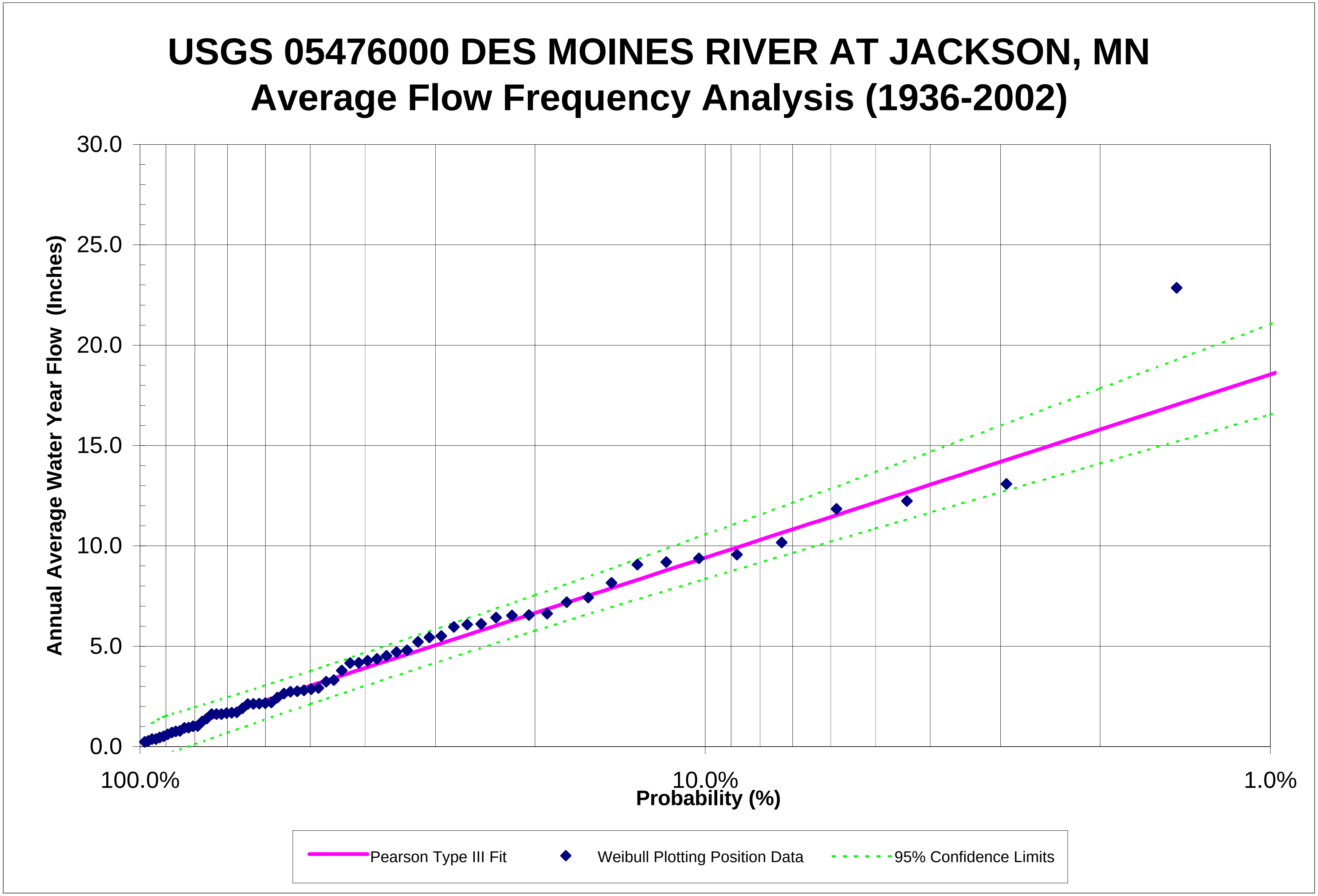
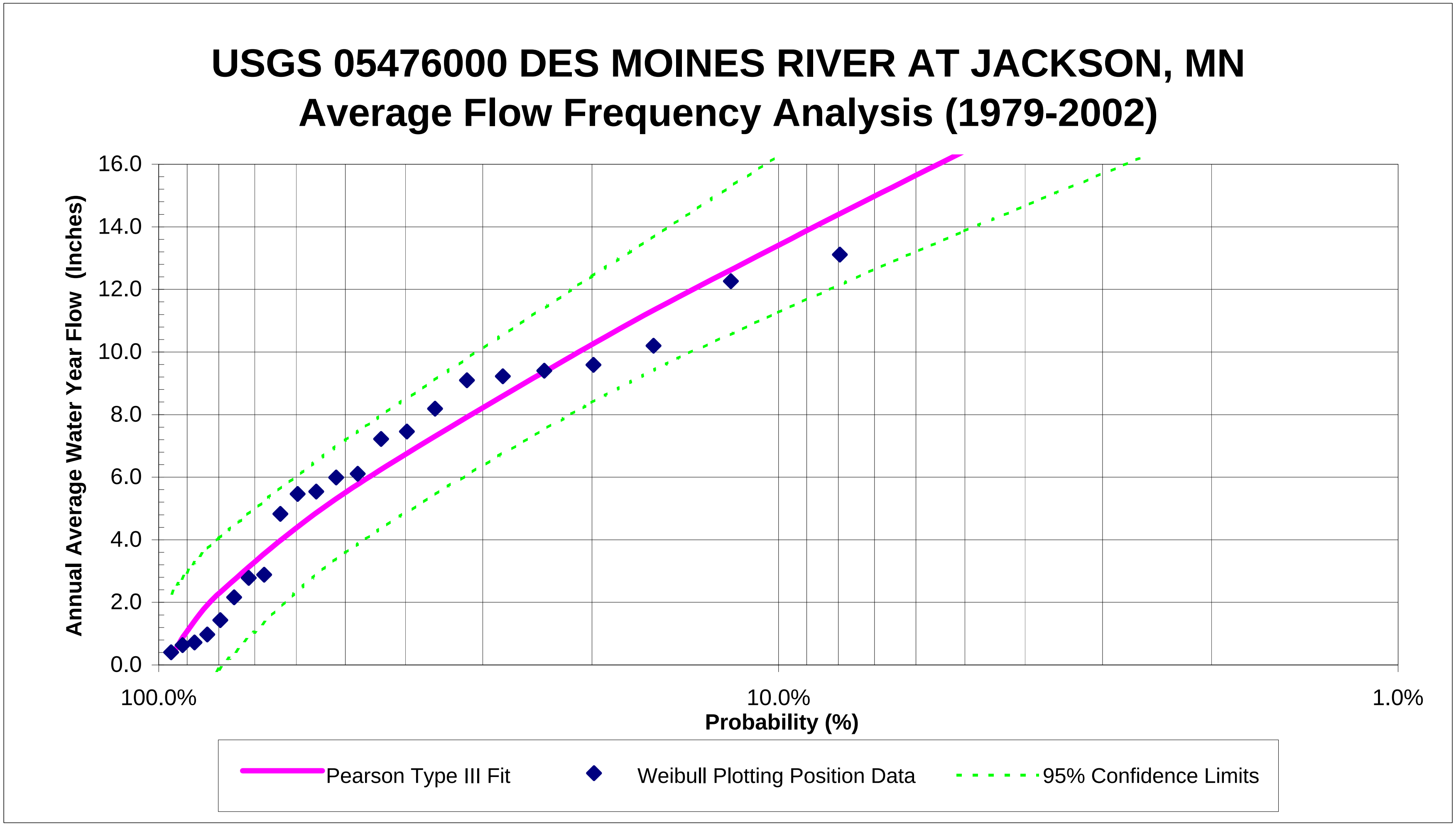
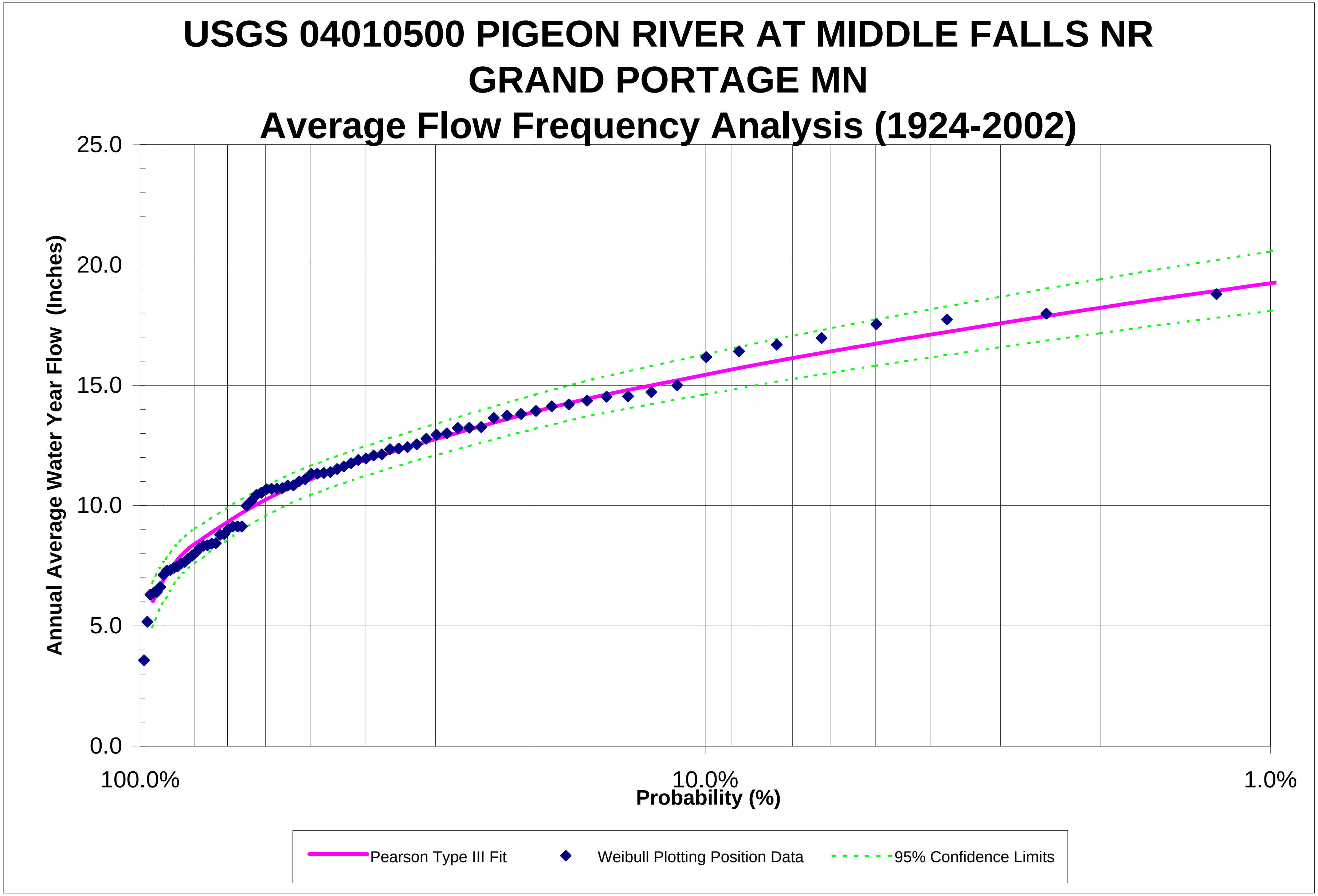

USGS 05476000 DES MOINES RIVER AT JACKSON, MN
Average Flow Frequency Analysis (1936-2002)
Annual Average Water Year Flow (Inches)
30.0
25.0
20.0
15.0
10.0
5.0
0.0
100.0%
10.0%
1.0%
Probability (%)
Pearson Type III Fit
Weibull Plotting Position Data
95% Confidence Limits


USGS 05476000 DES MOINES RIVER AT JACKSON, MN
Average Flow Frequency Analysis (1979-2002)
Annual Average Water Year Flow (Inches)
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
100.0%
10.0%
1.0%
Probability (%)
Pearson Type III Fit
Weibull Plotting Position Data
95% Confidence Limits



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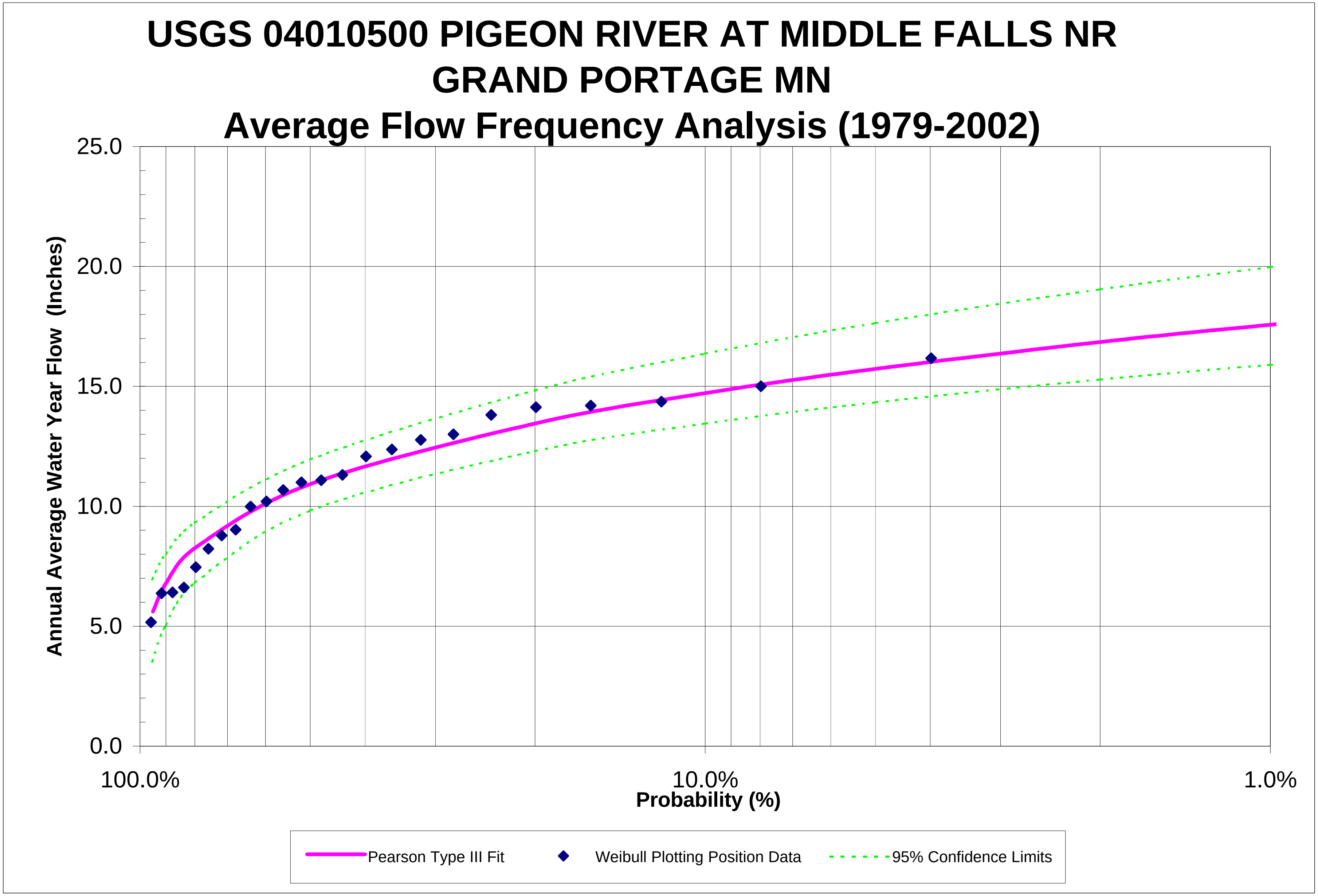

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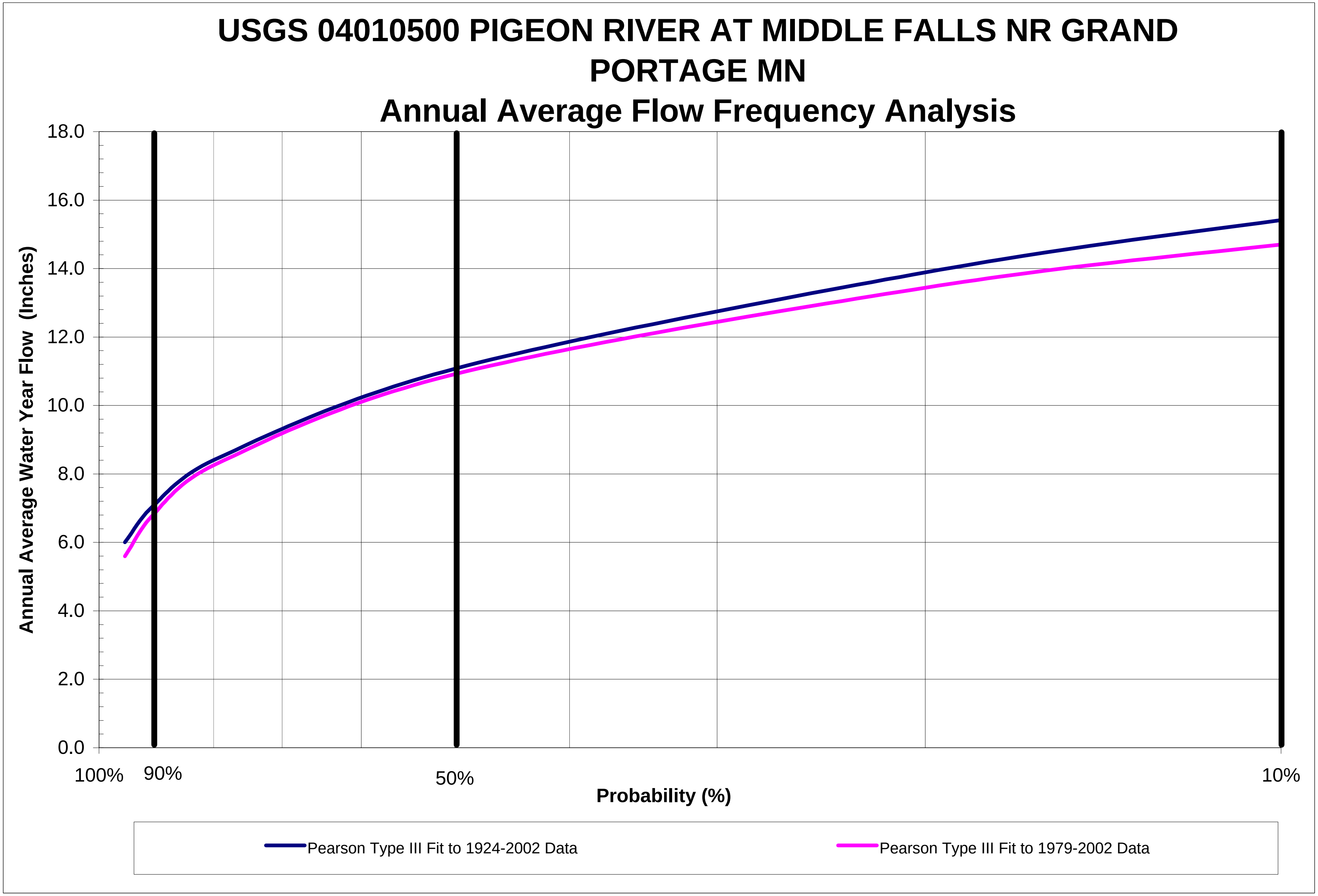
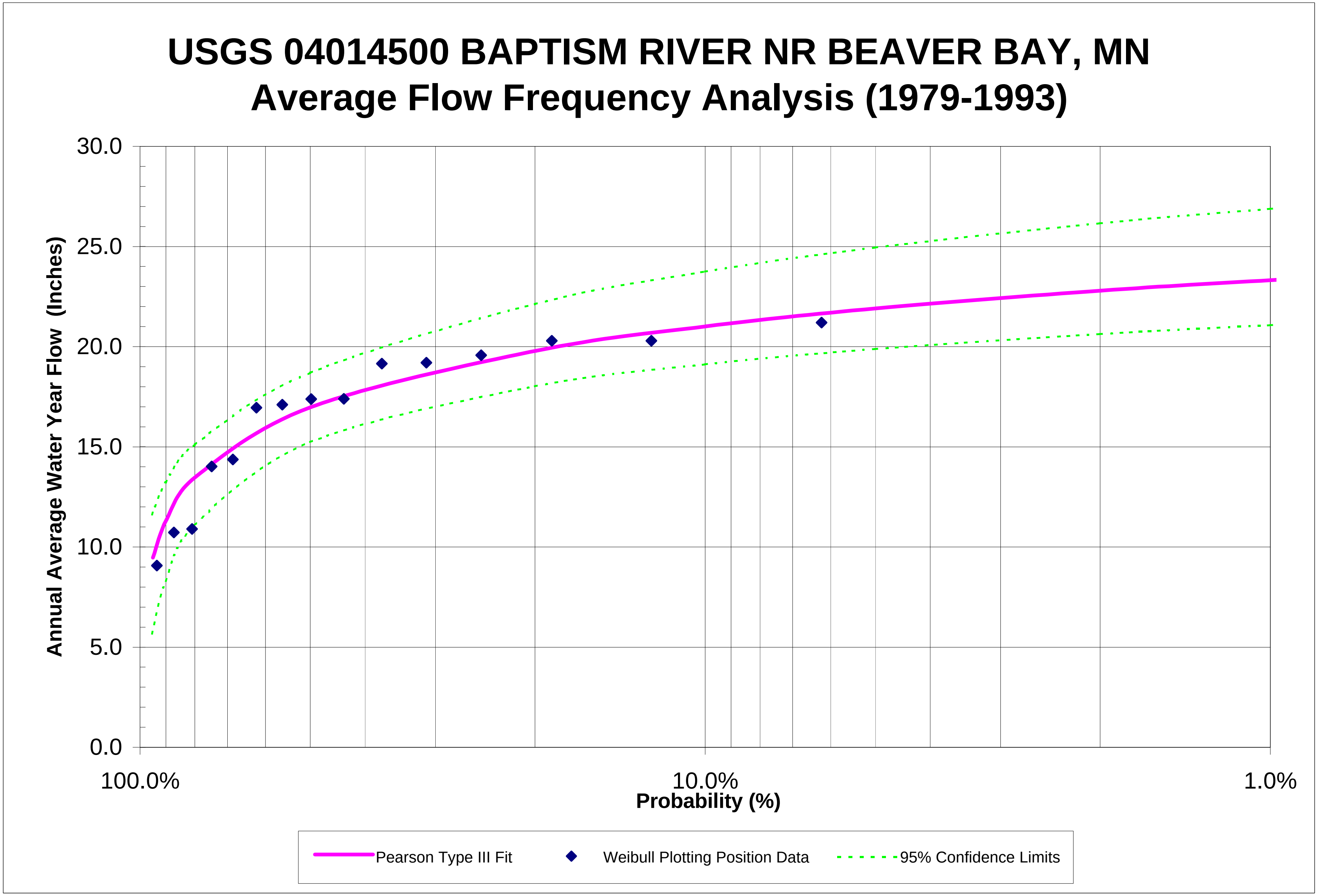


USGS 04010500 PIGEON RIVER AT MIDDLE FALLS NR GRAND PORTAGE MN
Annual Average Flow Frequency Analysis
Annual Average Water Year Flow (Inches)
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
100%
90%
50%
10%
Probability (%)
Pearson Type III Fit to 1924-2002 Data
Pearson Type III Fit to 1979-2002 Data



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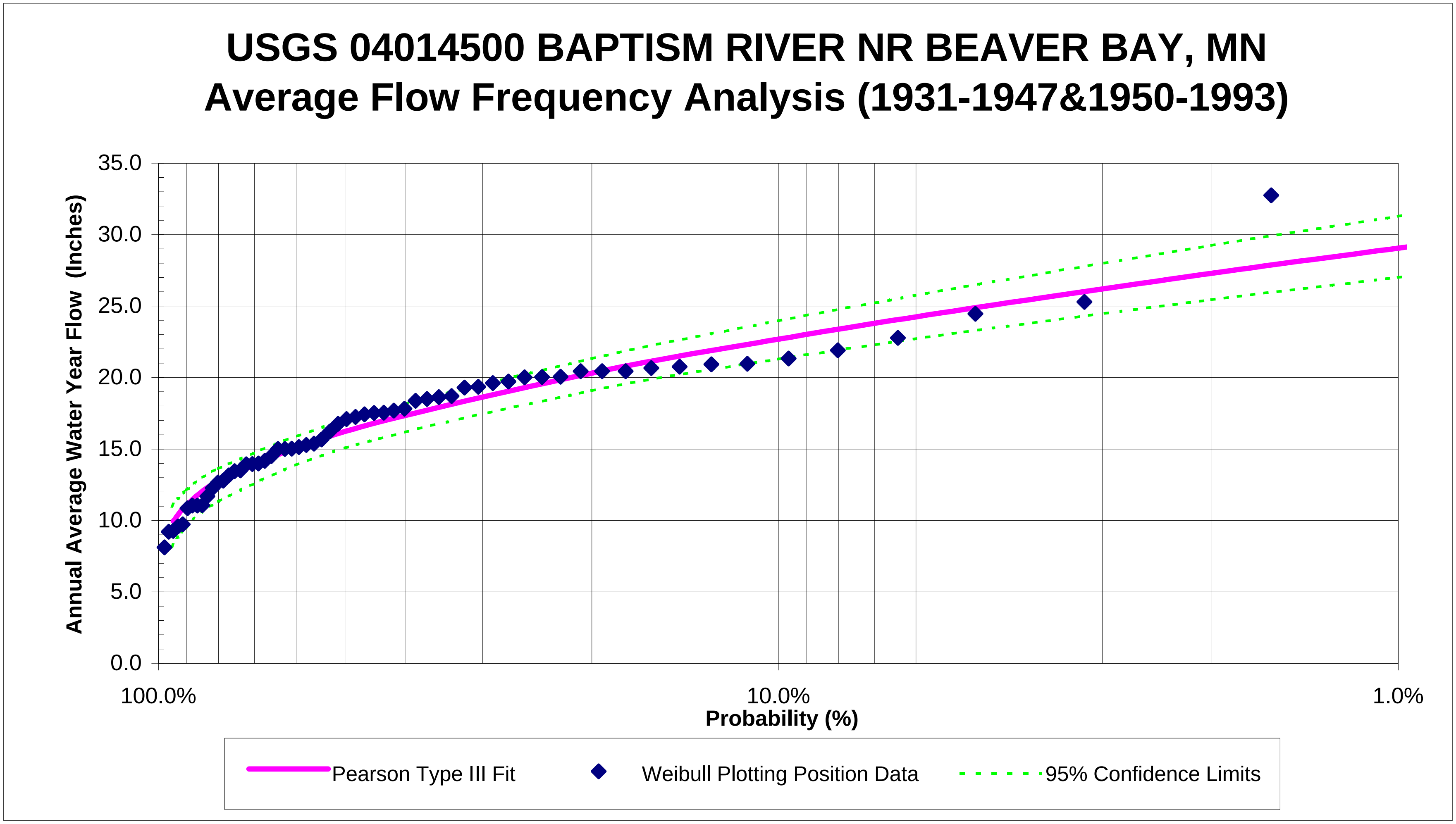

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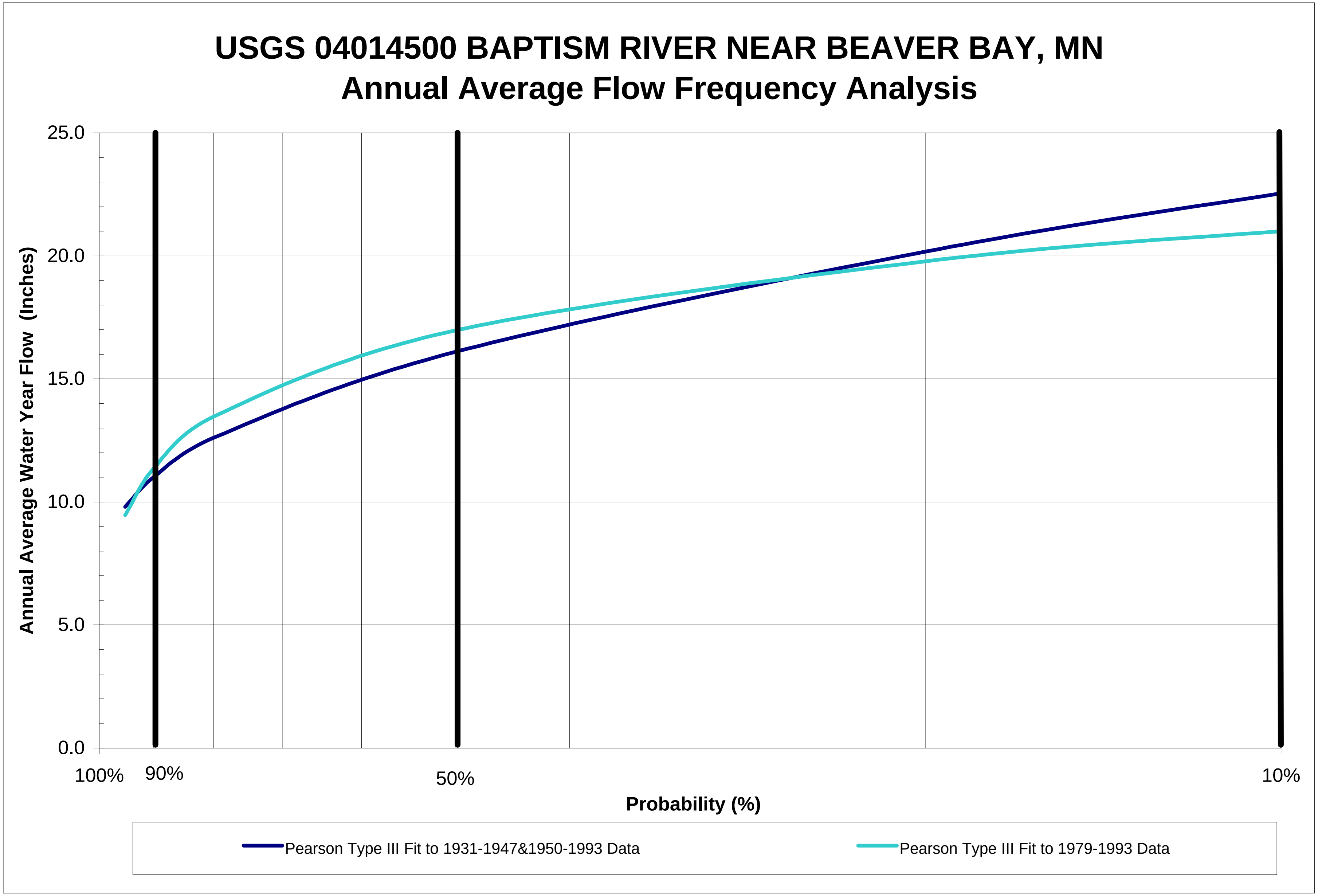
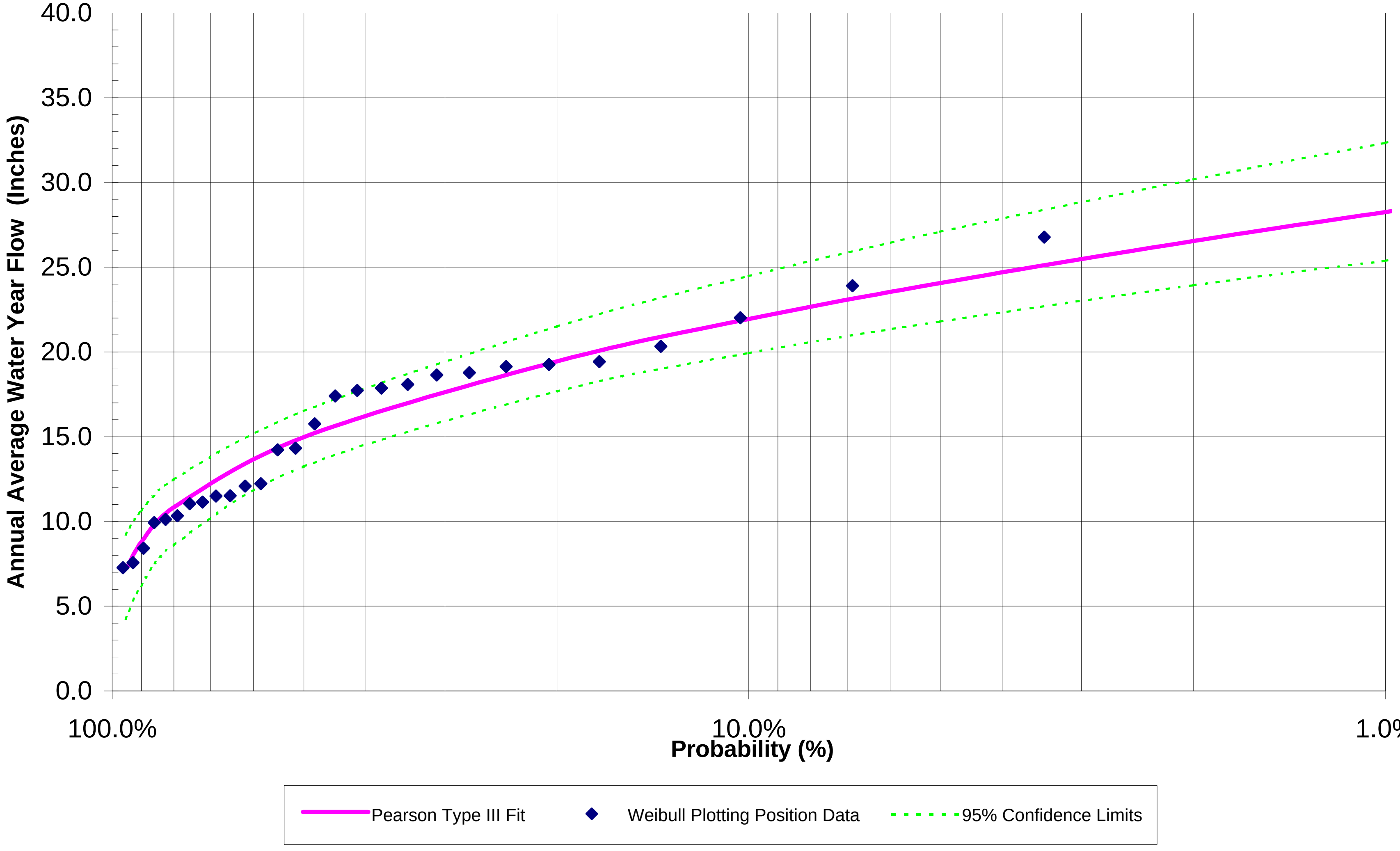


USGS 04014500 BAPTISM RIVER NEAR BEAVER BAY, MN
Annual Average Flow Frequency Analysis
Annual Average Water Year Flow (Inches)
25.0
20.0
15.0
10.0
5.0
0.0
100%
90%
50%
10%
Probability (%)
Pearson Type III Fit to 1931-1947&1950-1993 Data
Pearson Type III Fit to 1979-1993 Data

USGS 04015330 KNIFE RIVER NEAR TWO HARBORS, MN
Average Flow Frequency Analysis (1975-2002)



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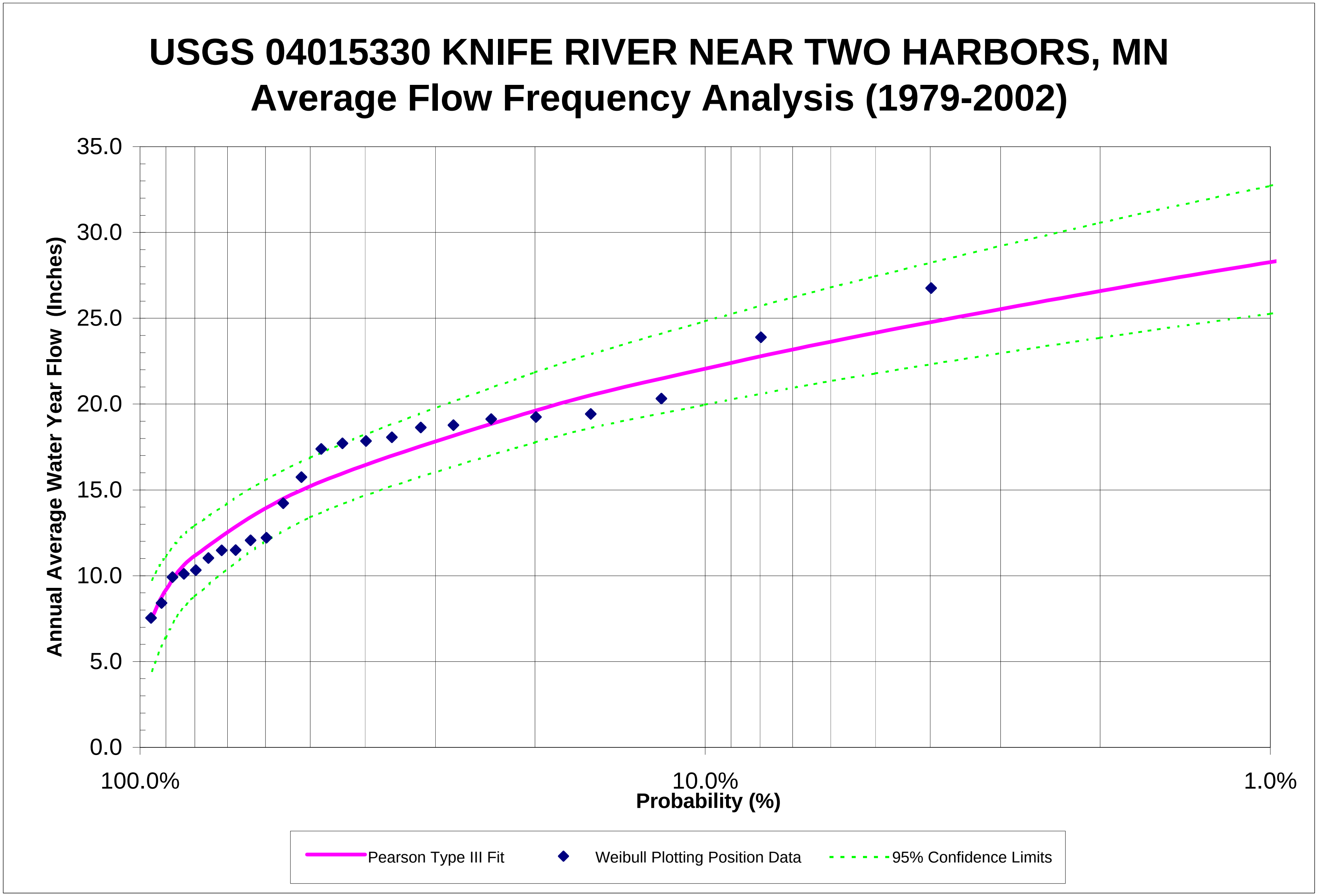

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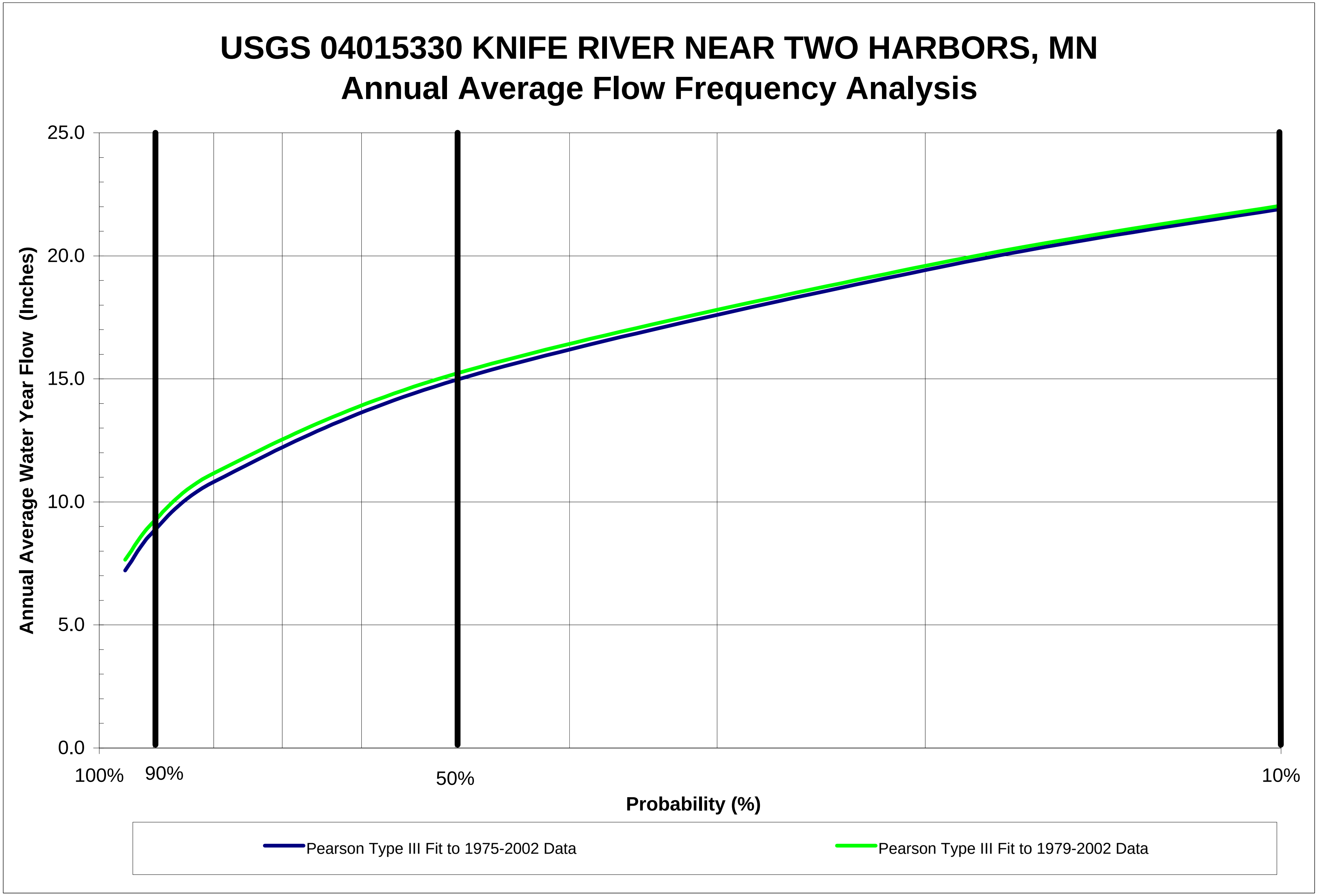

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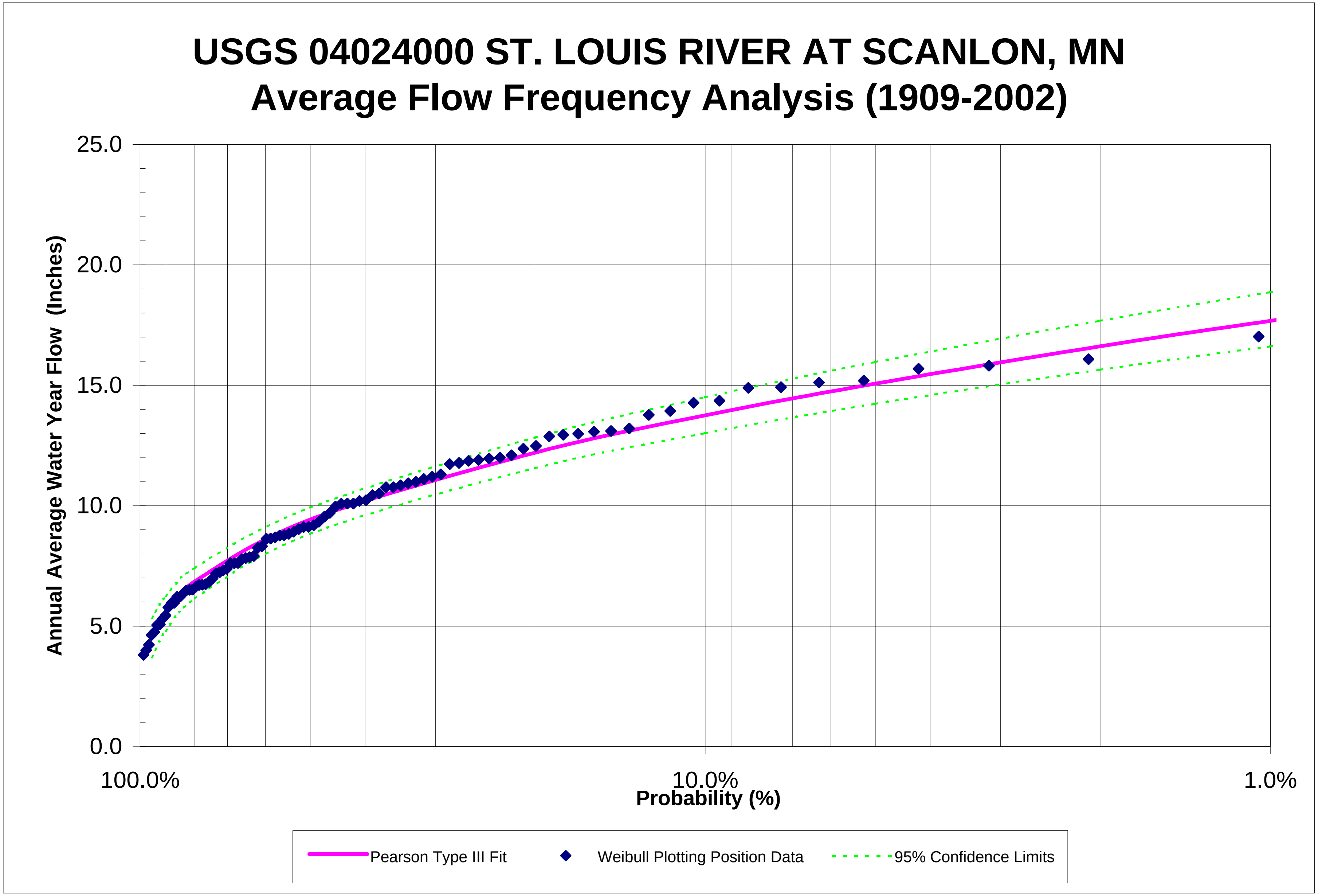

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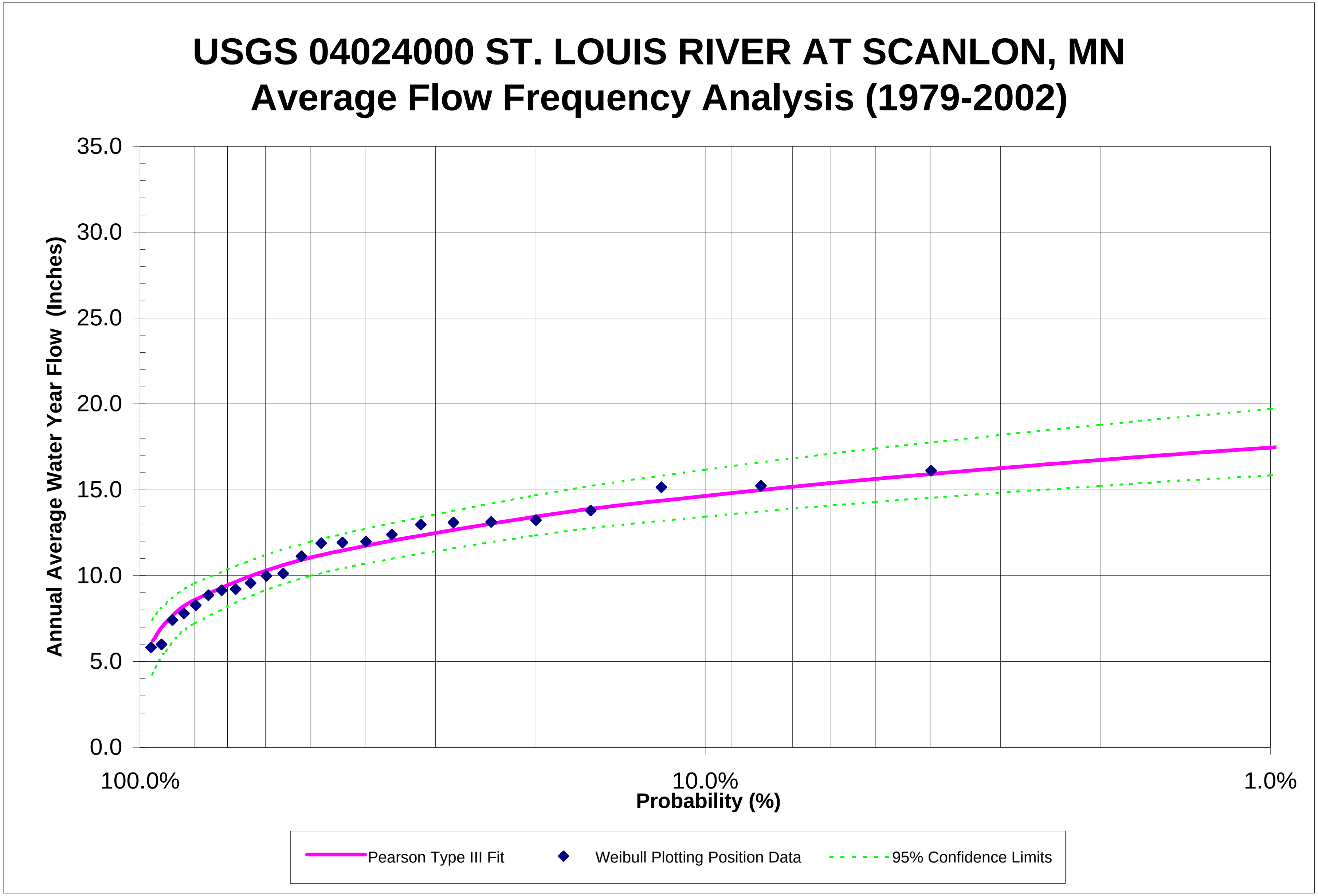

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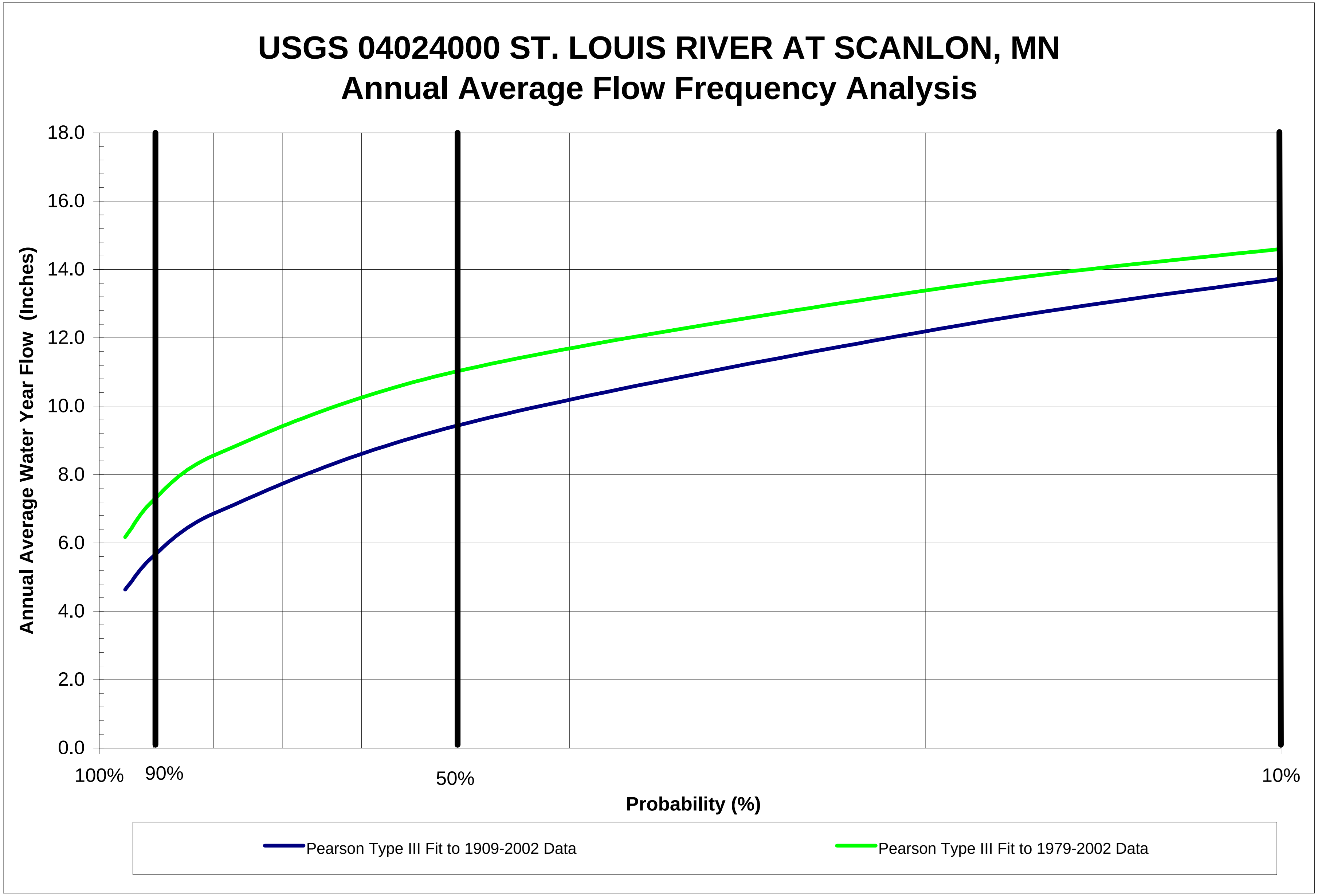

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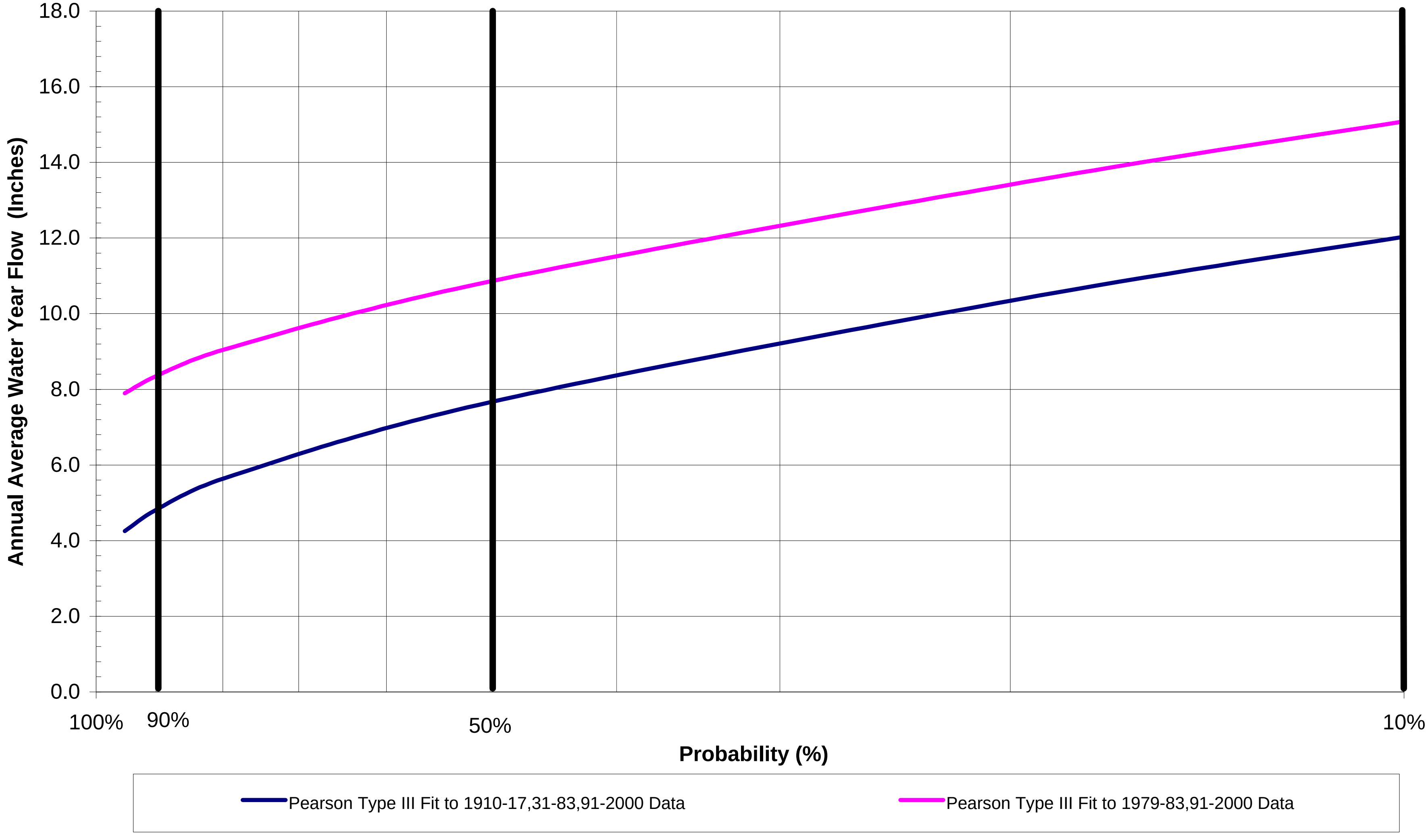
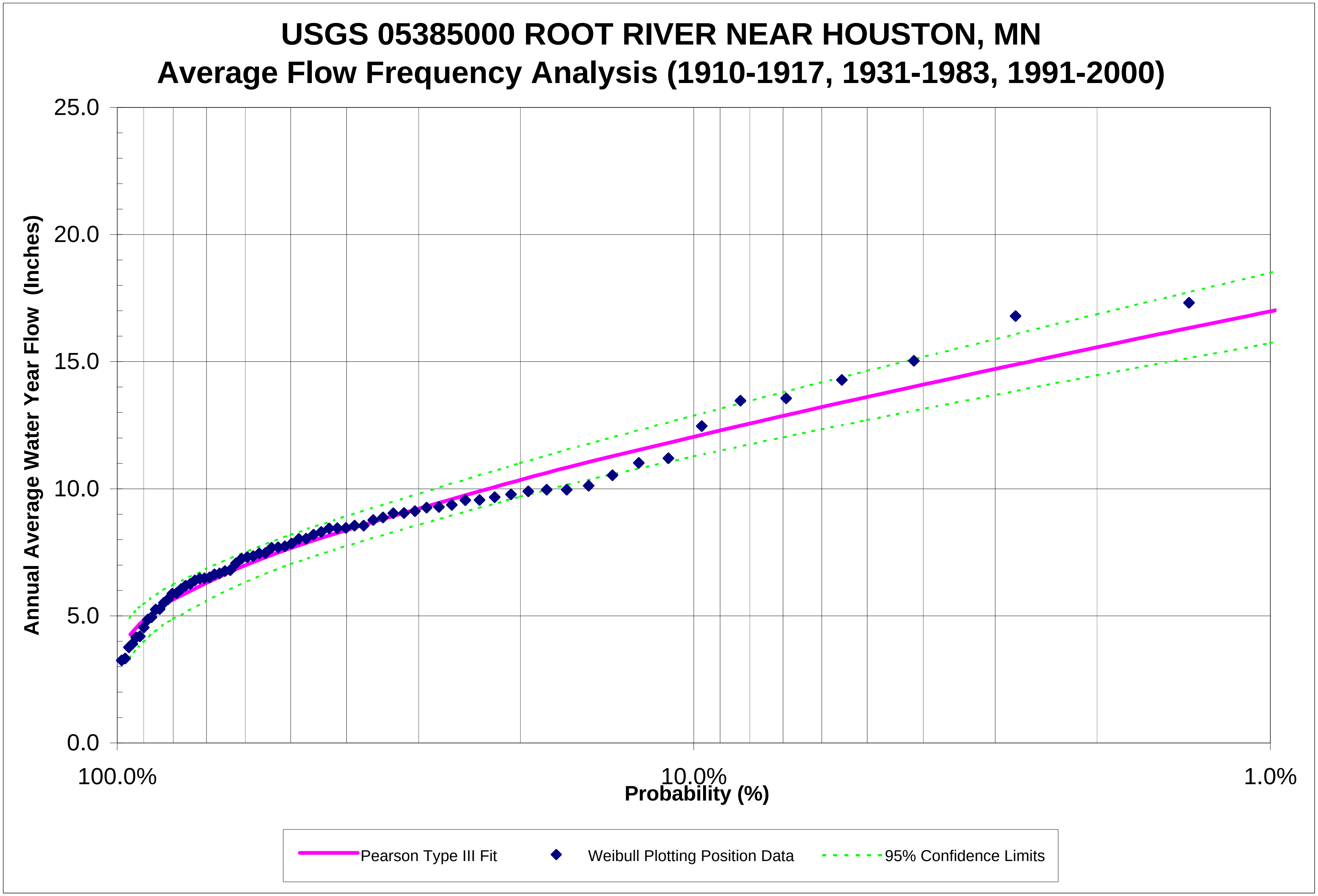
USGS 05385000 ROOT RIVER NEAR HOUSTON, MN
Annual Average Flow Frequency Analysis





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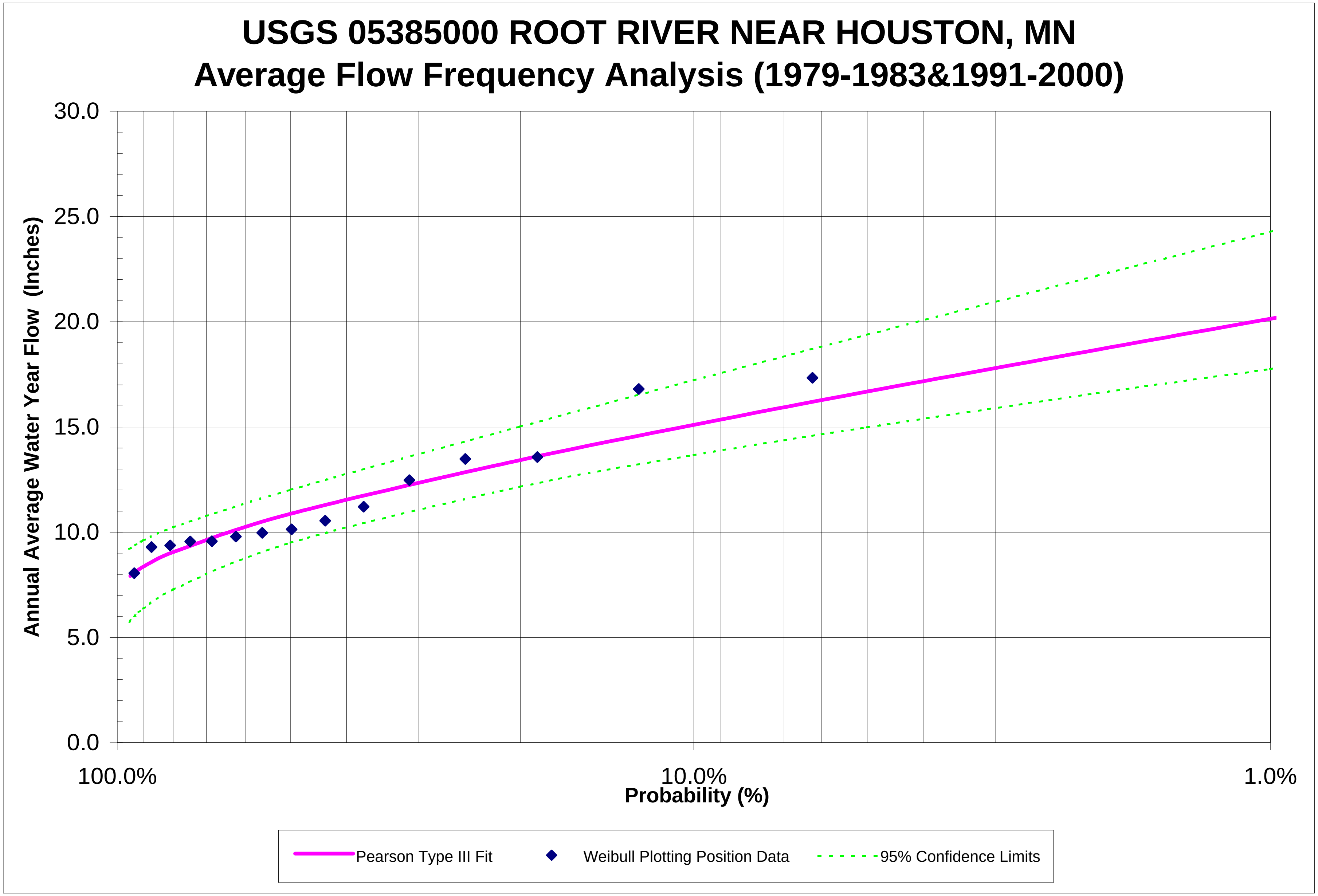
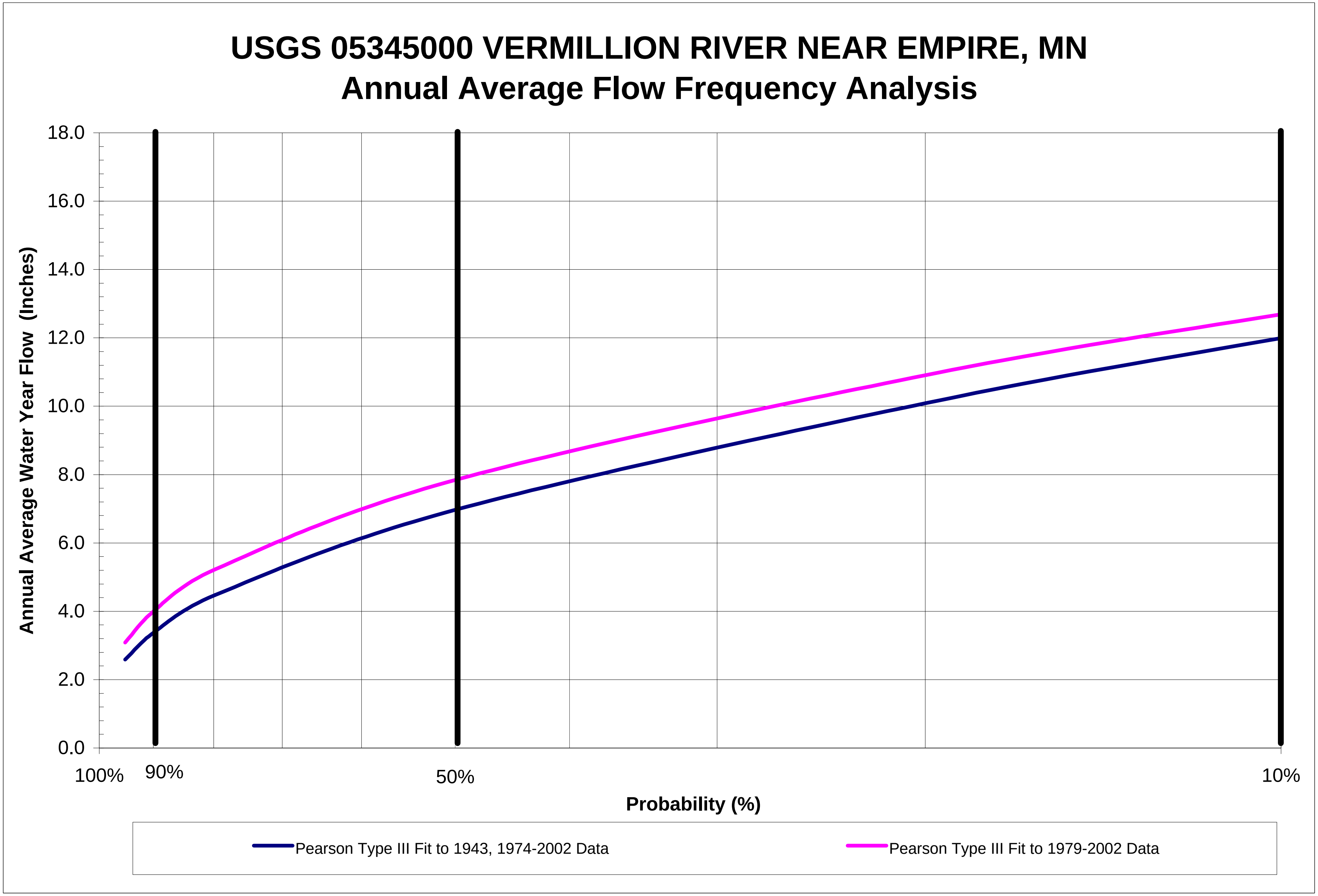
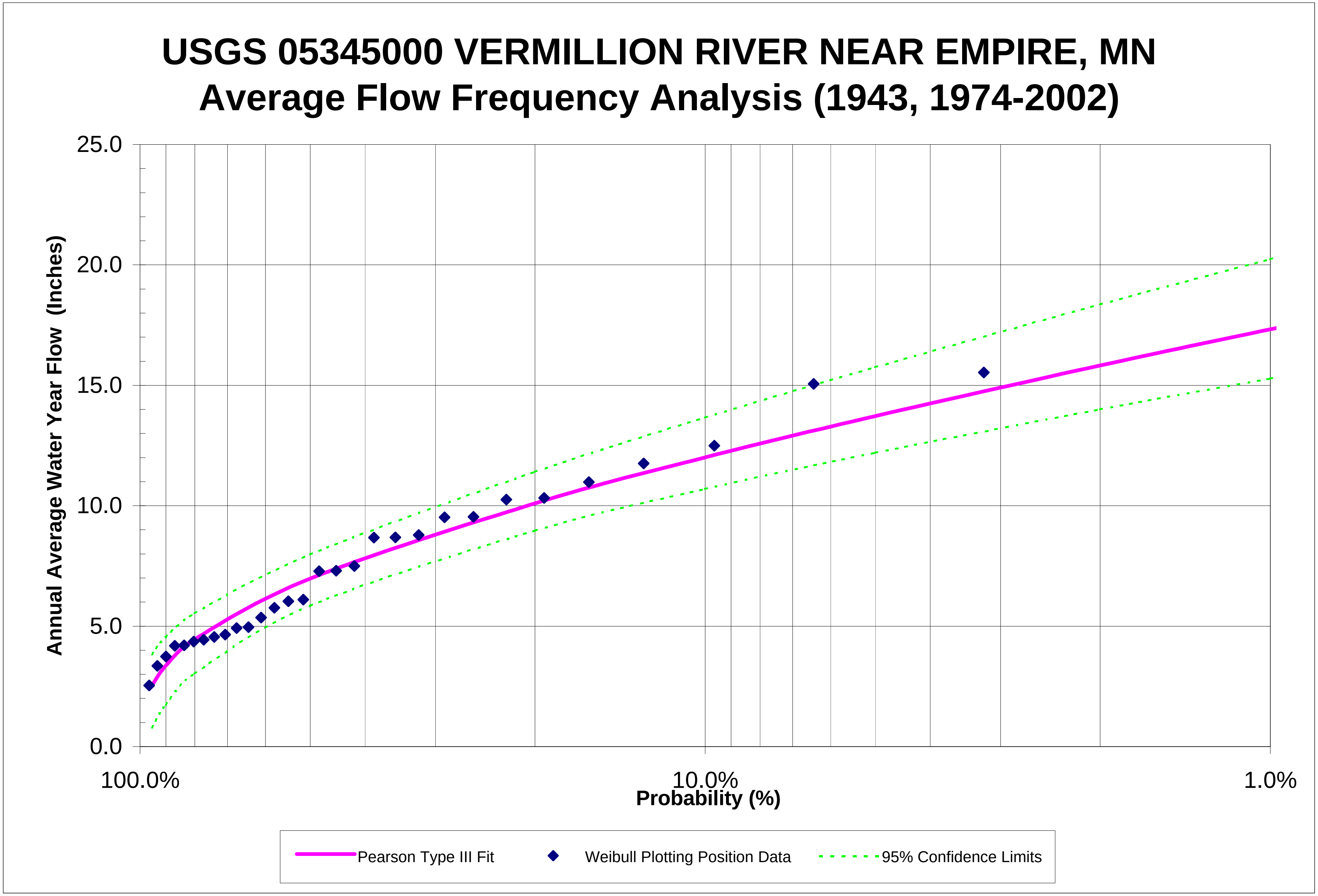

USGS 05385000 ROOT RIVER NEAR HOUSTON, MN
Average Flow Frequency Analysis (1979-1983&1991-2000)
Annual Average Water Year Flow (Inches)
30.0
25.0
20.0
15.0
10.0
5.0
0.0
100.0%
10.0%
1.0%
Probability (%)
Pearson Type III Fit
Weibull Plotting Position Data
95% Confidence Limits


USGS 05345000 VERMILLION RIVER NEAR EMPIRE, MN
Annual Average Flow Frequency Analysis
Annual Average Water Year Flow (Inches)
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
100%
90%
50%
10%
Probability (%)
Pearson Type III Fit to 1943, 1974-2002 Data
Pearson Type III Fit to 1979-2002 Data



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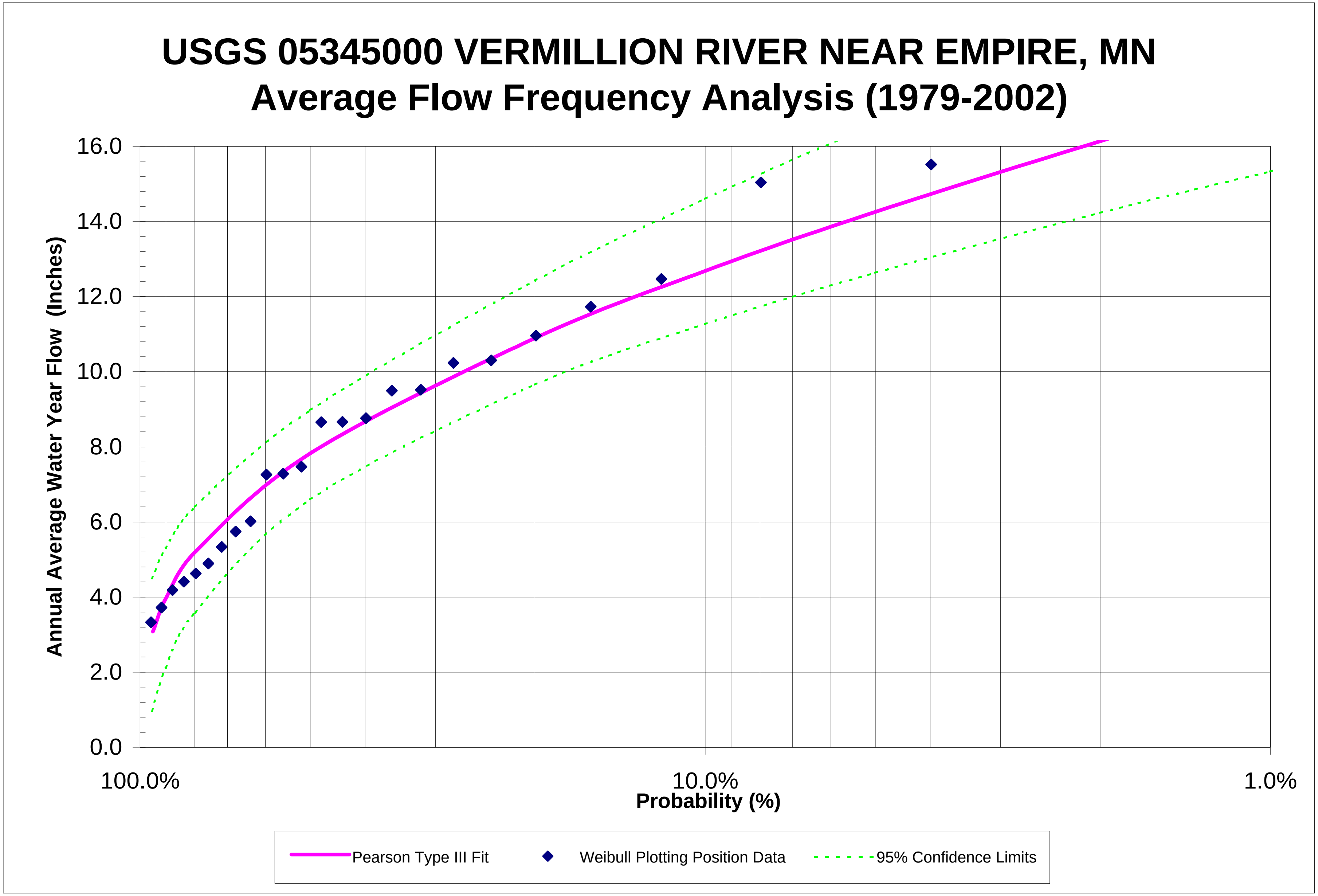
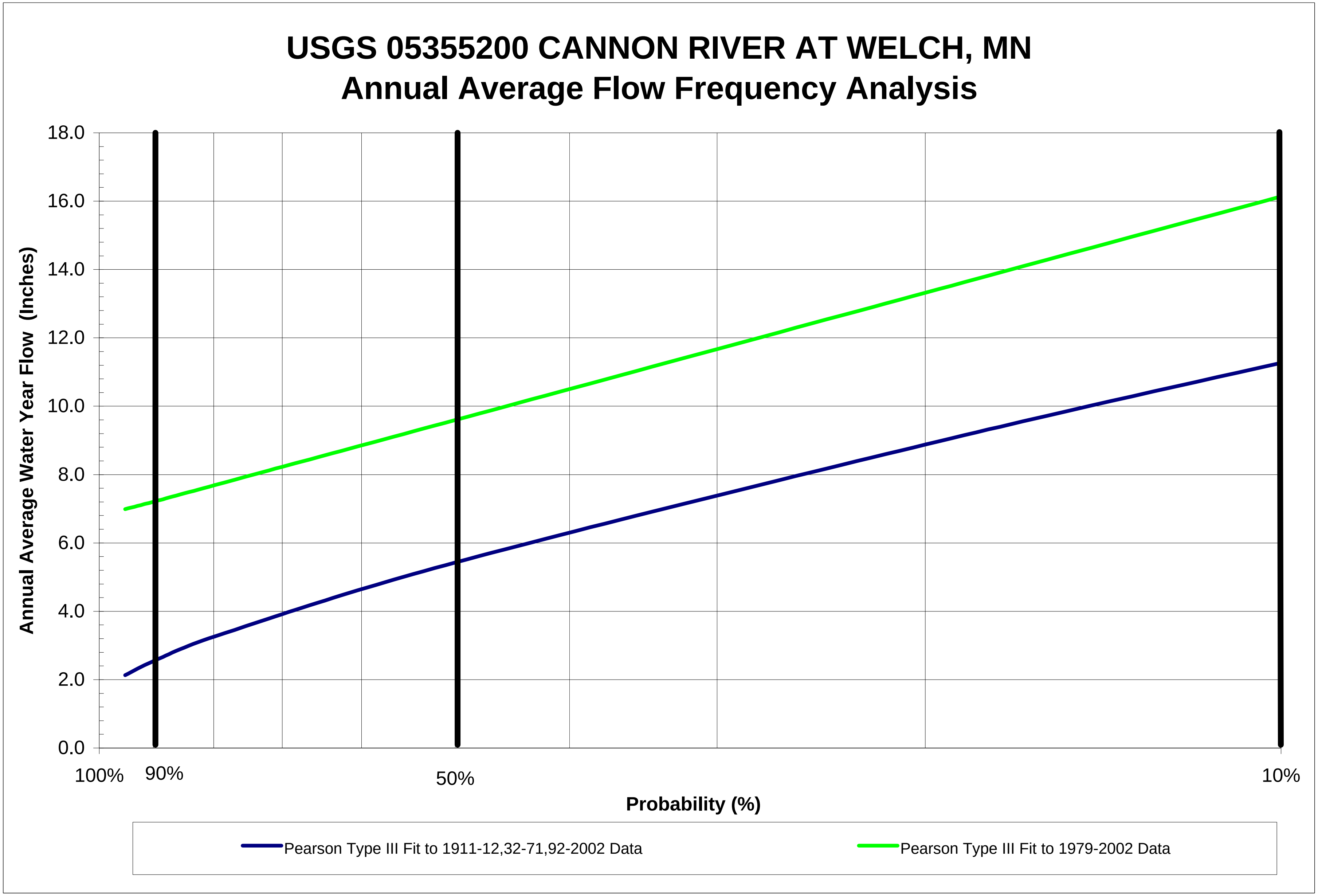

USGS 05345000 VERMILLION RIVER NEAR EMPIRE, MN
Average Flow Frequency Analysis (1979-2002)
Annual Average Water Year Flow (Inches)
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
100.0%
10.0%
1.0%
Probability (%)
Pearson Type III Fit
Weibull Plotting Position Data
95% Confidence Limits



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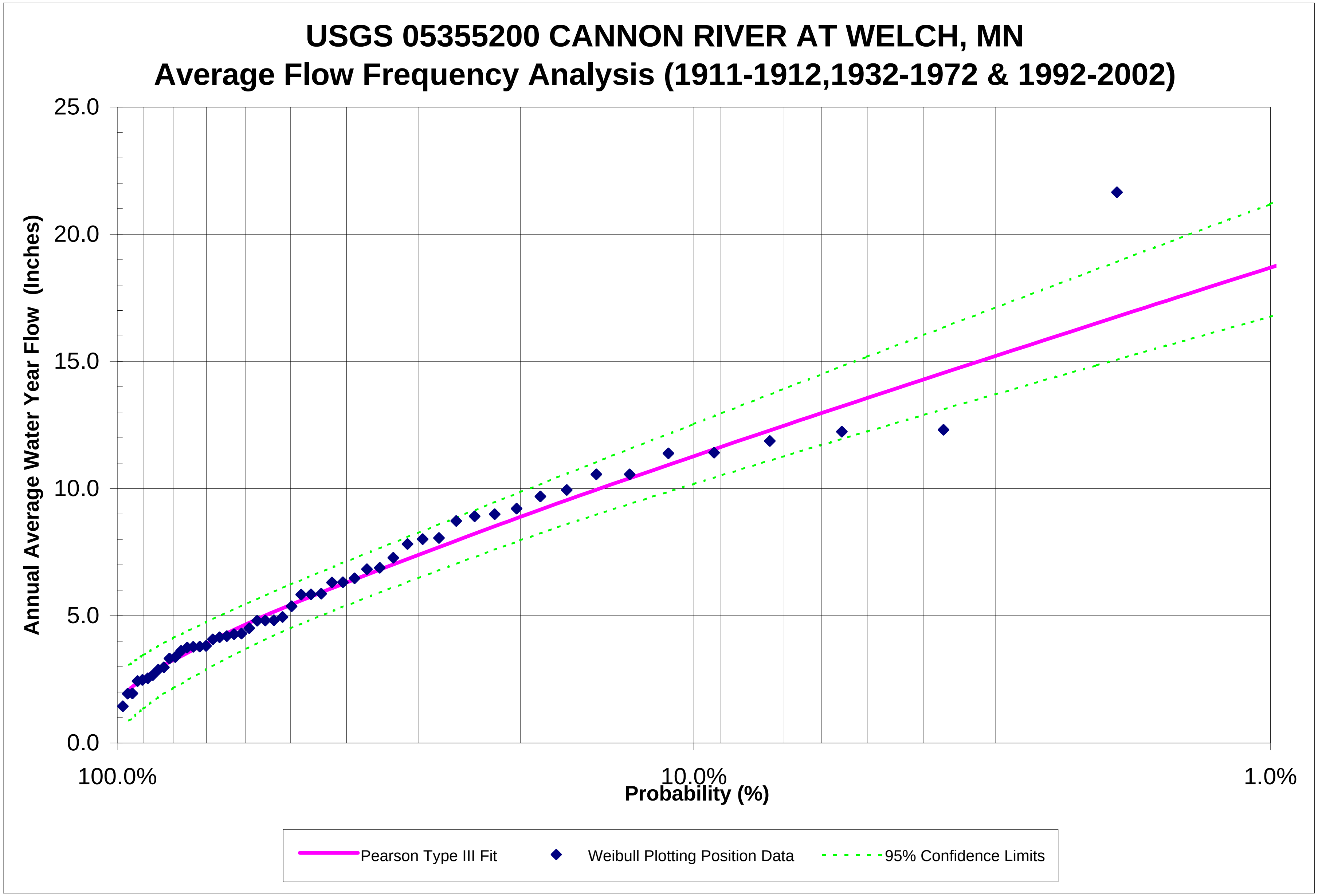

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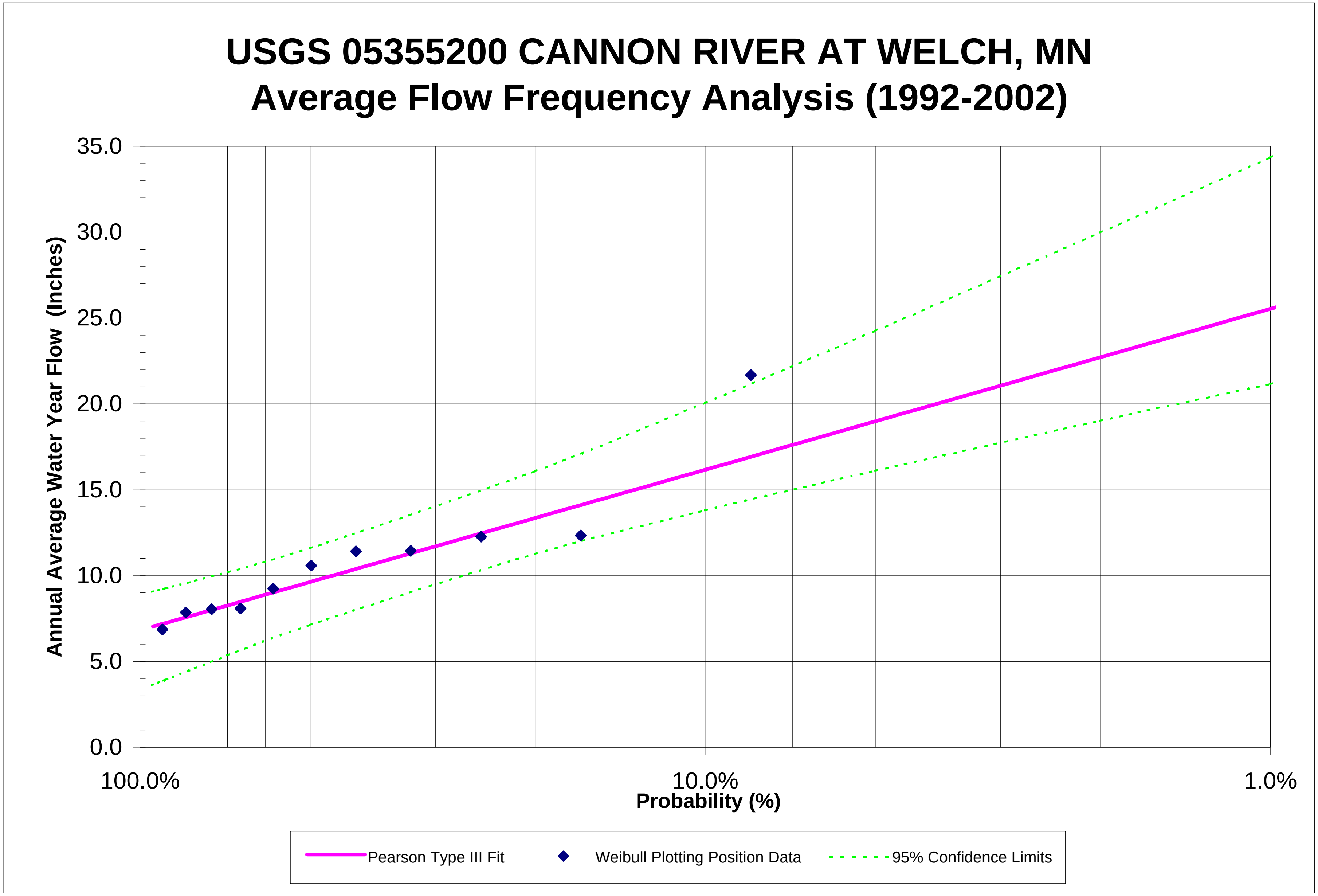

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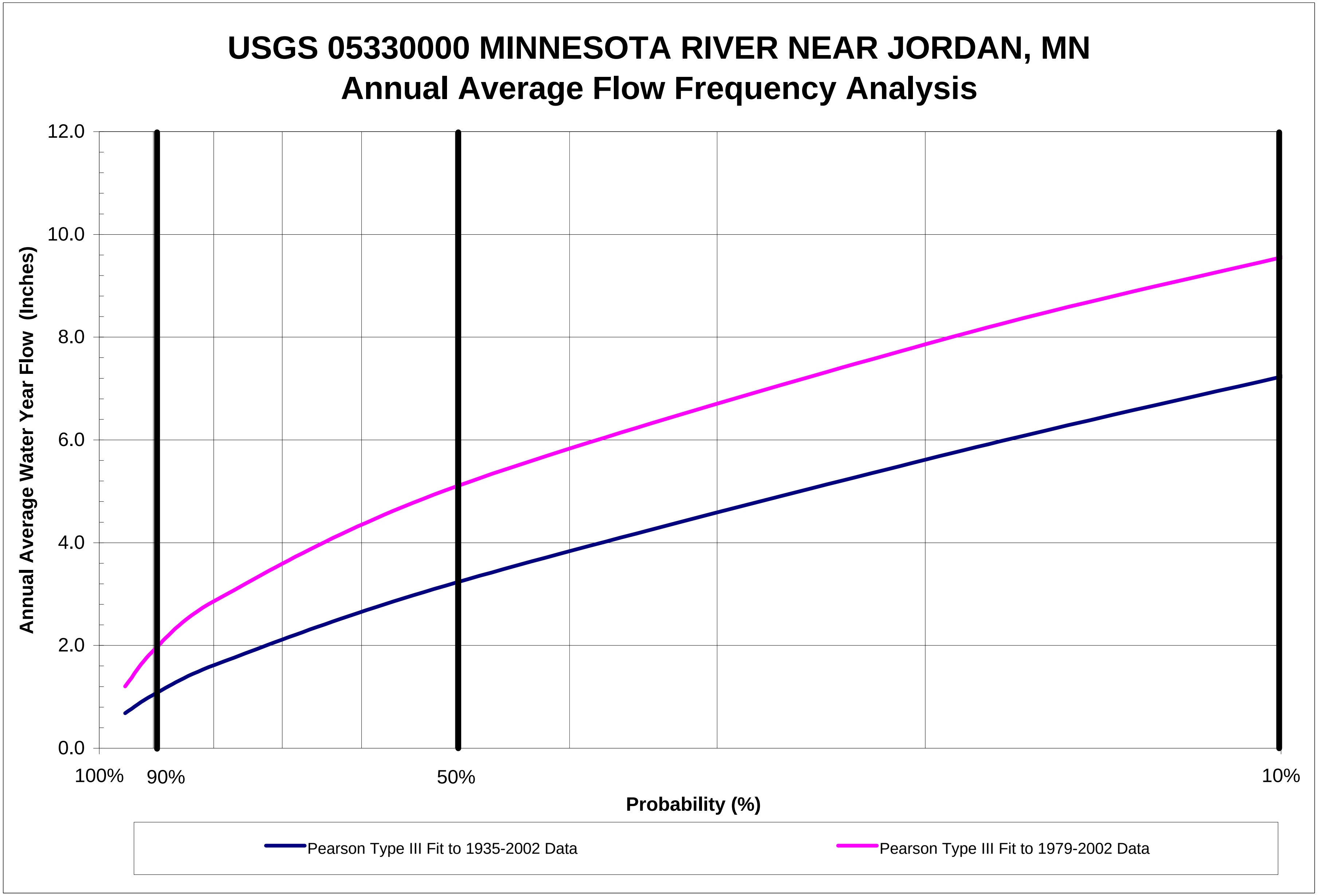
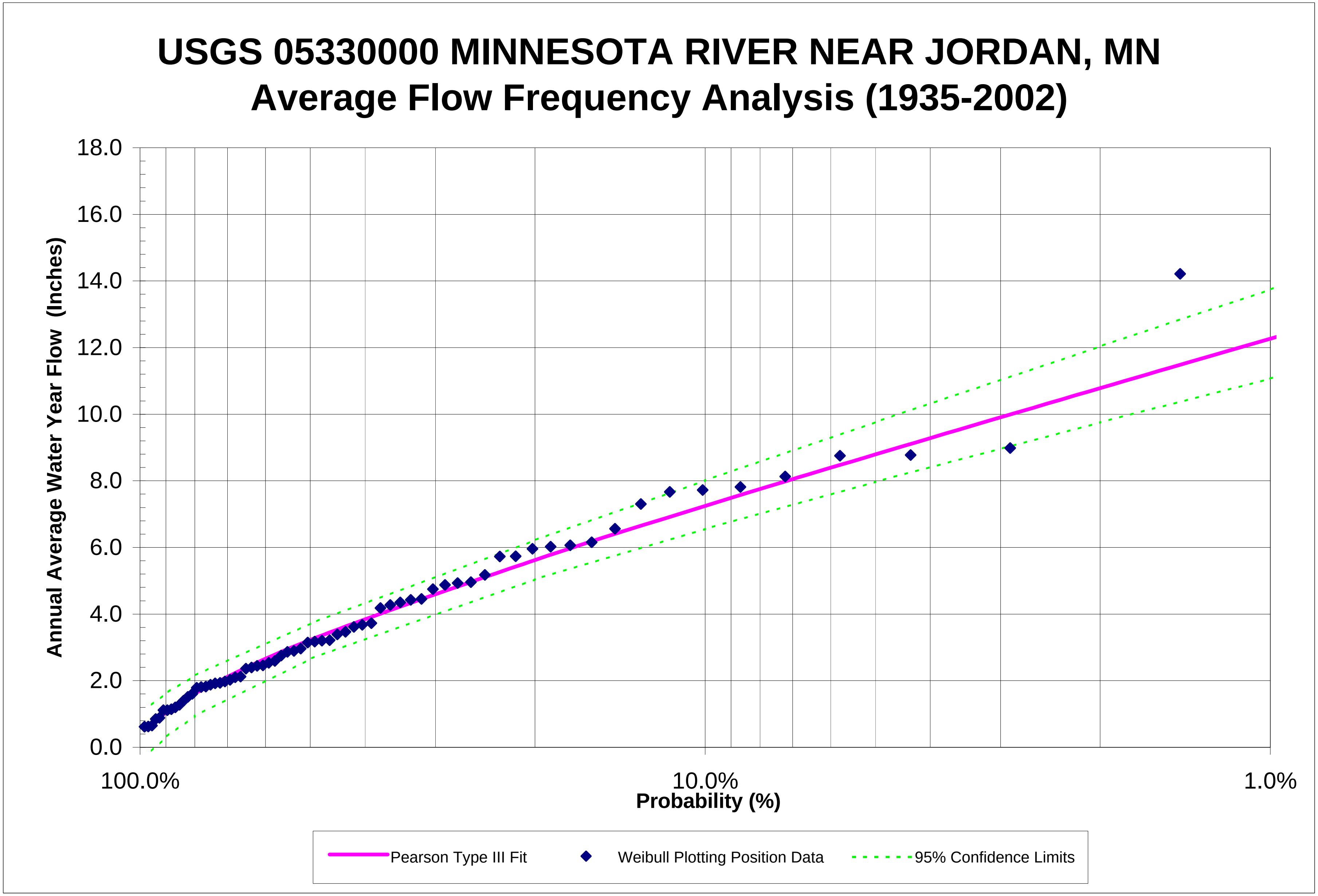
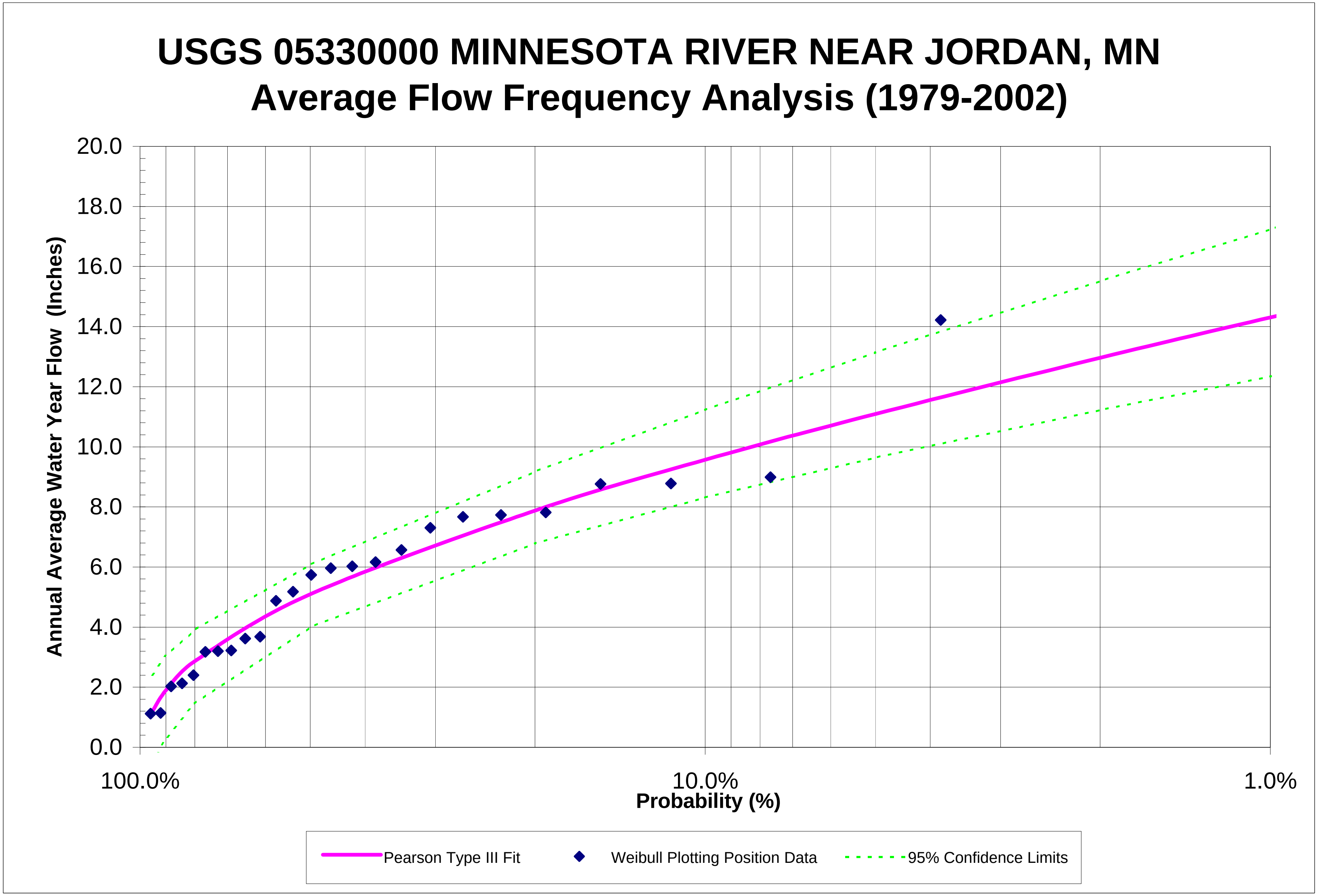
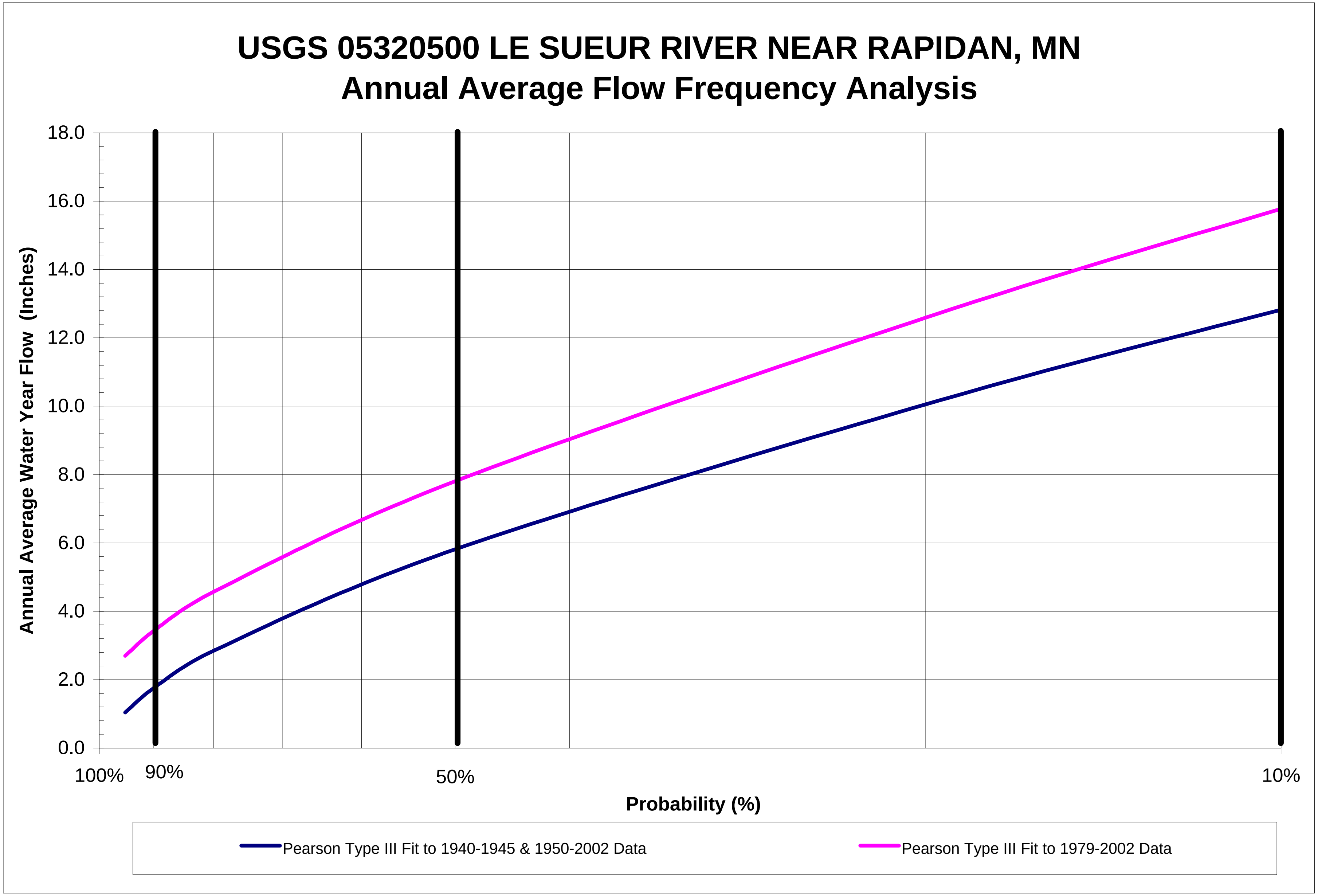

USGS 05330000 MINNESOTA RIVER NEAR JORDAN, MN
Annual Average Flow Frequency Analysis
Annual Average Water Year Flow (Inches)
12.0
10.0
8.0
6.0
4.0
2.0
0.0
100%
90%
50%
10%
Probability (%)
Pearson Type III Fit to 1935-2002 Data
Pearson Type III Fit to 1979-2002 Data

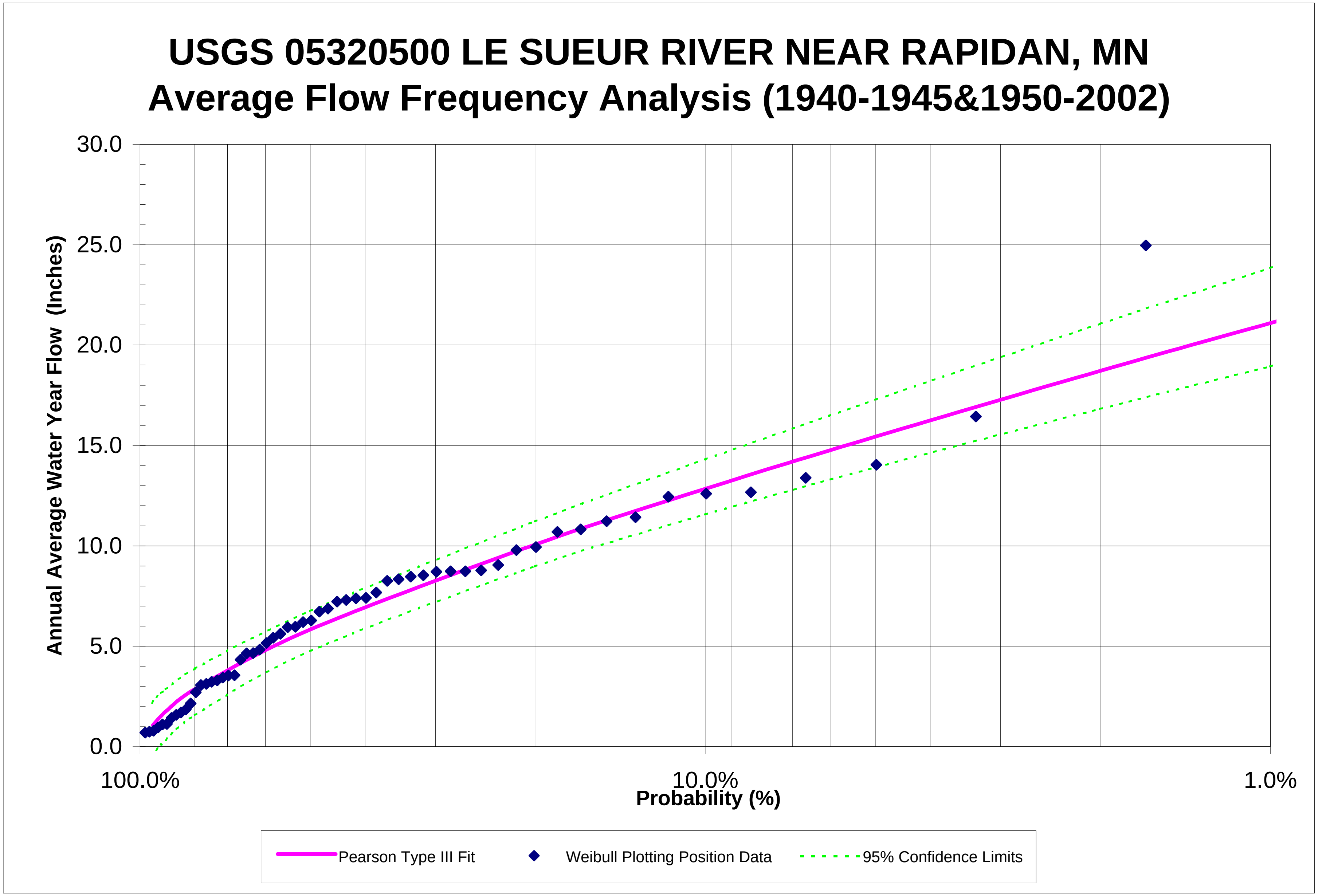


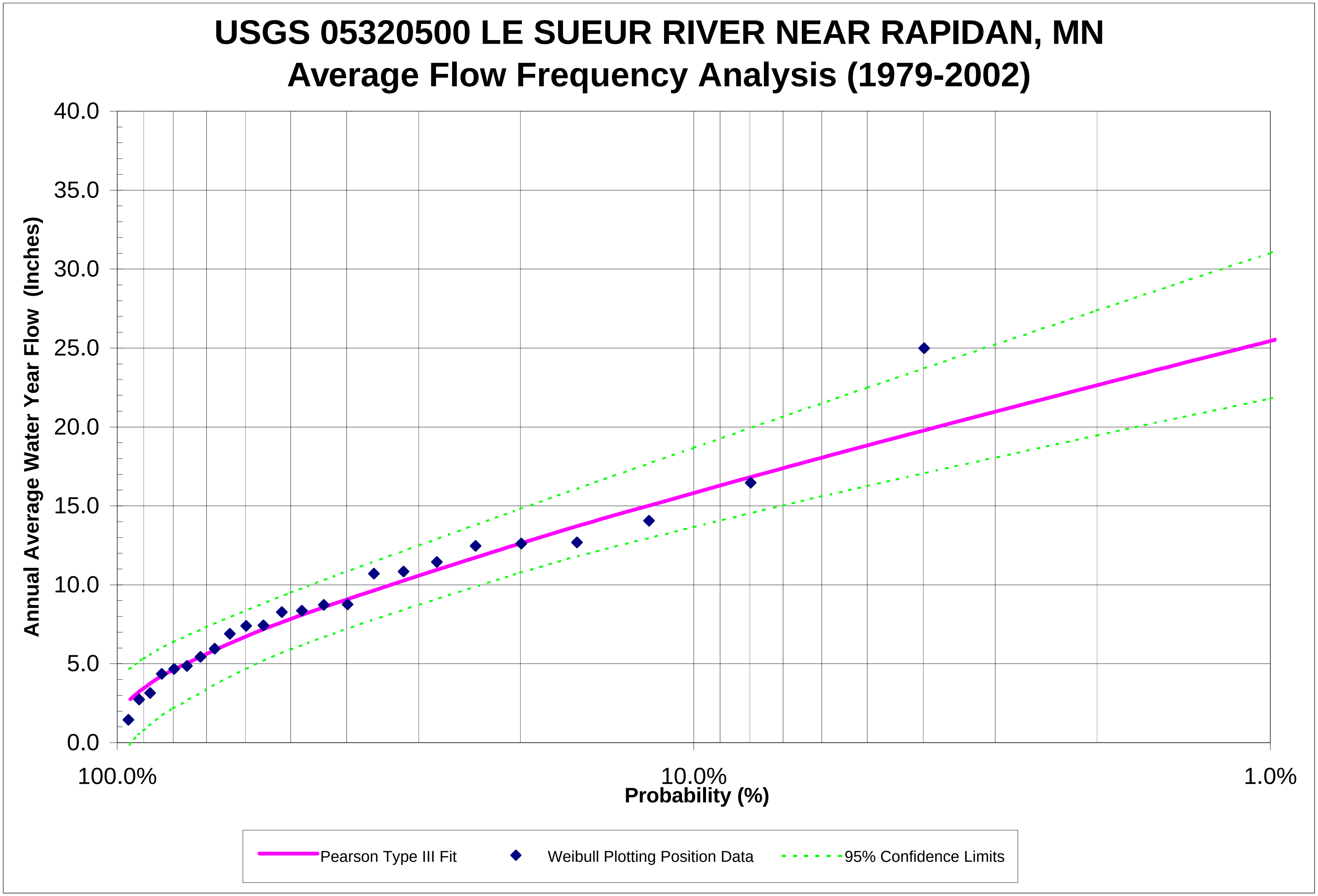
P:\23\62\853\Basin Hydrology_Mass Balance\MNRiver_FrequencyAnalysis



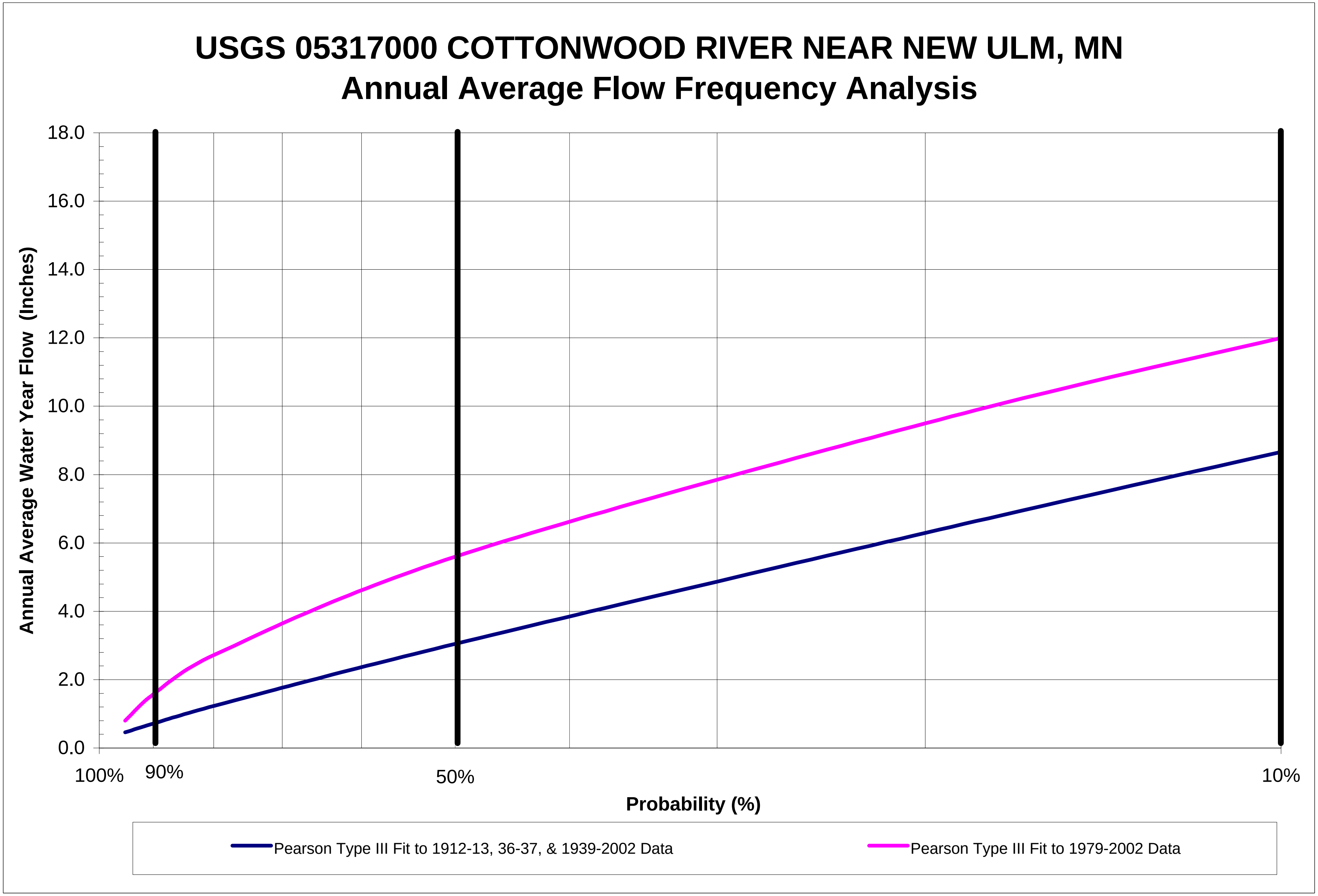
P:\23\62\853\Basin Hydrology_Mass Balance\MNRiver_FrequencyAnalysis


USGS 05320500 LE SUEUR RIVER NEAR RAPIDAN, MN
Annual Average Flow Frequency Analysis
Annual Average Water Year Flow (Inches)
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
100%
90%
50%
10%
Probability (%)
Pearson Type III Fit to 1940-1945 & 1950-2002 Data
Pearson Type III Fit to 1979-2002 Data

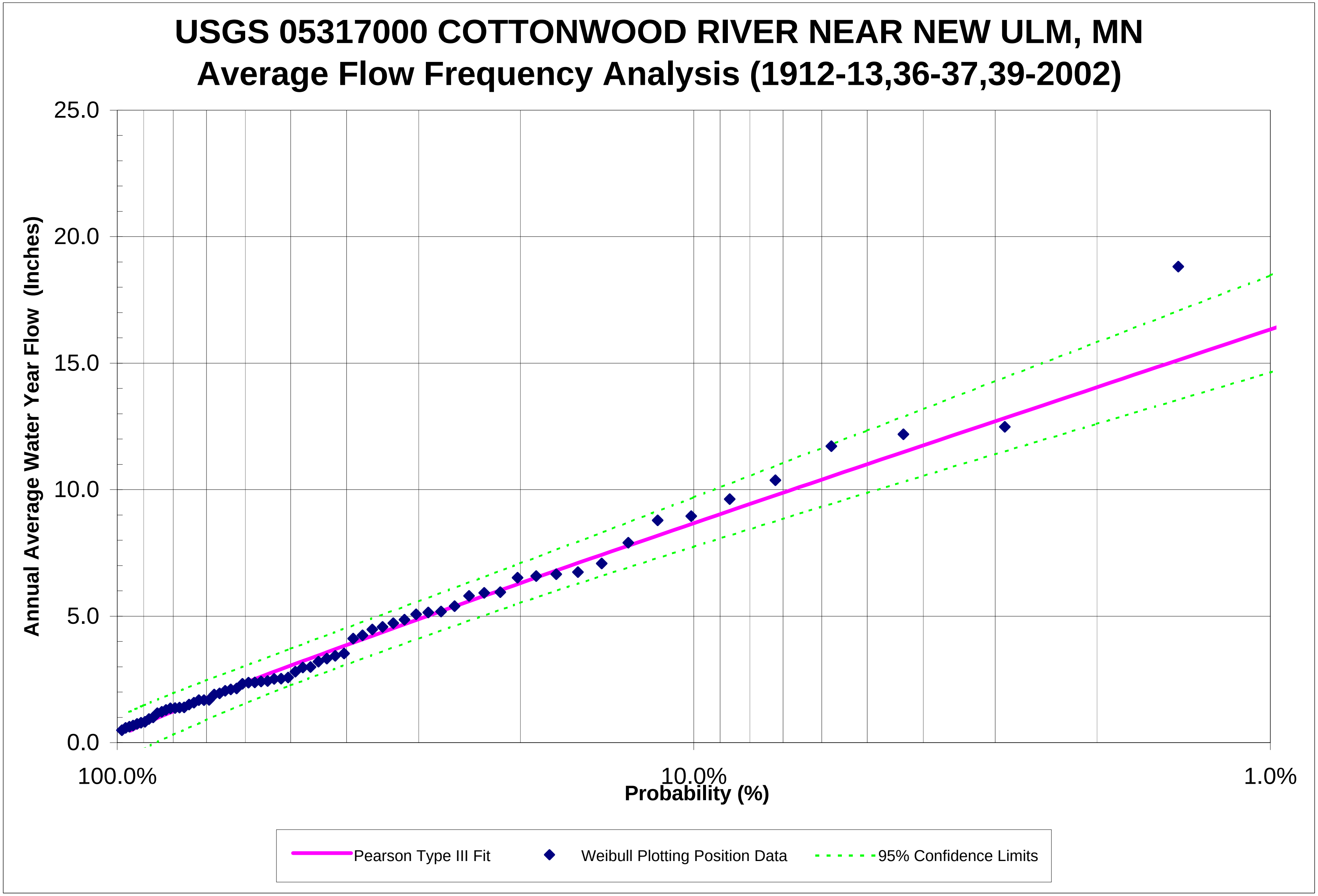

USGS 05320500 LE SUEUR RIVER NEAR RAPIDAN, MN
Average Flow Frequency Analysis (1940-1945&1950-2002)
Annual Average Water Year Flow (Inches)
30.0
25.0
20.0
15.0
10.0
5.0
0.0
100.0%
10.0%
1.0%
Probability (%)
Pearson Type III Fit
Weibull Plotting Position Data
95% Confidence Limits



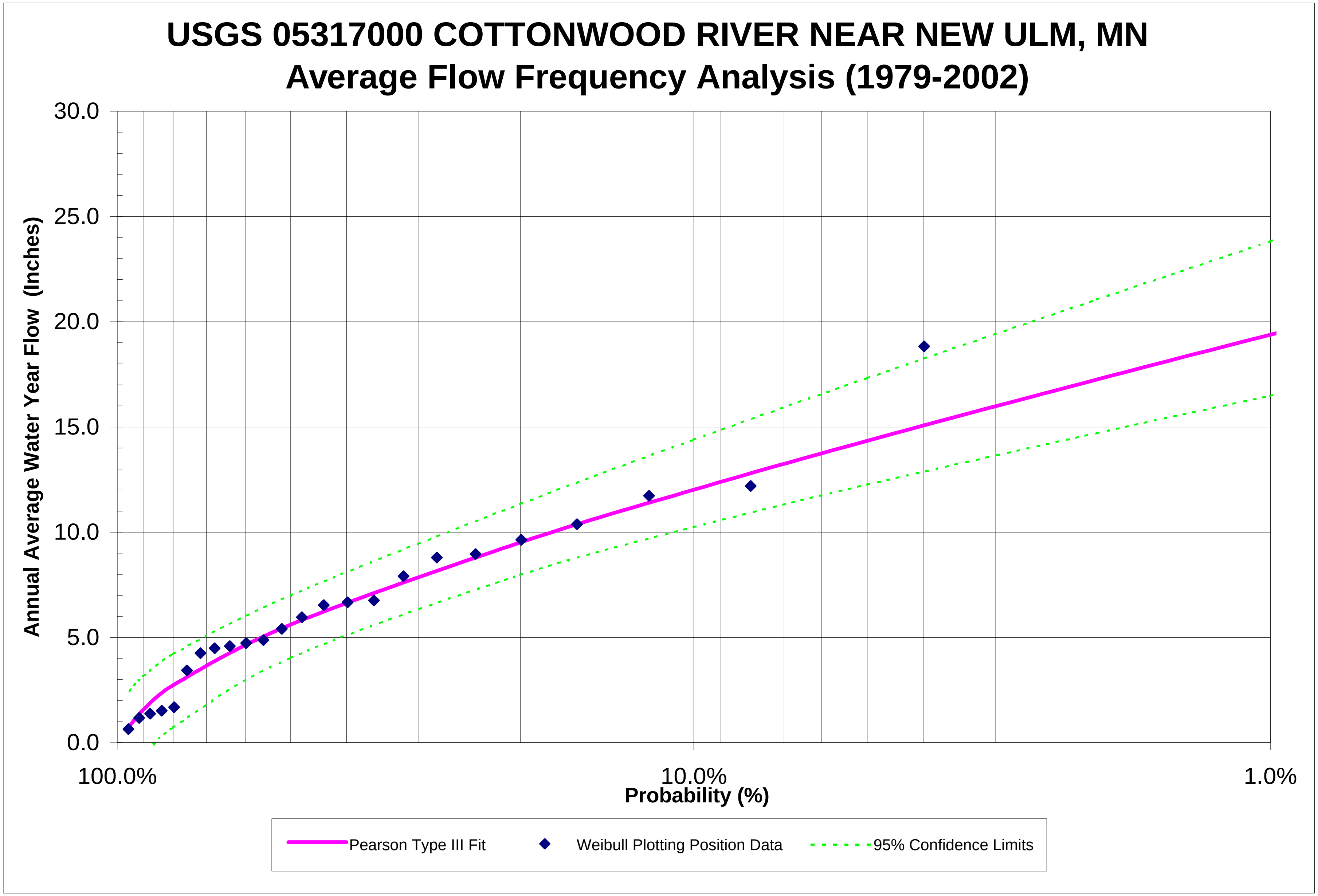
P:\23\62\853\Basin Hydrology_Mass Balance\WatershedData\USGS\DAN_Figs\LeSueurRiver_FrequencyAnalysis



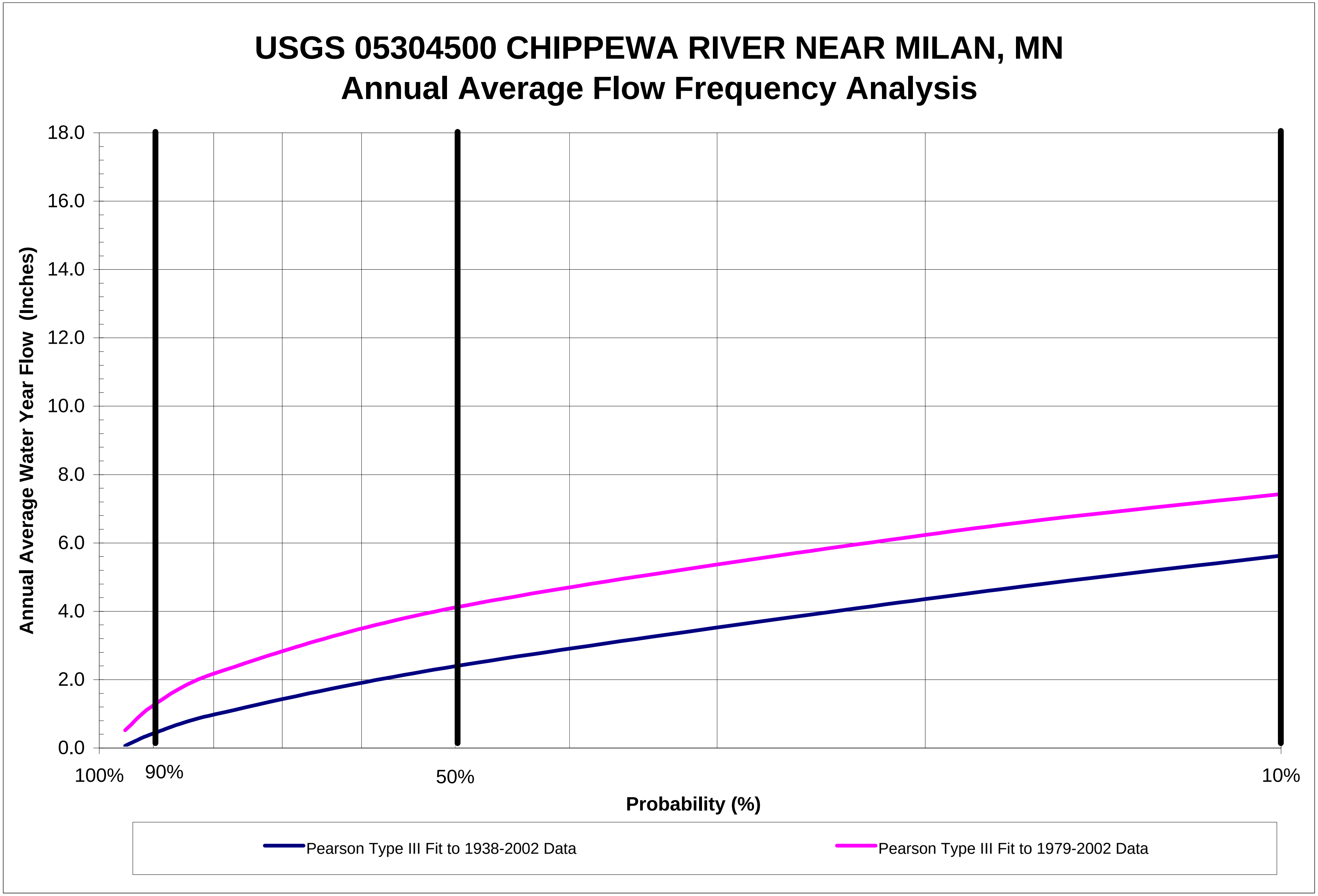
USGS 05317000 COTTONWOOD RIVER NEAR NEW ULM, MN
Annual Average Flow Frequency Analysis
Annual Average Water Year Flow (Inches)
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
100%
90%
50%
10%
Probability (%)
Pearson Type III Fit to 1912-13, 36-37, & 1939-2002 Data
Pearson Type III Fit to 1979-2002 Data

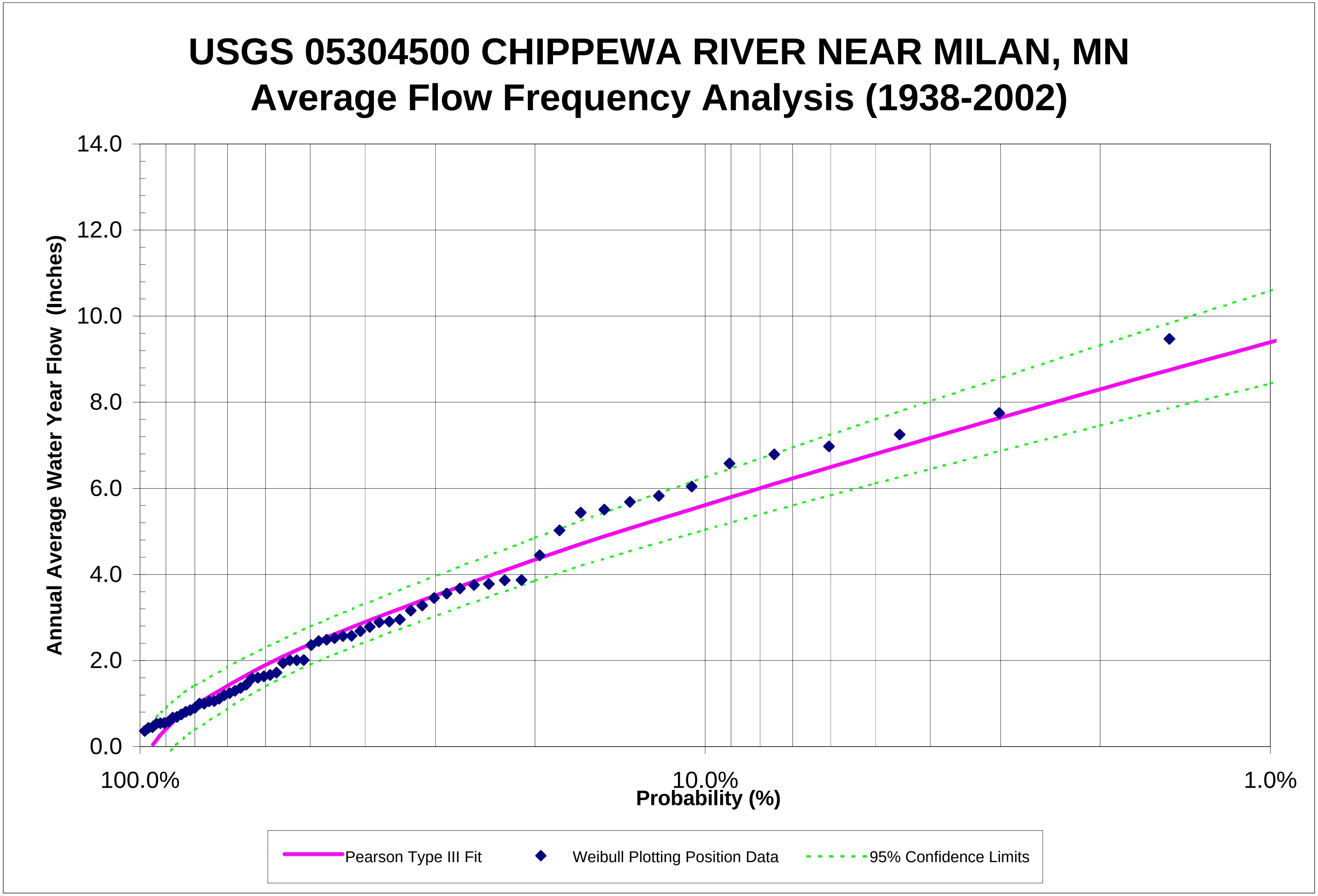


P:\23\62\853\Basin Hydrology_Mass Balance\WatershedData\USGS\DAN_Figs\CottonRiver_FrequencyAnalysis

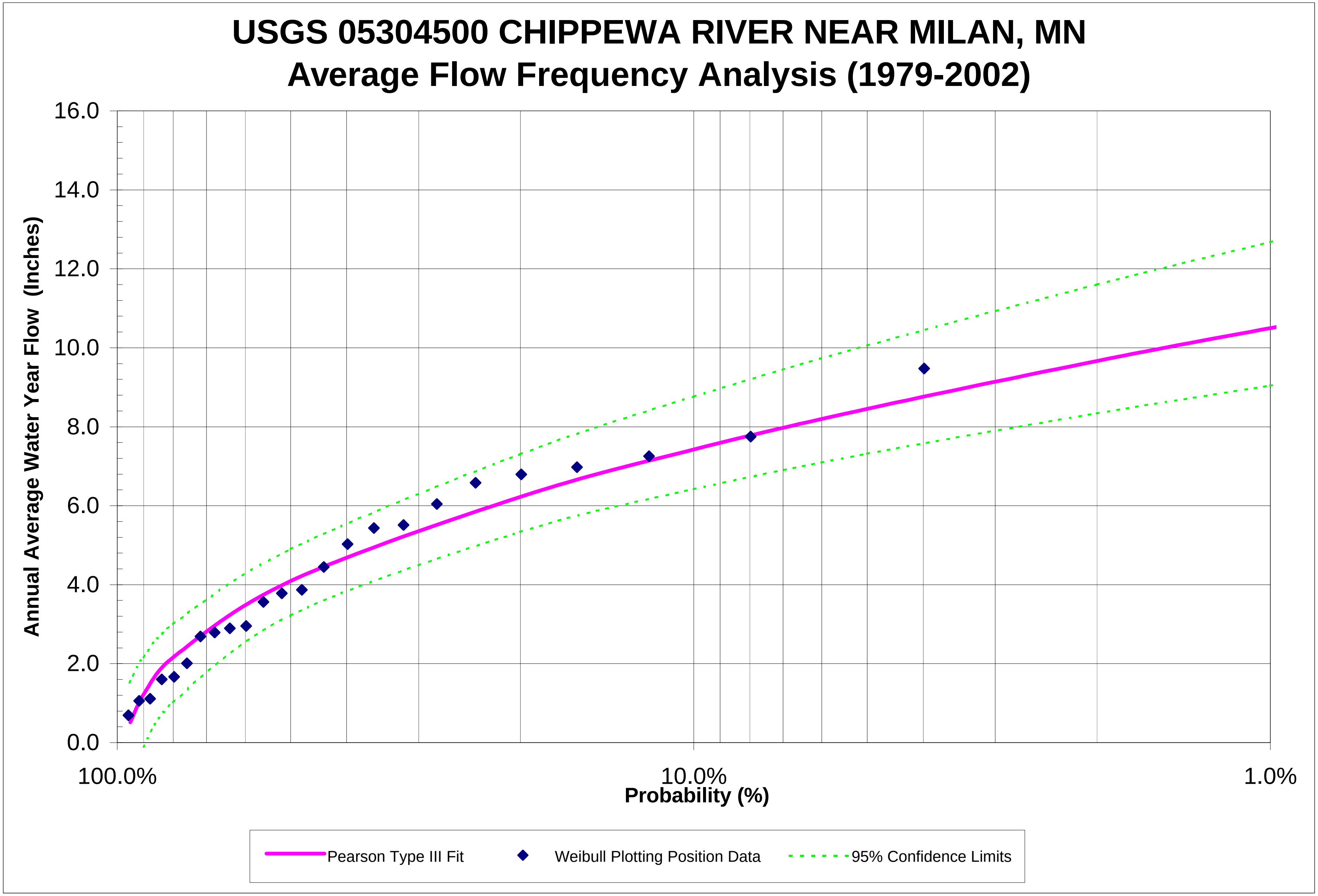


USGS 05317000 COTTONWOOD RIVER NEAR NEW ULM, MN
Average Flow Frequency Analysis (1979-2002)
Annual Average Water Year Flow (Inches)
30.0
25.0
20.0
15.0
10.0
5.0
0.0
100.0%
10.0%
1.0%
Probability (%)
Pearson Type III Fit
Weibull Plotting Position Data
95% Confidence Limits

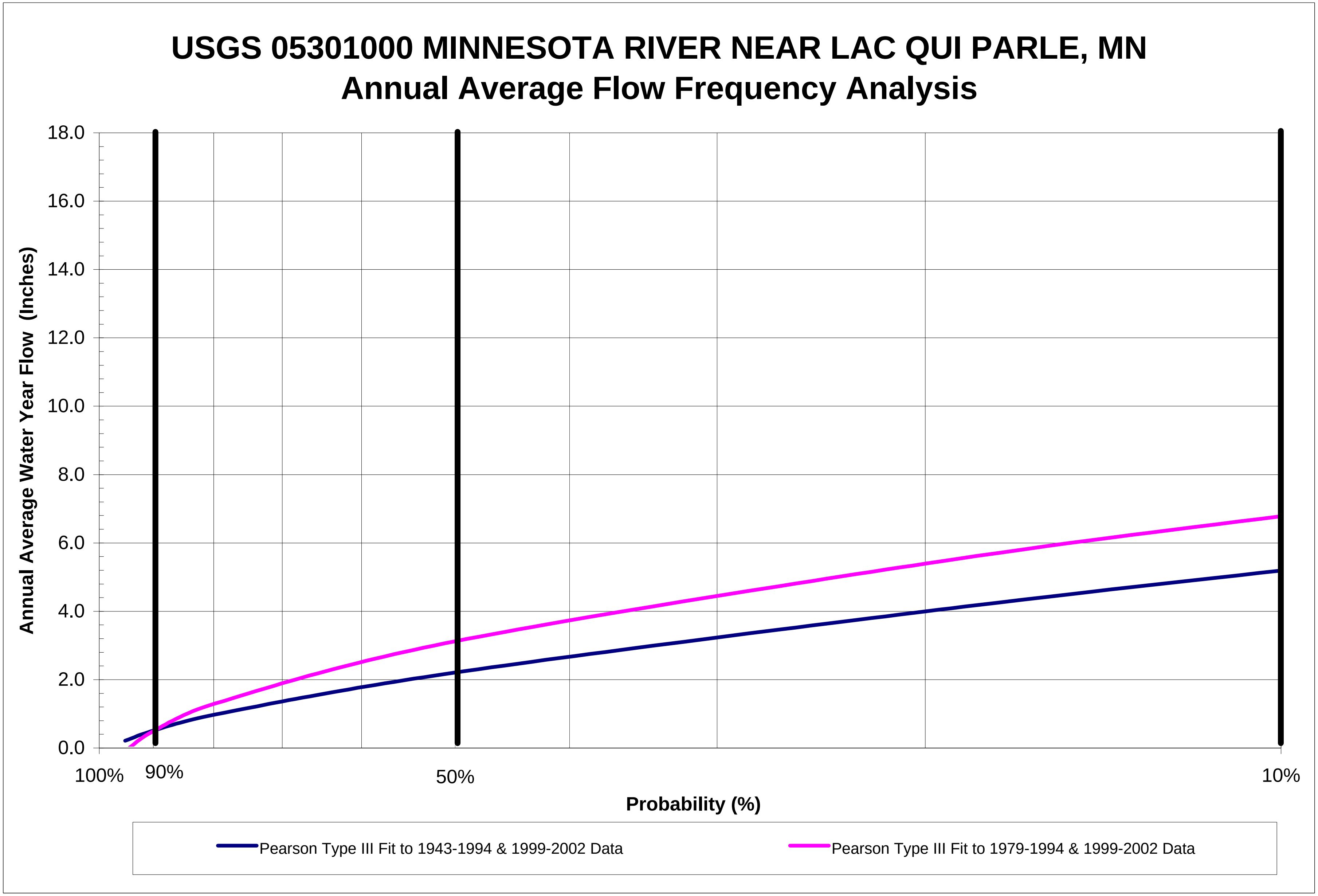

USGS 05304500 CHIPPEWA RIVER NEAR MILAN, MN
Annual Average Flow Frequency Analysis
Annual Average Water Year Flow (Inches)
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
100%
90%
50%
10%
Probability (%)
Pearson Type III Fit to 1938-2002 Data
Pearson Type III Fit to 1979-2002 Data

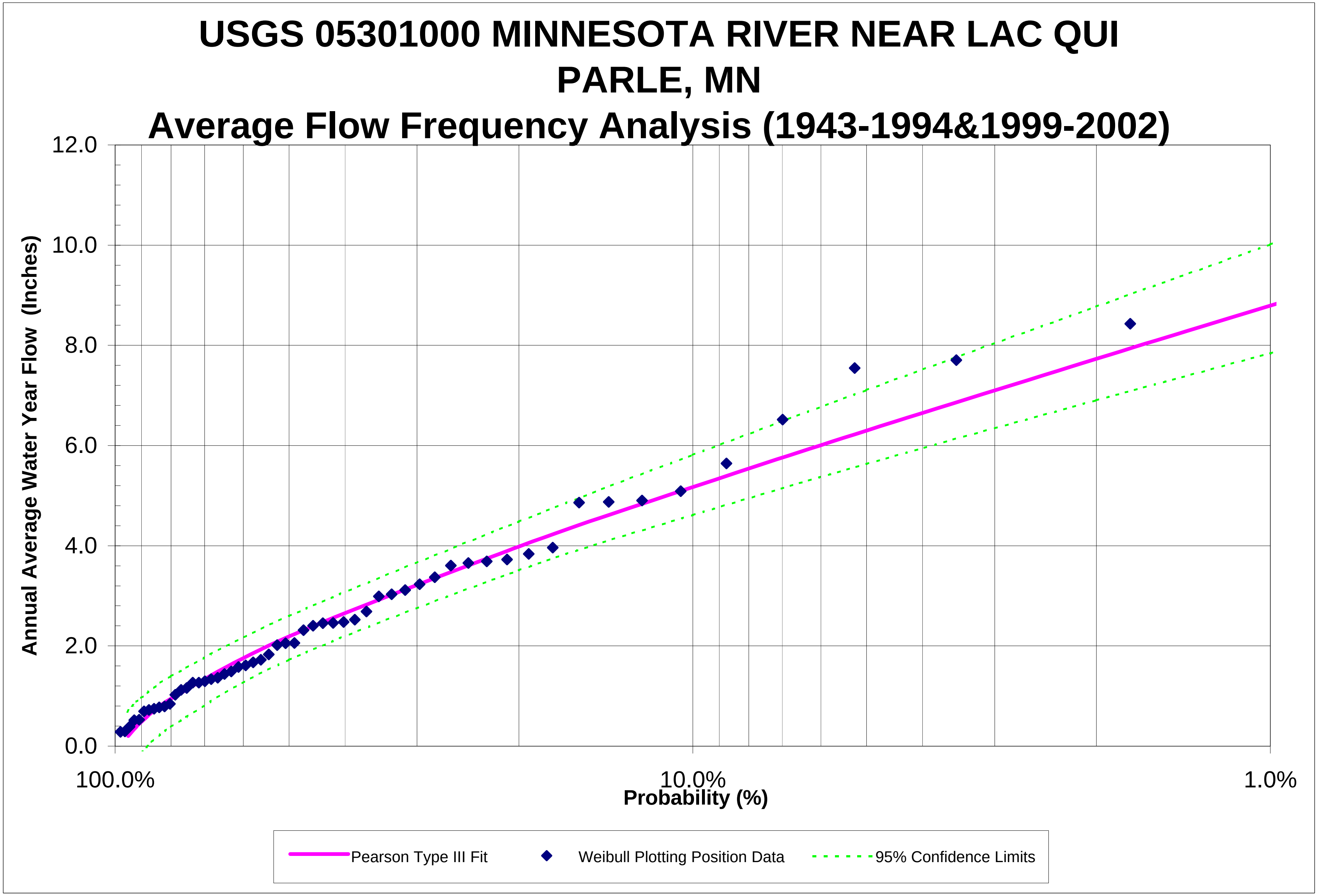


P:\23\62\853\Basin Hydrology_Mass Balance\WatershedData\USGS\DAN_Figs\ChippewaRiver_FrequencyAnalysis

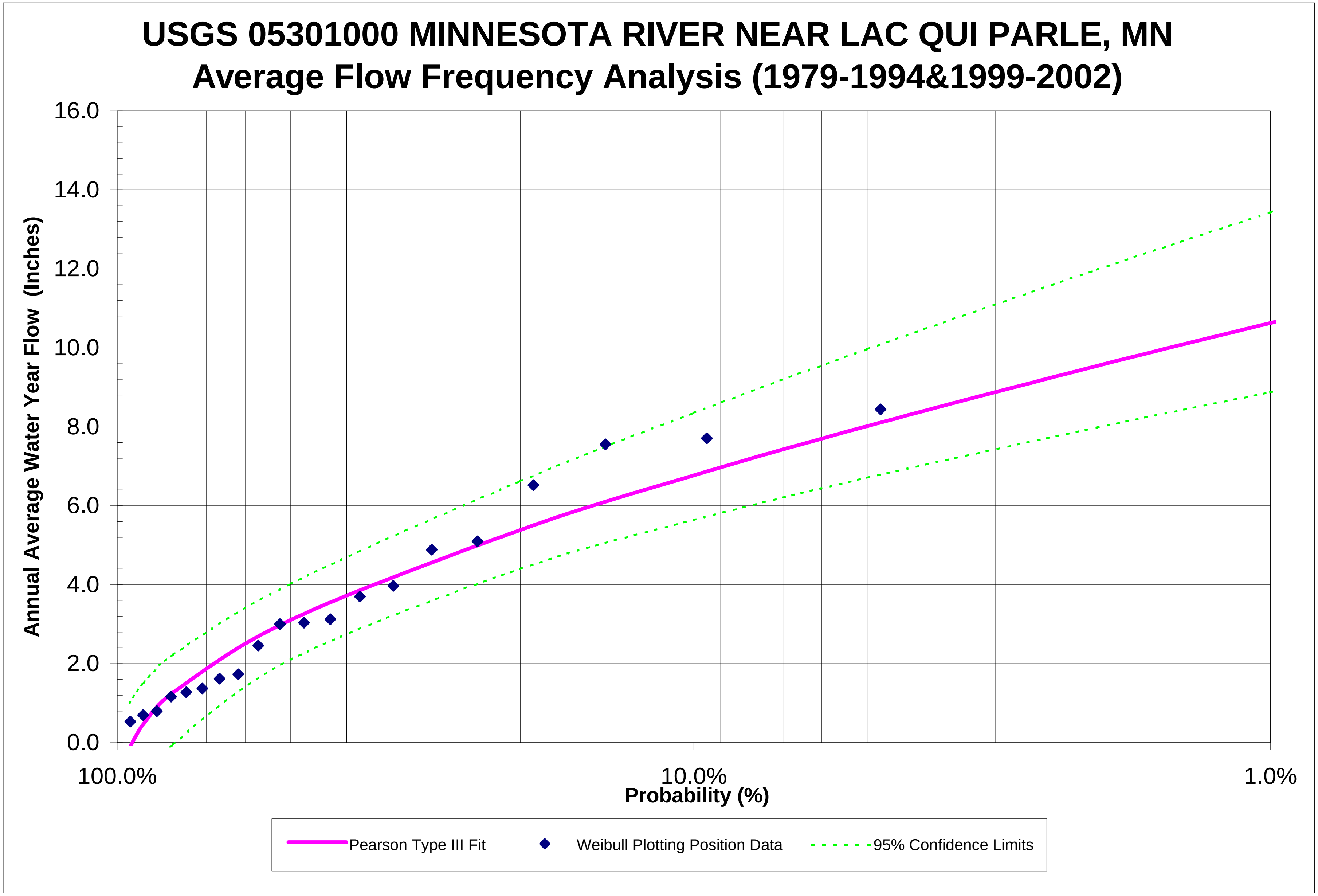


P:\23\62\853\Basin Hydrology_Mass Balance\WatershedData\USGS\DAN_Figs\ChippewaRiver_FrequencyAnalysis

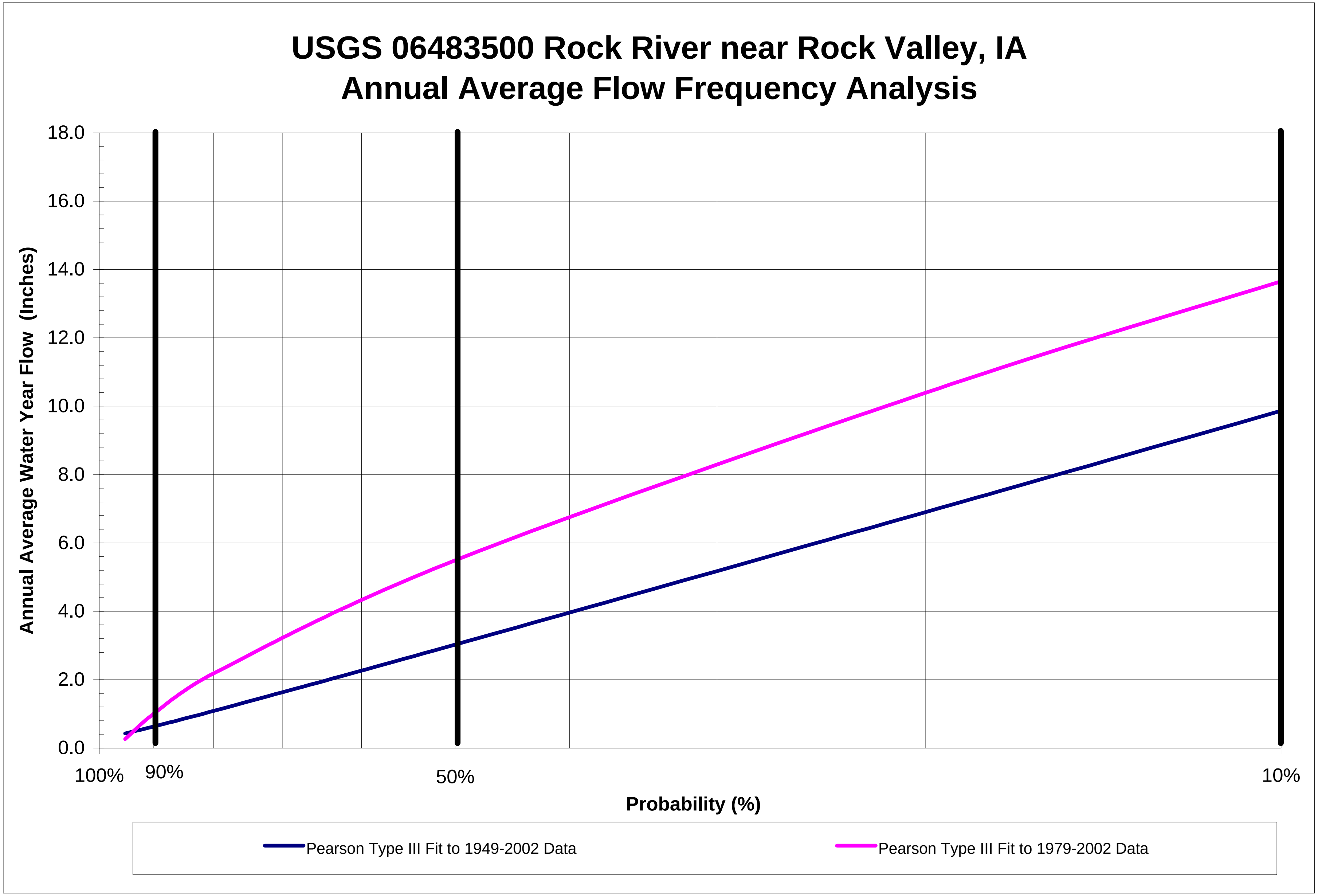

USGS 05301000 MINNESOTA RIVER NEAR LAC QUI PARLE, MN
Annual Average Flow Frequency Analysis
Annual Average Water Year Flow (Inches)
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
100%
90%
50%
10%
Probability (%)
Pearson Type III Fit to 1943-1994 & 1999-2002 Data
Pearson Type III Fit to 1979-1994 & 1999-2002 Data

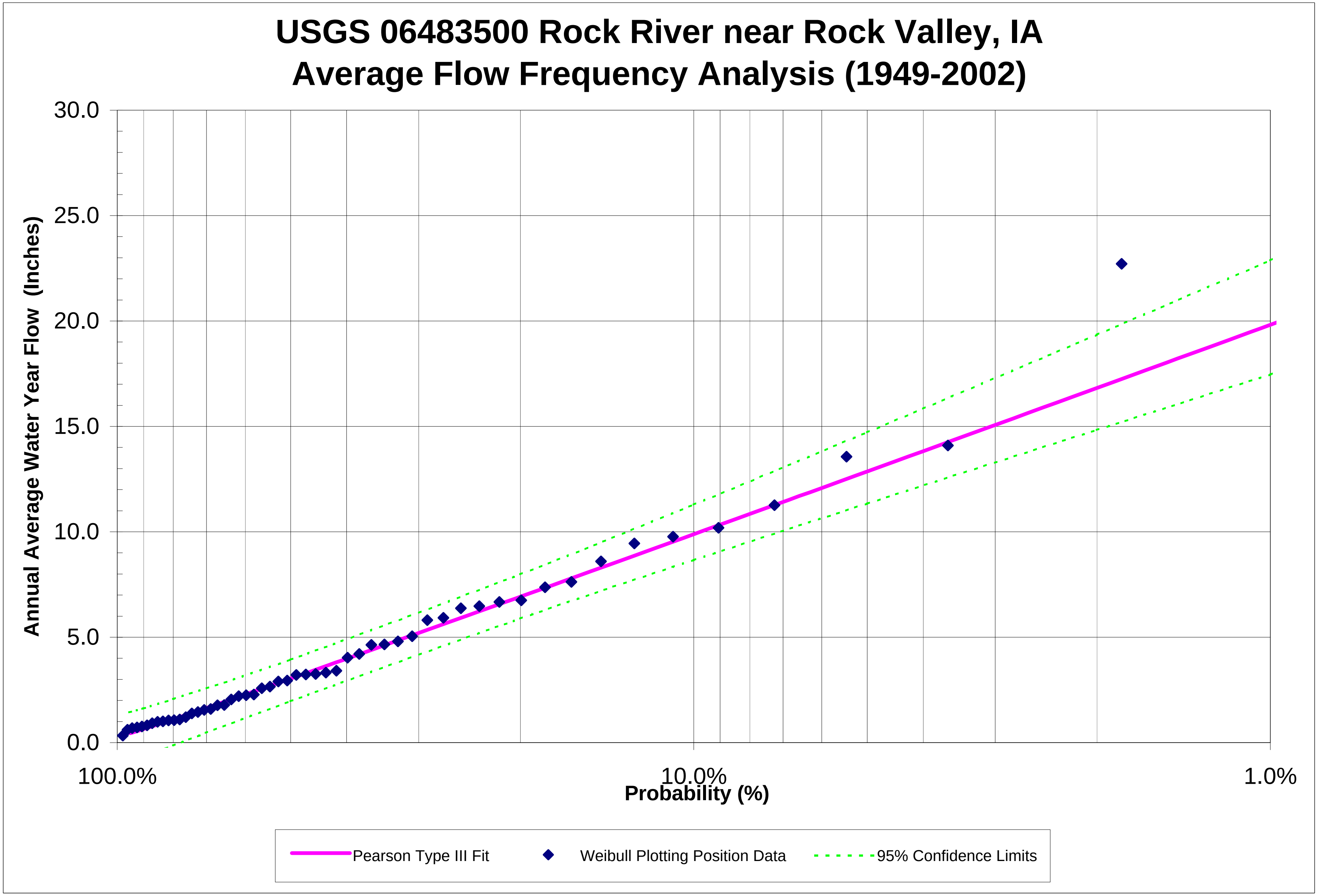


P:\23\62\853\Basin Hydrology_Mass Balance\WatershedData\USGS\DAN_Figs\MinnesotaRiver_FrequencyAnalysis

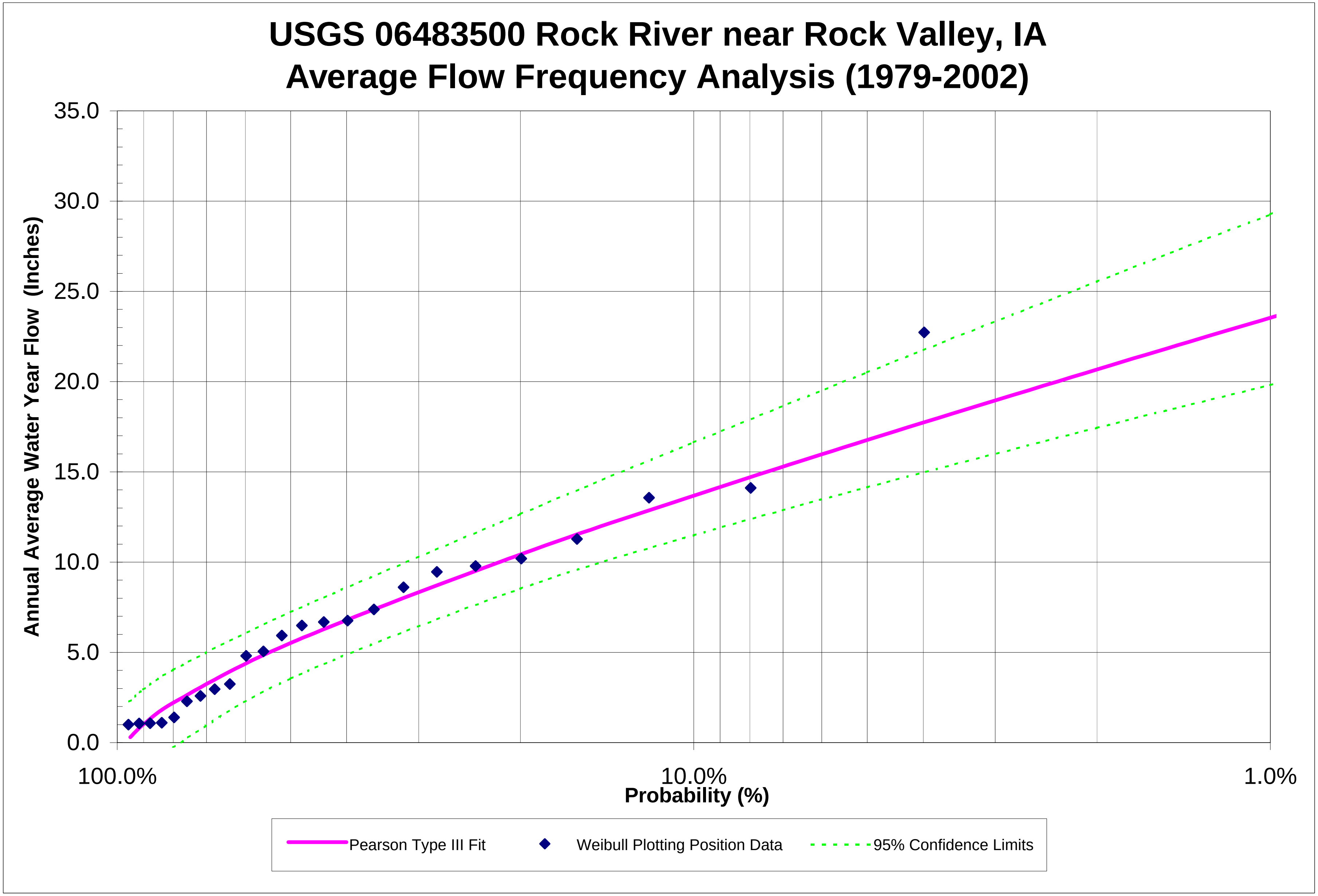


P:\23\62\853\Basin Hydrology_Mass Balance\WatershedData\USGS\DAN_Figs\MinnesotaRiver_FrequencyAnalysis

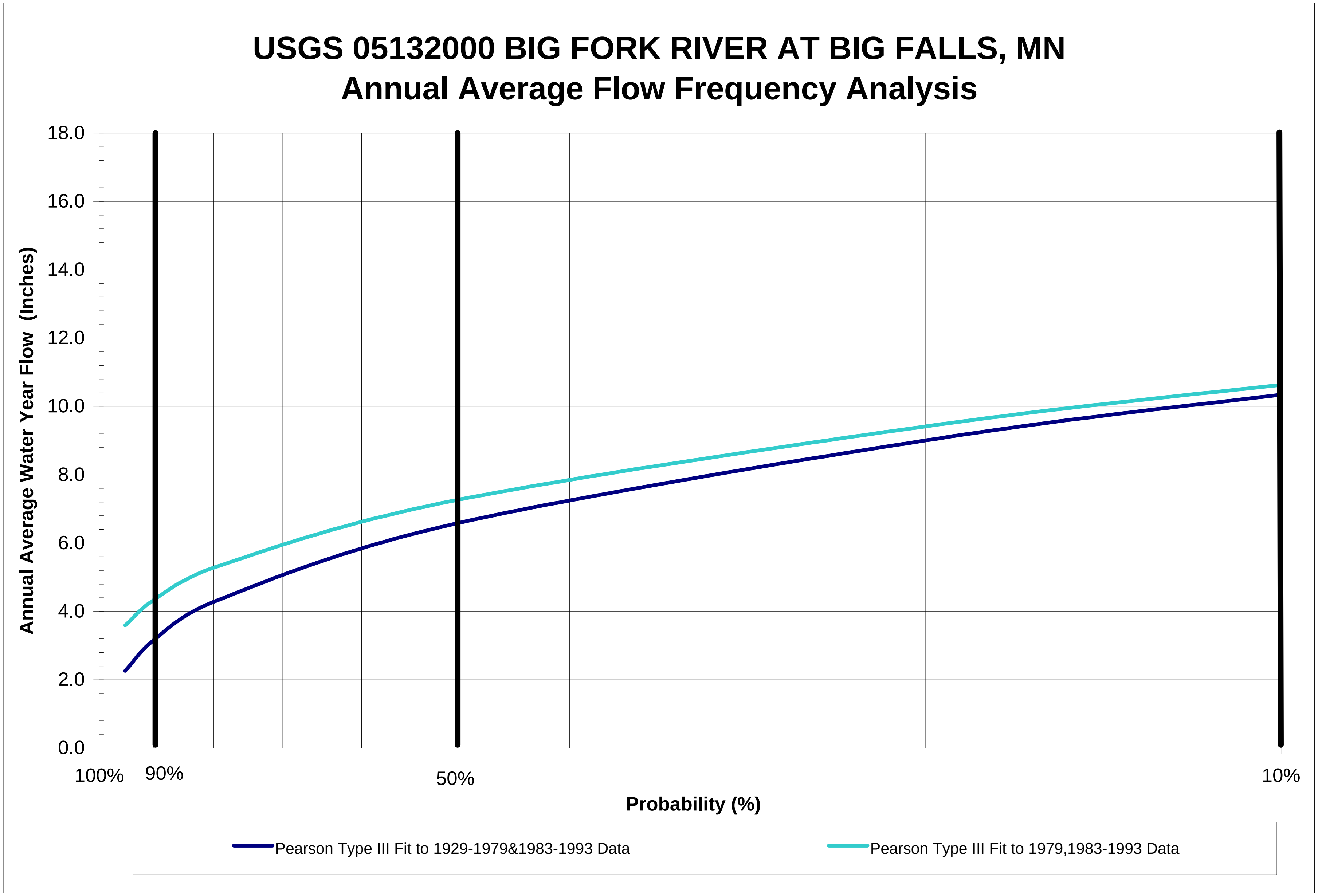

USGS 06483500 Rock River near Rock Valley, IA
Annual Average Flow Frequency Analysis
Annual Average Water Year Flow (Inches)
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
100%
90%
50%
10%
Probability (%)
Pearson Type III Fit to 1949-2002 Data
Pearson Type III Fit to 1979-2002 Data

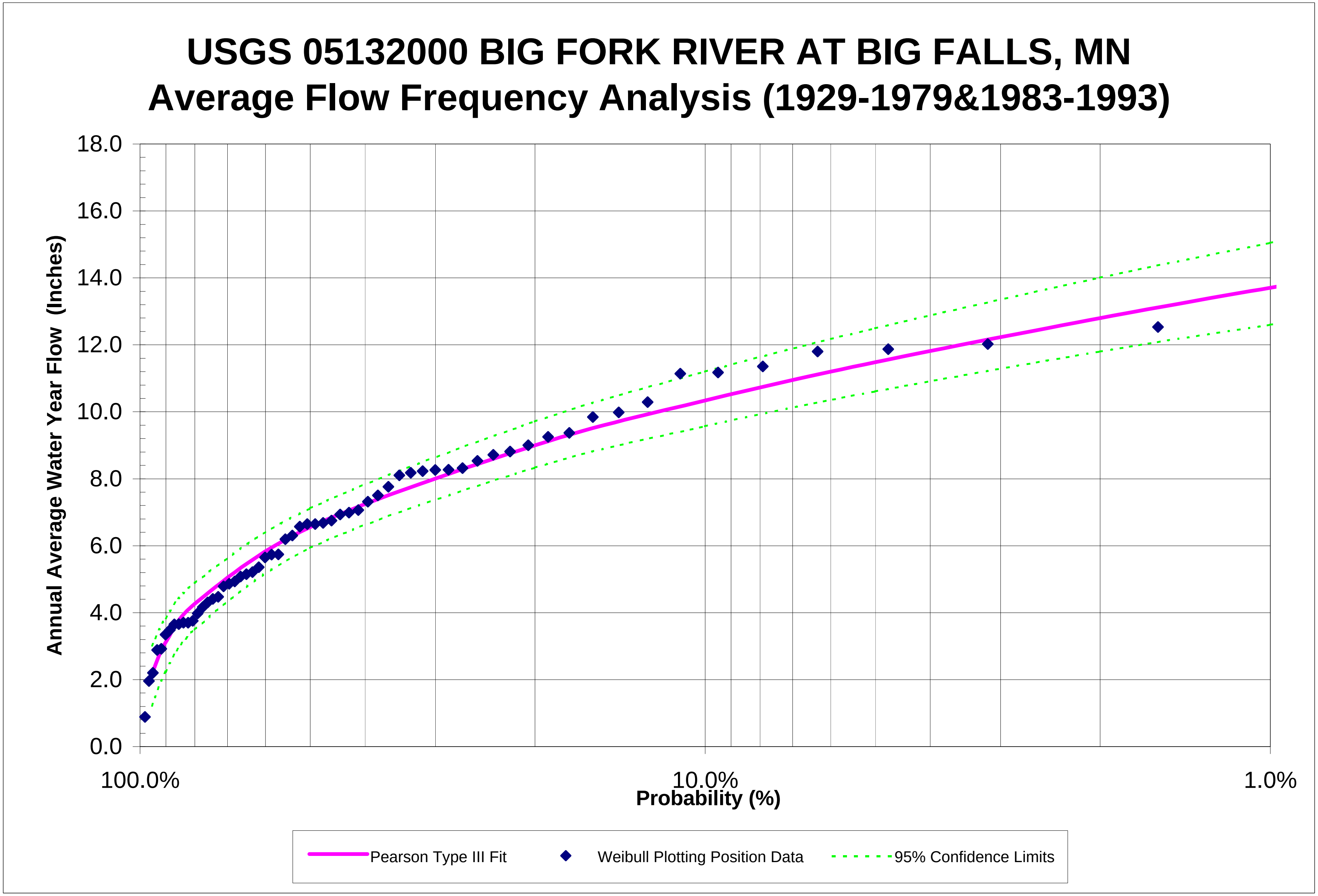


P:\23\62\853\Basin Hydrology_Mass Balance\WatershedData\USGS\DAN_Figs\RockRiver@RockValley_FrequencyAnalysis

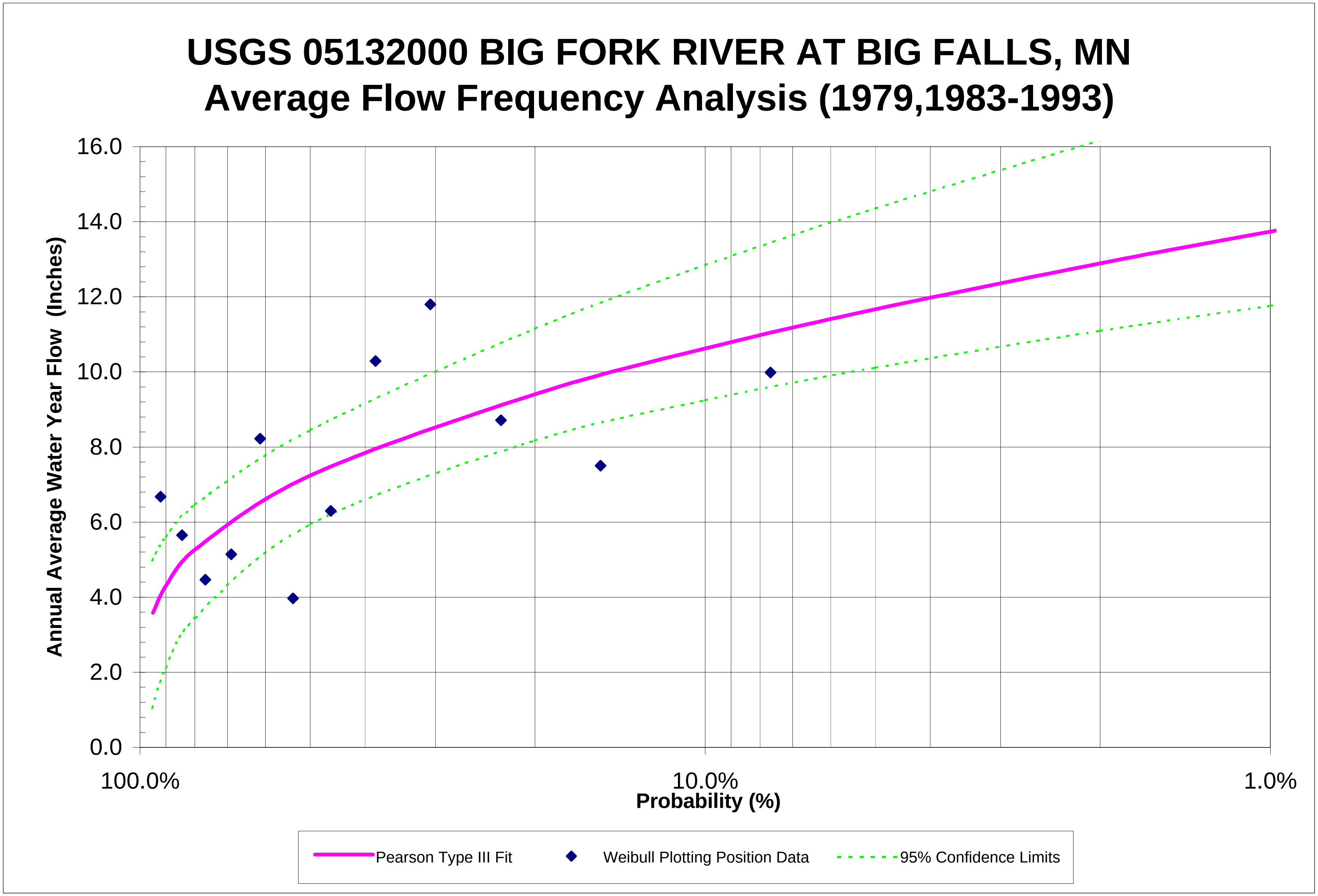


P:\23\62\853\Basin Hydrology_Mass Balance\WatershedData\USGS\DAN_Figs\RockRiver@RockValley_FrequencyAnalysis


USGS 05132000 BIG FORK RIVER AT BIG FALLS, MN
Annual Average Flow Frequency Analysis
Annual Average Water Year Flow (Inches)
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
100%
90%
50%
10%
Probability (%)
Pearson Type III Fit to 1929-1979&1983-1993 Data
Pearson Type III Fit to 1979,1983-1993 Data

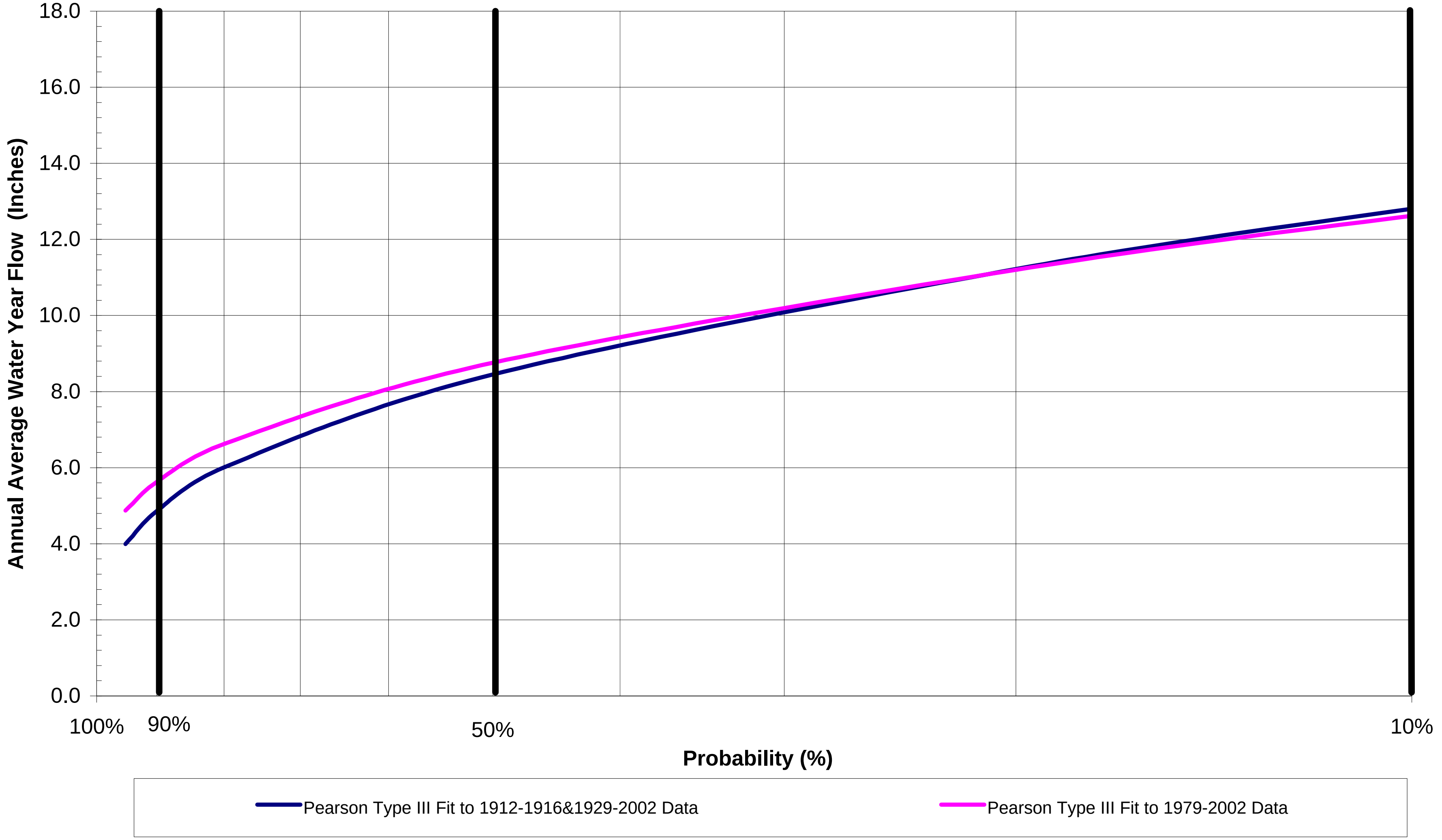


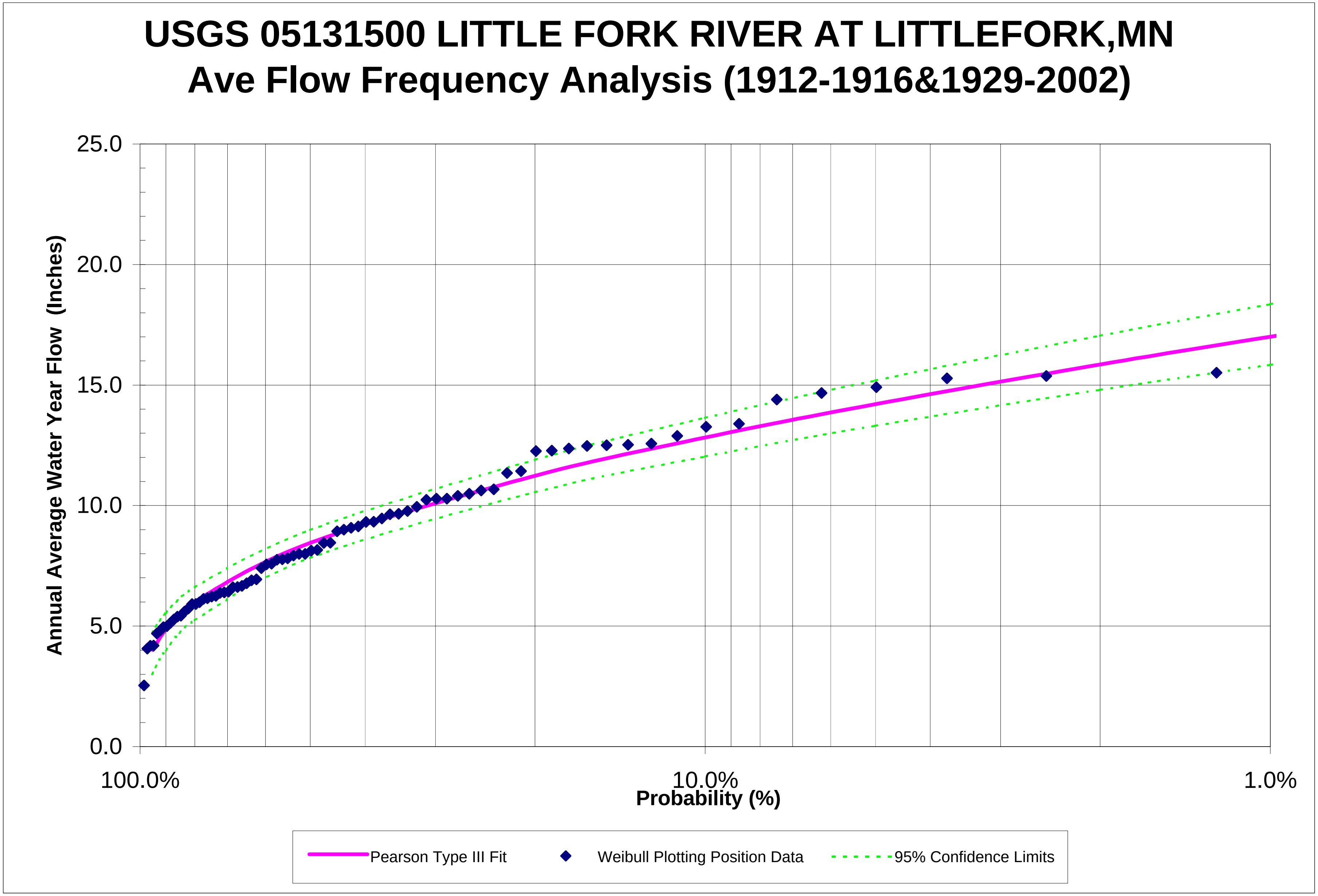
P:\23\62\853\Basin Hydrology_Mass Balance\WatershedData\USGS\DAN_Figs\BigForkRiver_FrequencyAnalysis



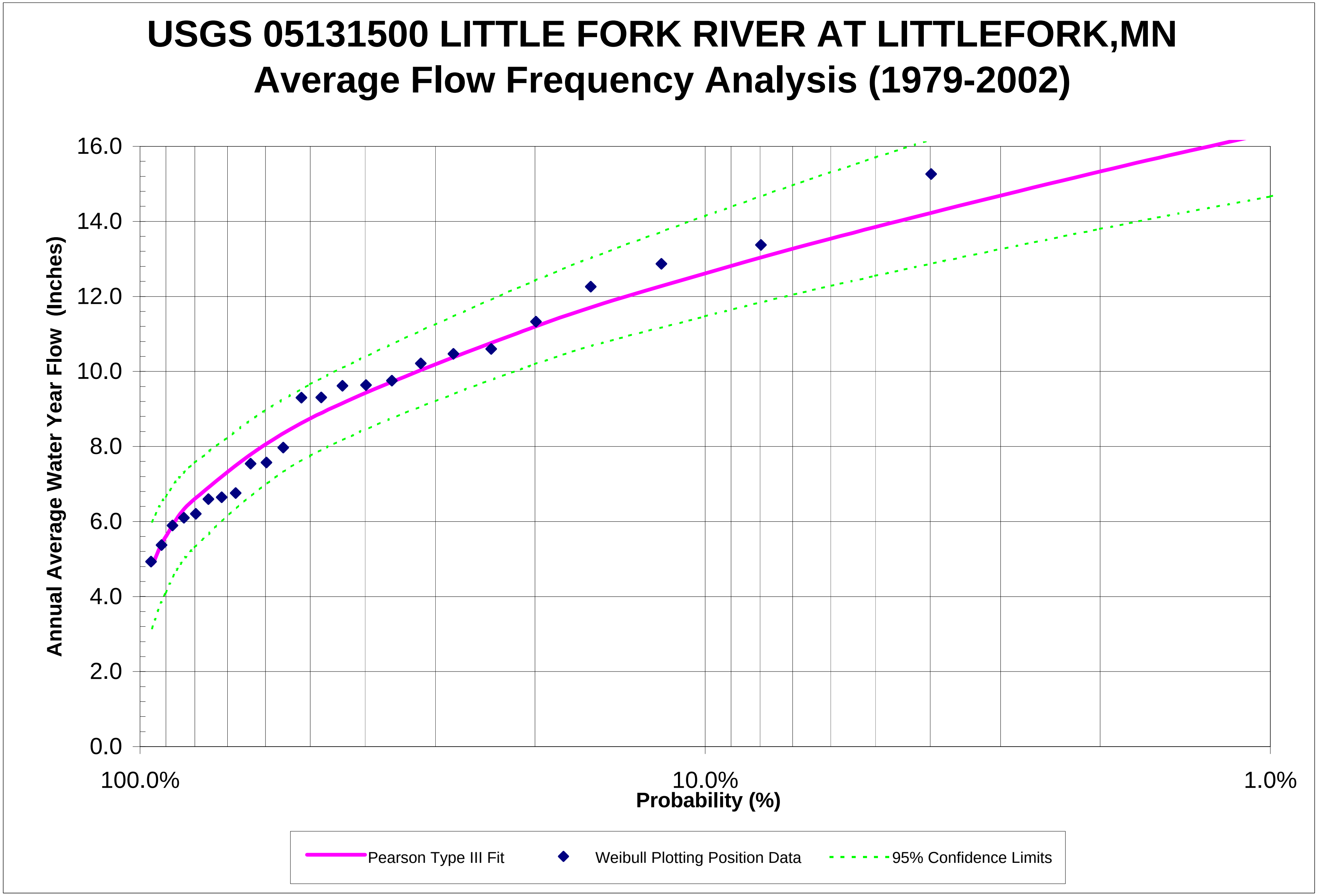
P:\23\62\853\Basin Hydrology_Mass Balance\WatershedData\USGS\DAN_Figs\BigForkRiver_FrequencyAnalysis

USGS 05131500 LITTLE FORK RIVER AT LITTLEFORK, MN
Annual Average Flow Frequency Analysis

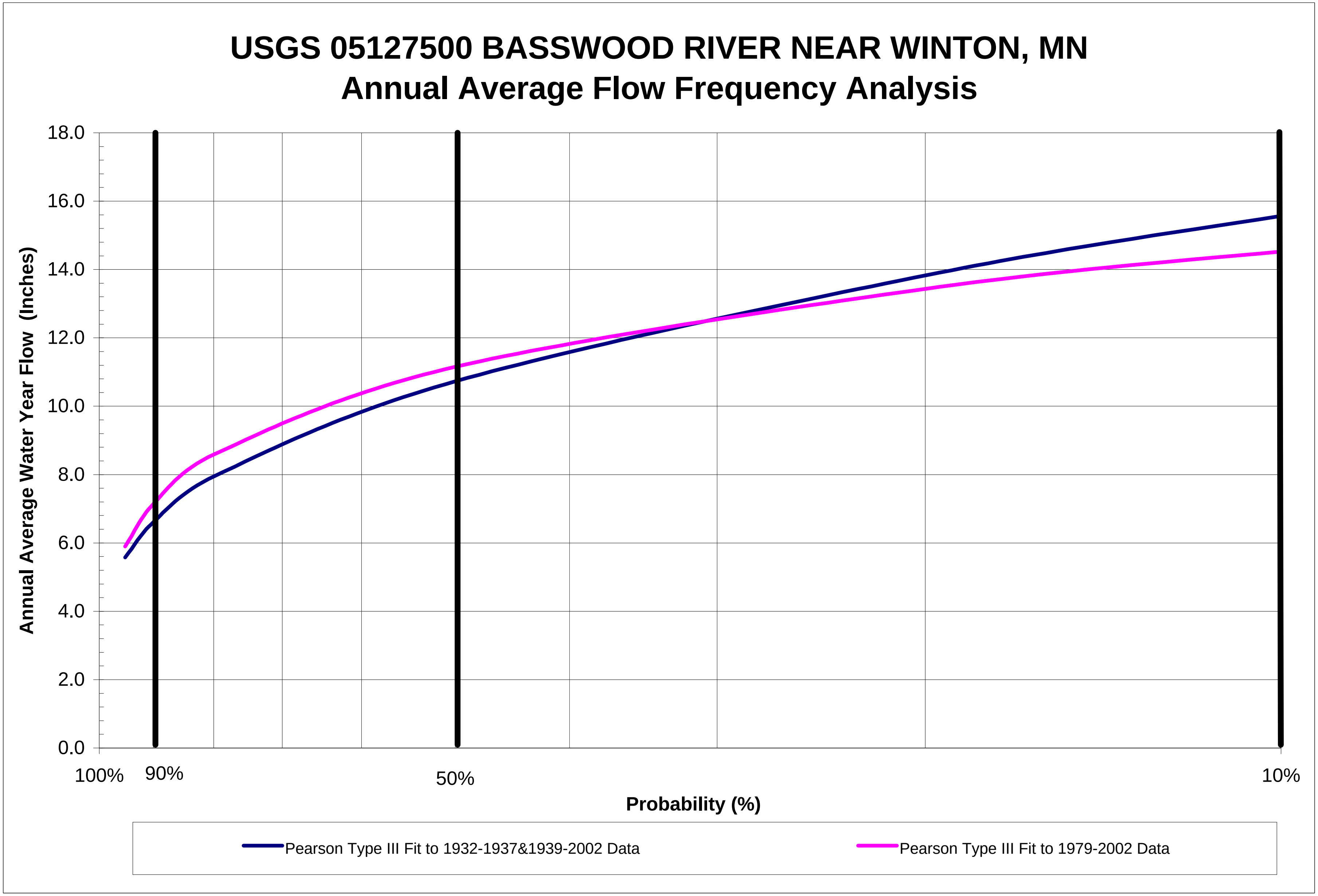




USGS 05131500 LITTLE FORK RIVER AT LITTLEFORK,MN
Ave Flow Frequency Analysis (1912-1916&1929-2002)
Annual Average Water Year Flow (Inches)
25.0
20.0
15.0
10.0
5.0
0.0
100.0%
10.0%
1.0%
Probability (%)
Pearson Type III Fit
Weibull Plotting Position Data
95% Confidence Limits

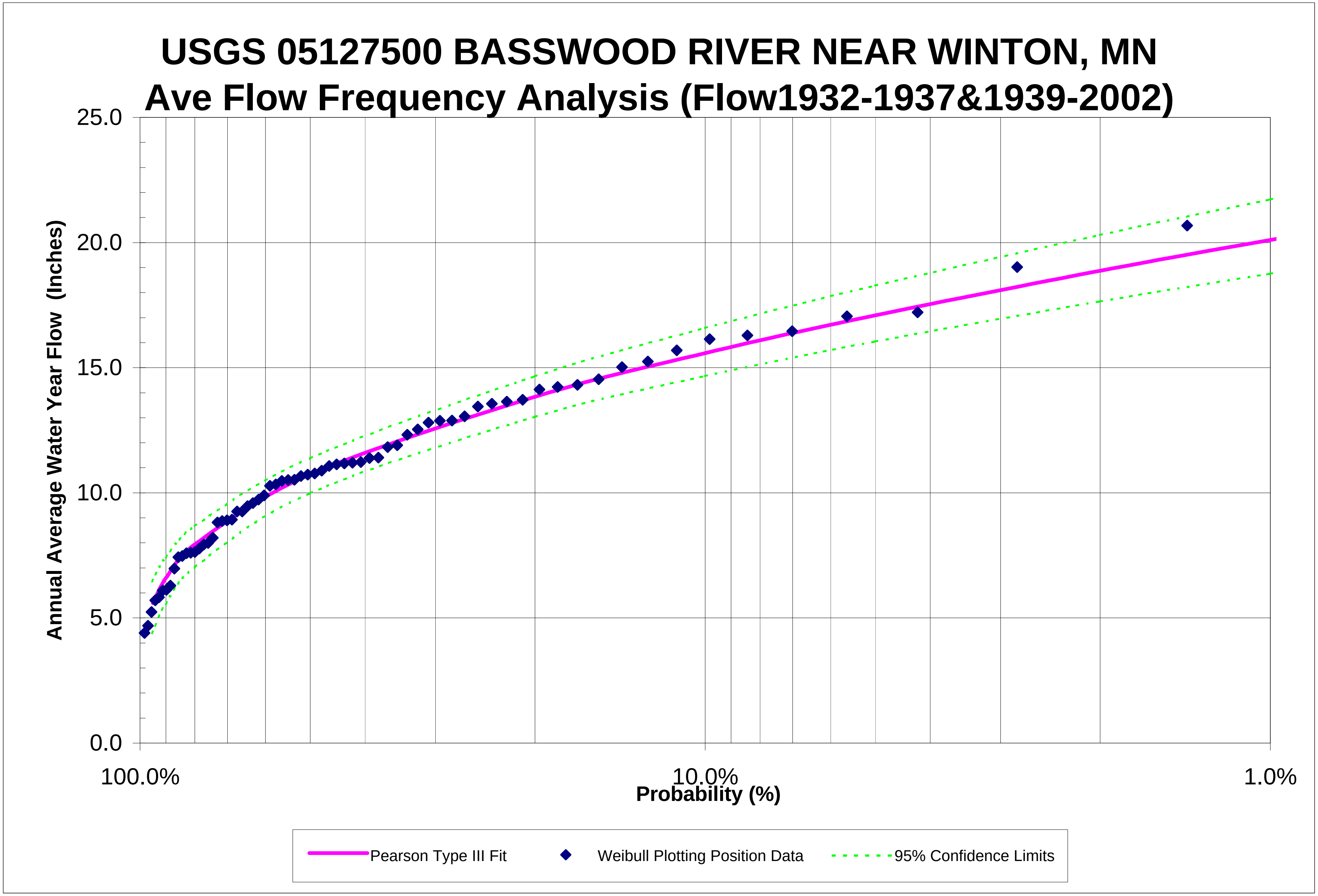


USGS 05131500 LITTLE FORK RIVER AT LITTLEFORK,MN
Average Flow Frequency Analysis (1979-2002)
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
Annual Average Water Year Flow (Inches)
100.0%
10.0%
1.0%
Probability (%)
Pearson Type III Fit
Weibull Plotting Position Data
95% Confidence Limits

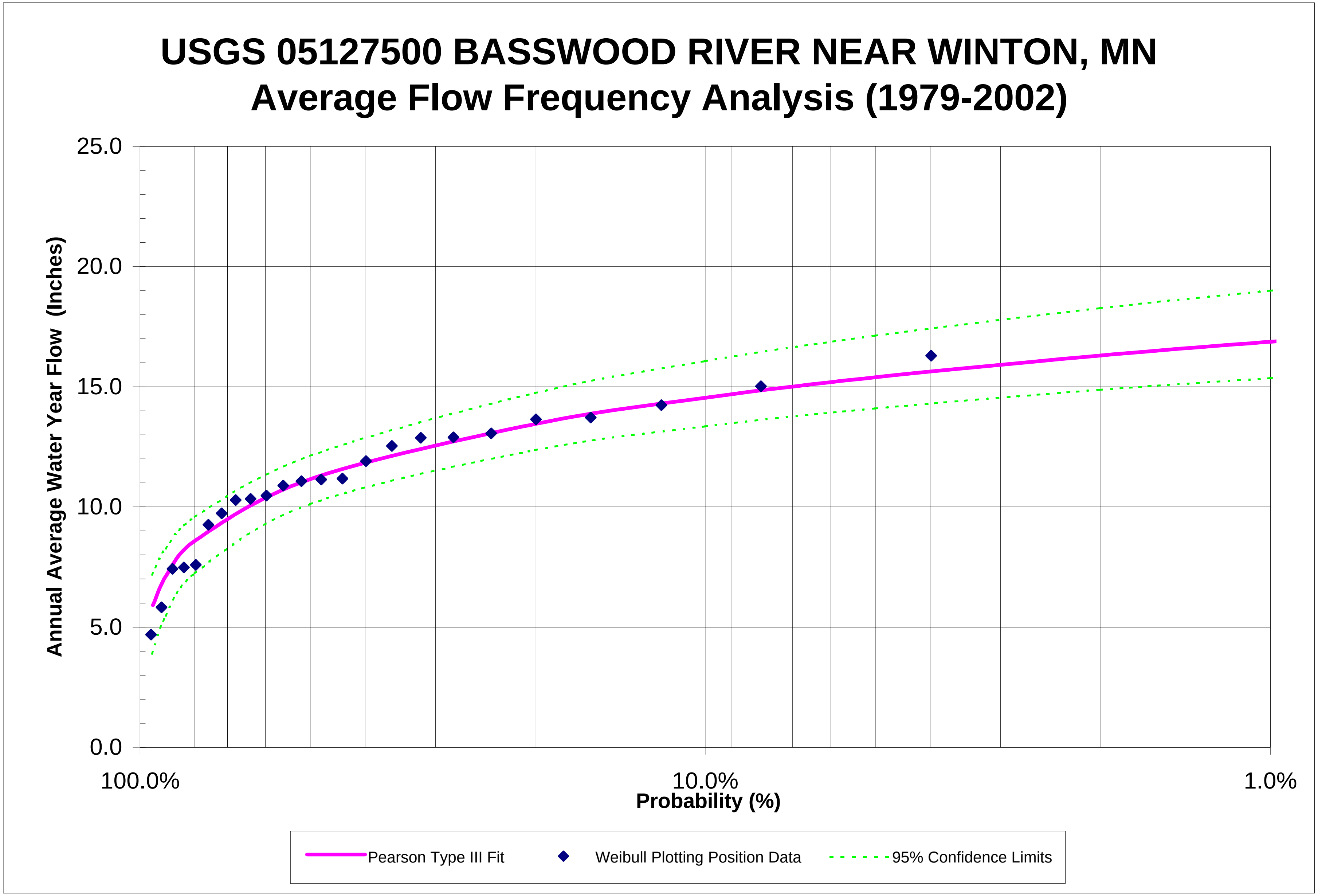


P:\23\62\853\Basin Hydrology_Mass Balance\WatershedData\USGS\DAN_Figs\BasswoodRiver_FrequencyAnalysis

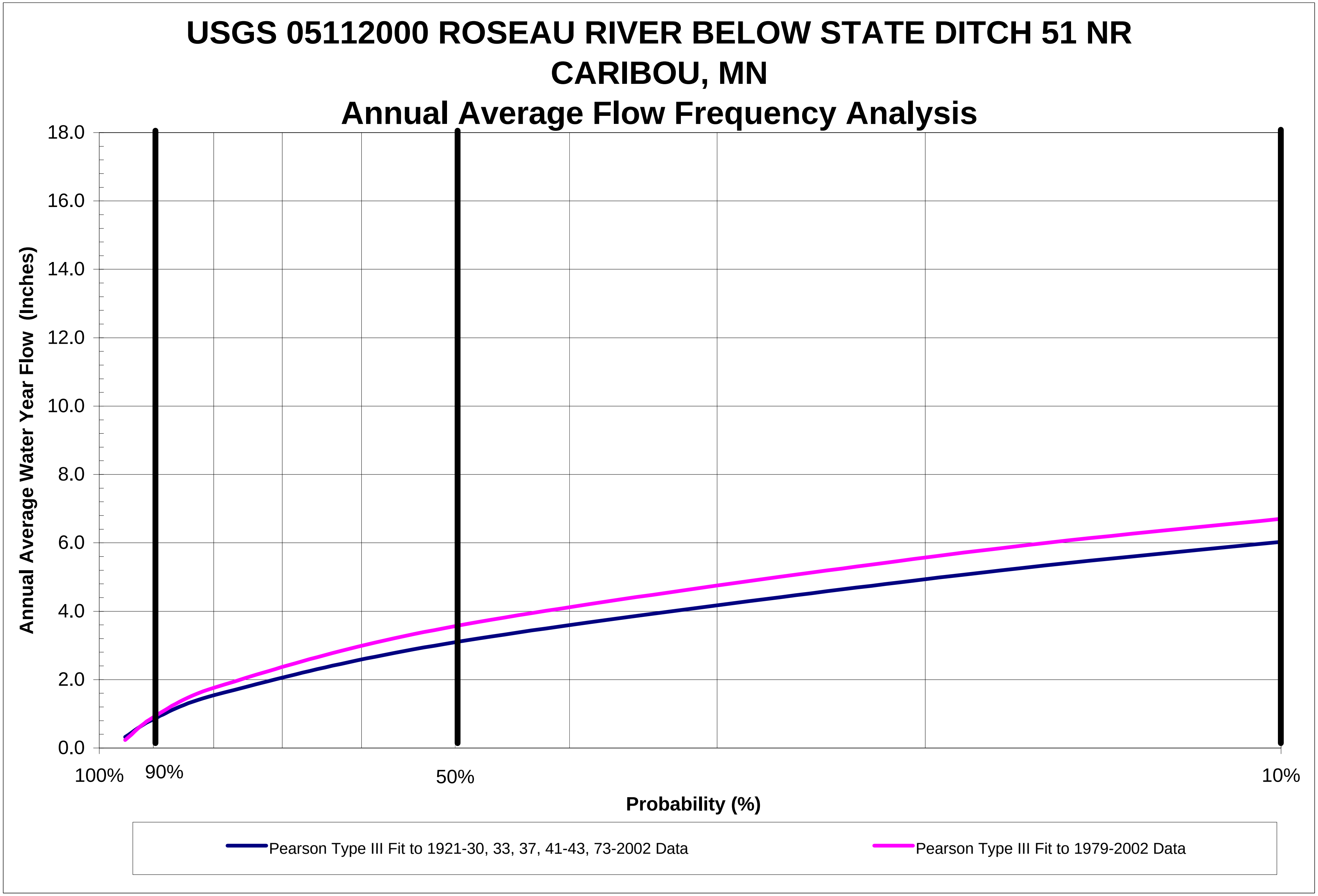
10/21/2003
9:24 AM



P:\23\62\853\Basin Hydrology_Mass Balance\WatershedData\USGS\DAN_Figs\BasswoodRiver_FrequencyAnalysis

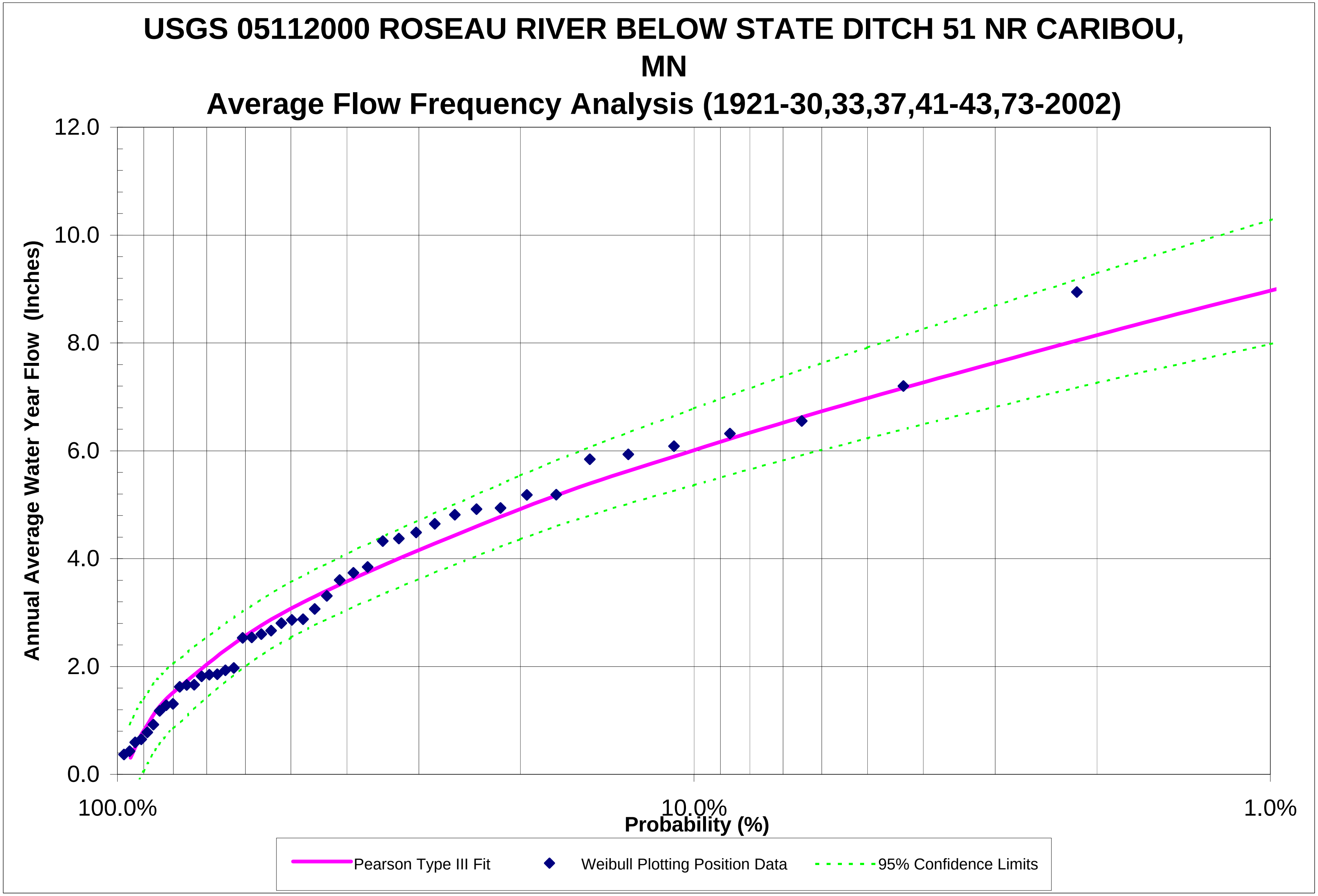


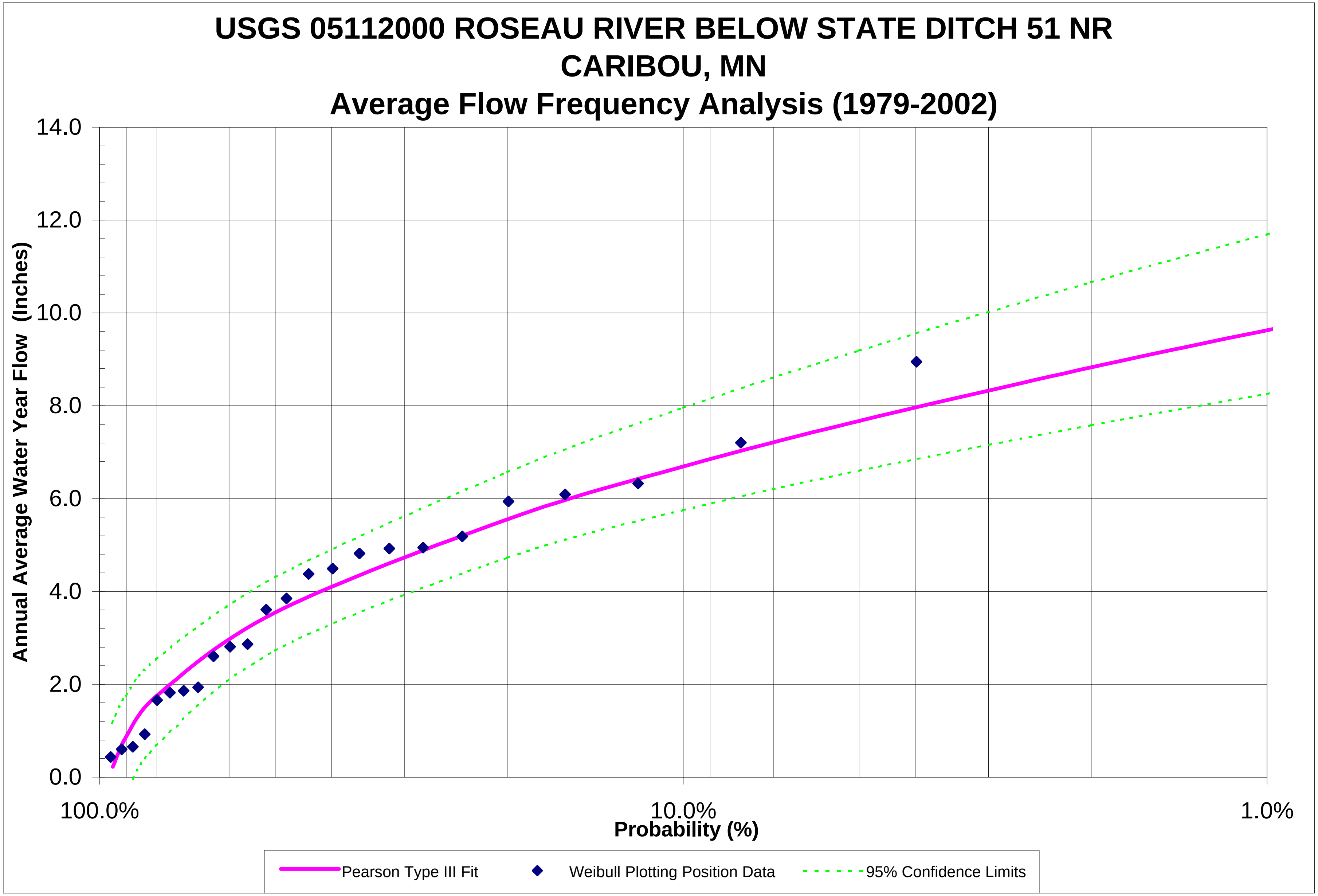
P:\23\62\853\Basin Hydrology_Mass Balance\WatershedData\USGS\DAN_Figs\BasswoodRiver_FrequencyAnalysis



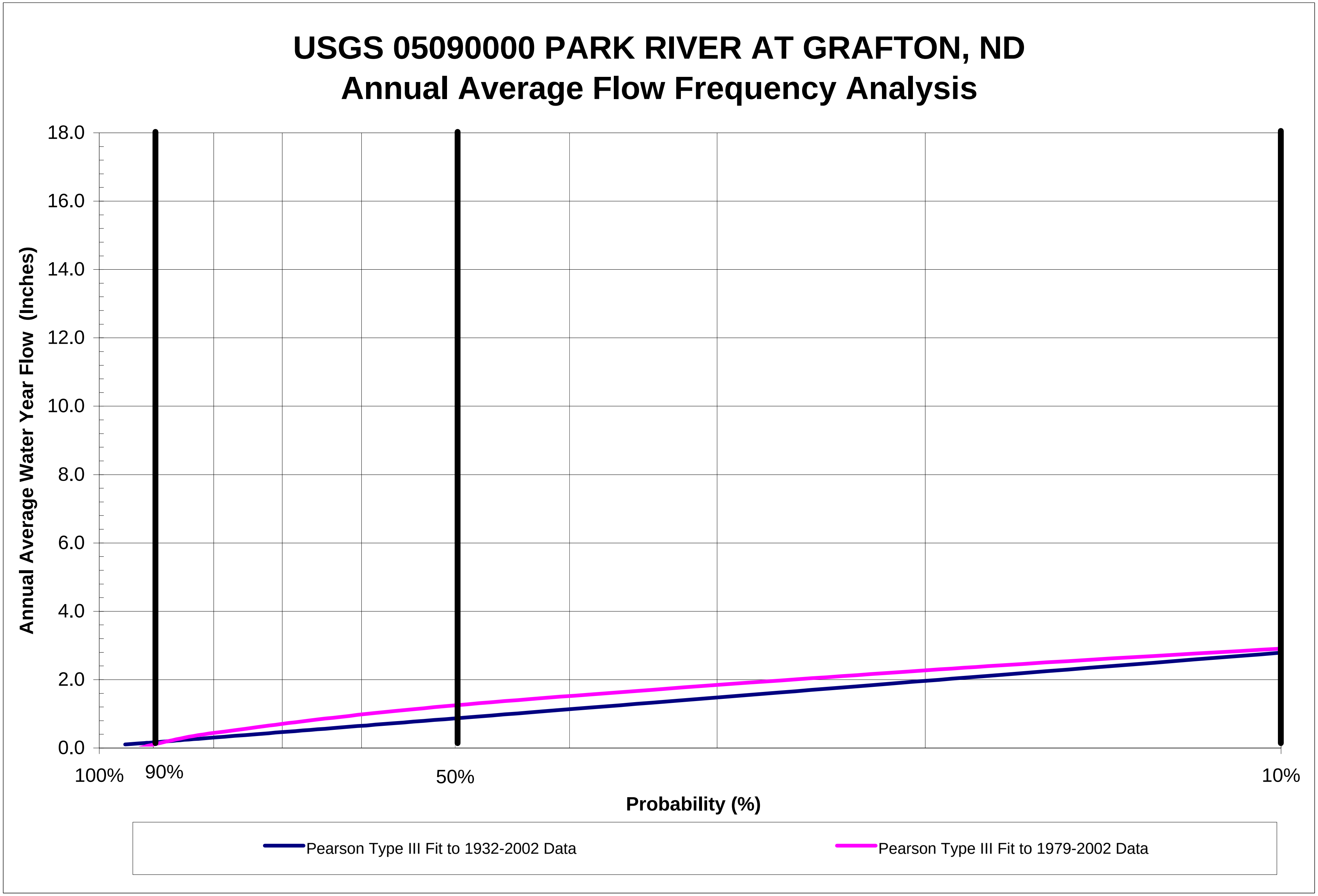
P:\23\62\853\Basin Hydrology_Mass Balance\WatershedData\USGS\DAN_Figs\RoseauRiver_FrequencyAnalysis

10/21/2003
9:26 AM

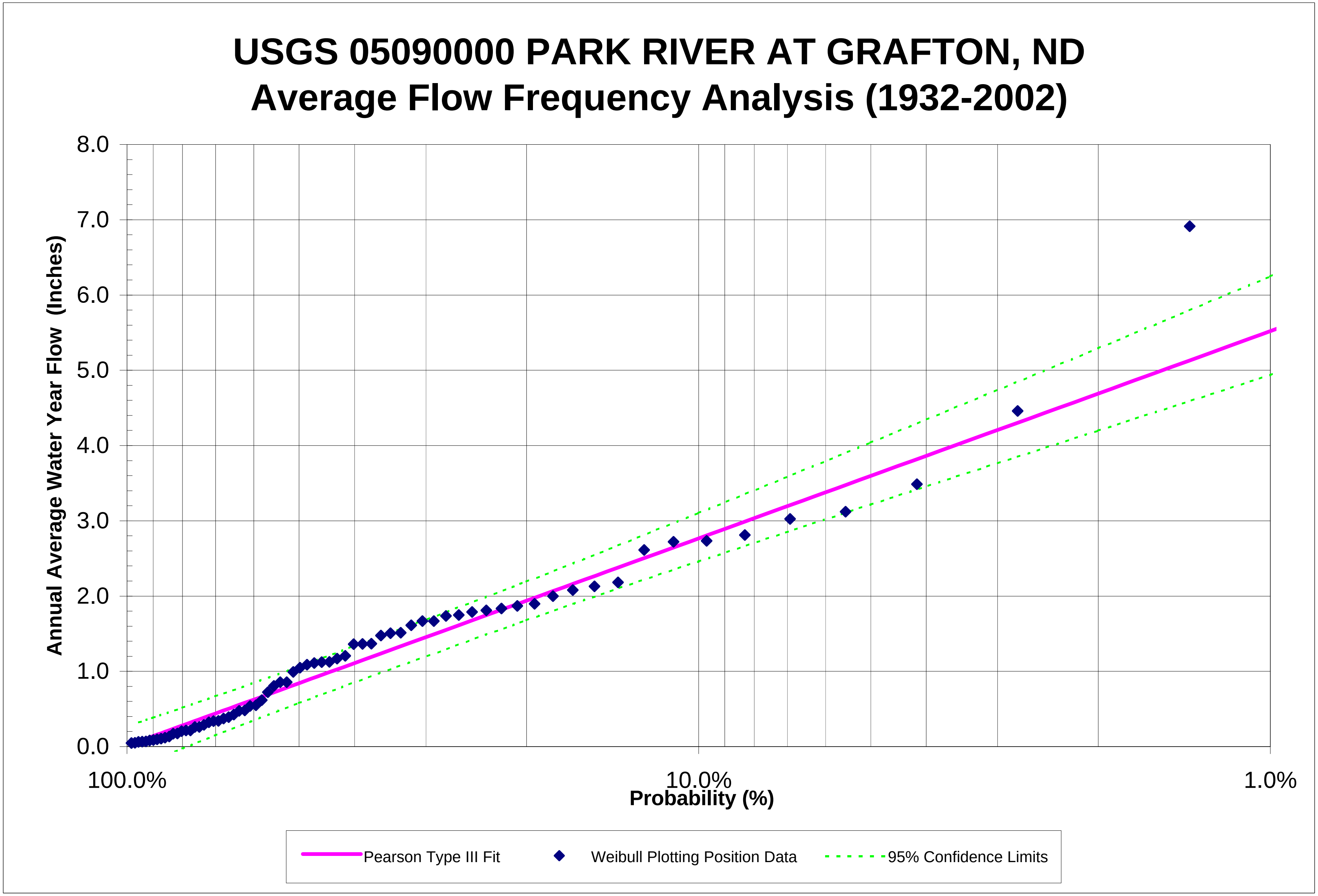

USGS 05112000 ROSEAU RIVER BELOW STATE DITCH 51 NR CARIBOU, MN
Average Flow Frequency Analysis (1921-30,33,37,41-43,73-2002)
Annual Average Water Year Flow (Inches)
12.0
10.0
8.0
6.0
4.0
2.0
0.0
100.0%
10.0%
1.0%
Probability (%)
Pearson Type III Fit
Weibull Plotting Position Data
95% Confidence Limits



P:\23\62\853\Basin Hydrology_Mass Balance\WatershedData\USGS\DAN_Figs\RoseauRiver_FrequencyAnalysis

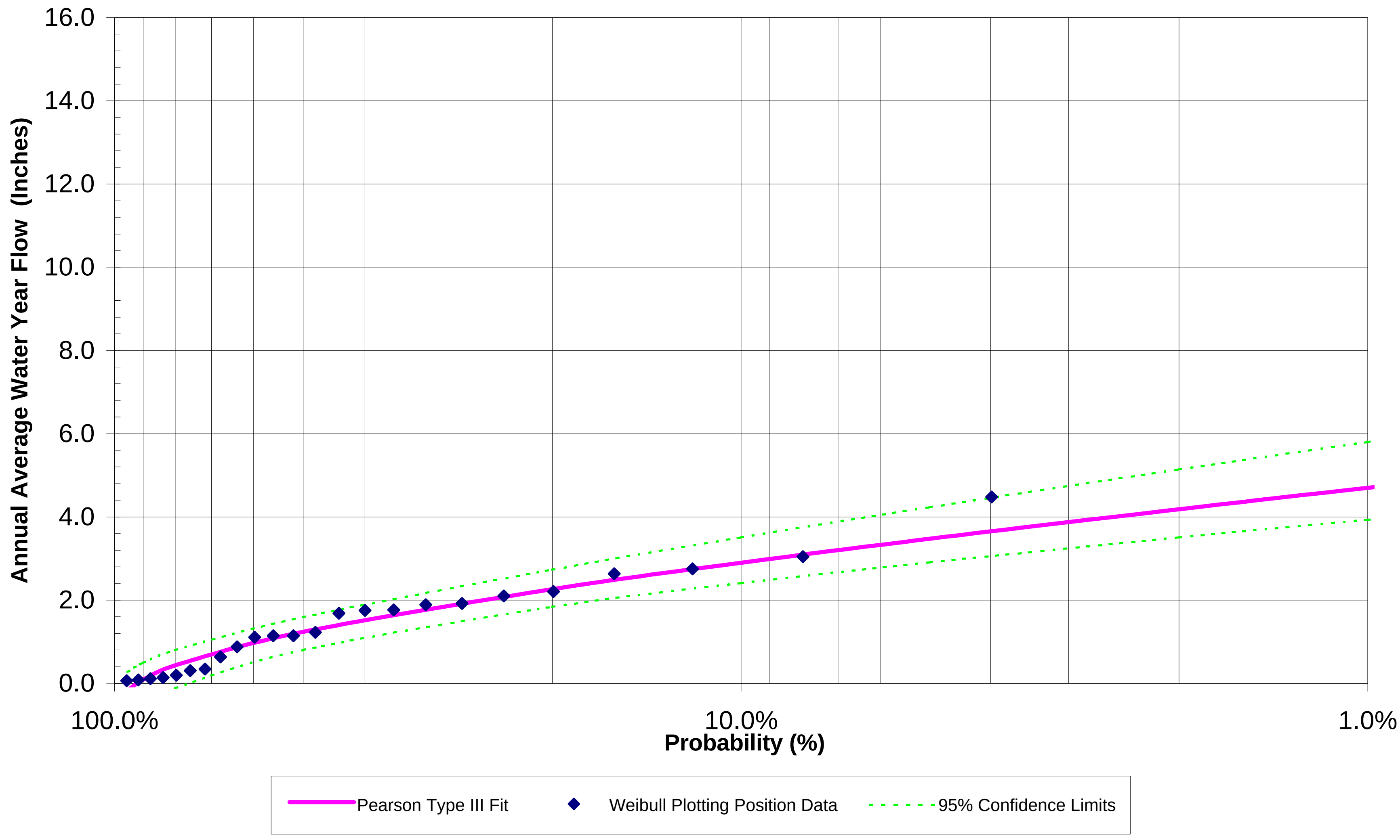


USGS 05090000 PARK RIVER AT GRAFTON, ND
Annual Average Flow Frequency Analysis
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
Annual Average Water Year Flow (Inches)
100%
90%
50%
10%
Probability (%)
Pearson Type III Fit to 1932-2002 Data
Pearson Type III Fit to 1979-2002 Data

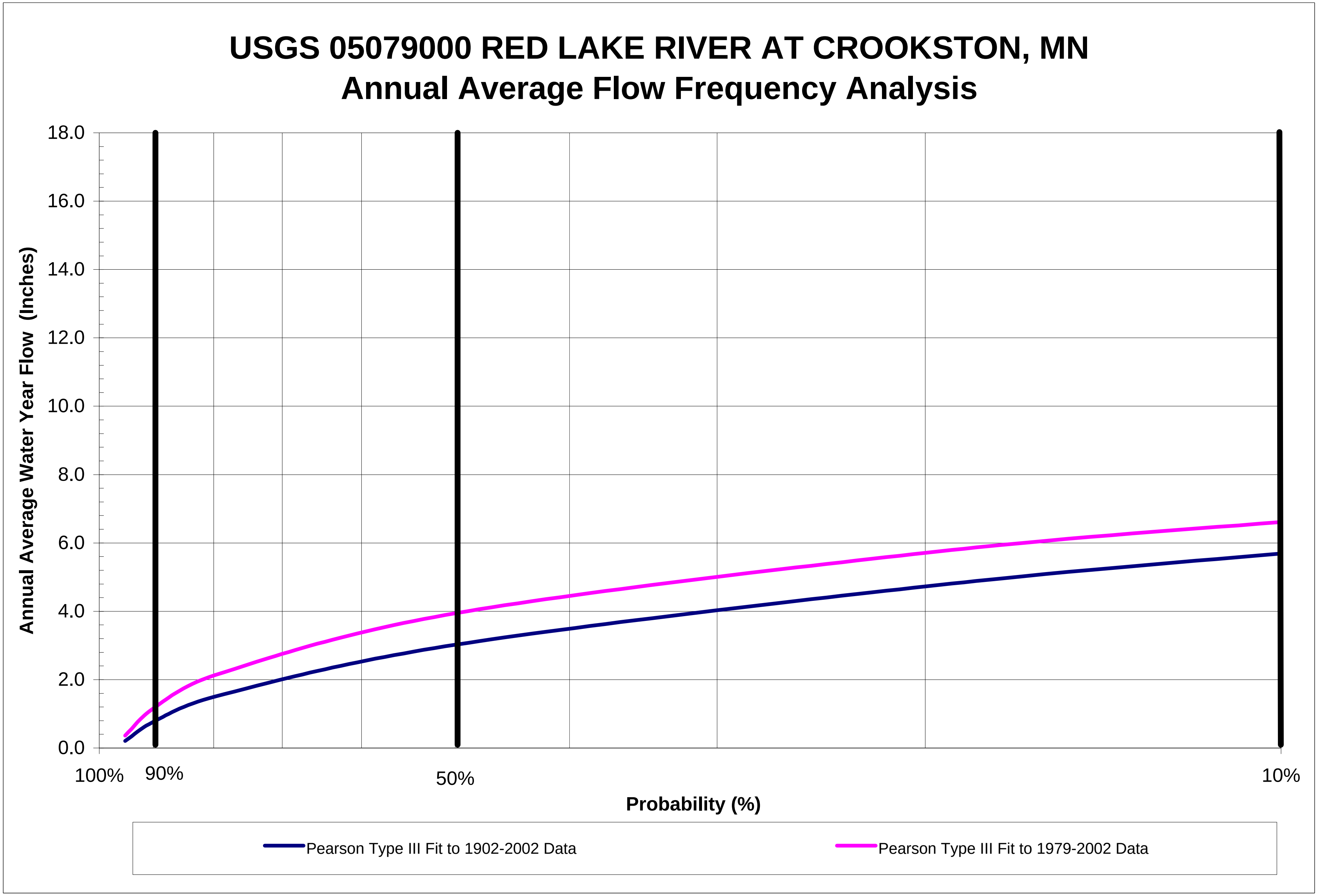


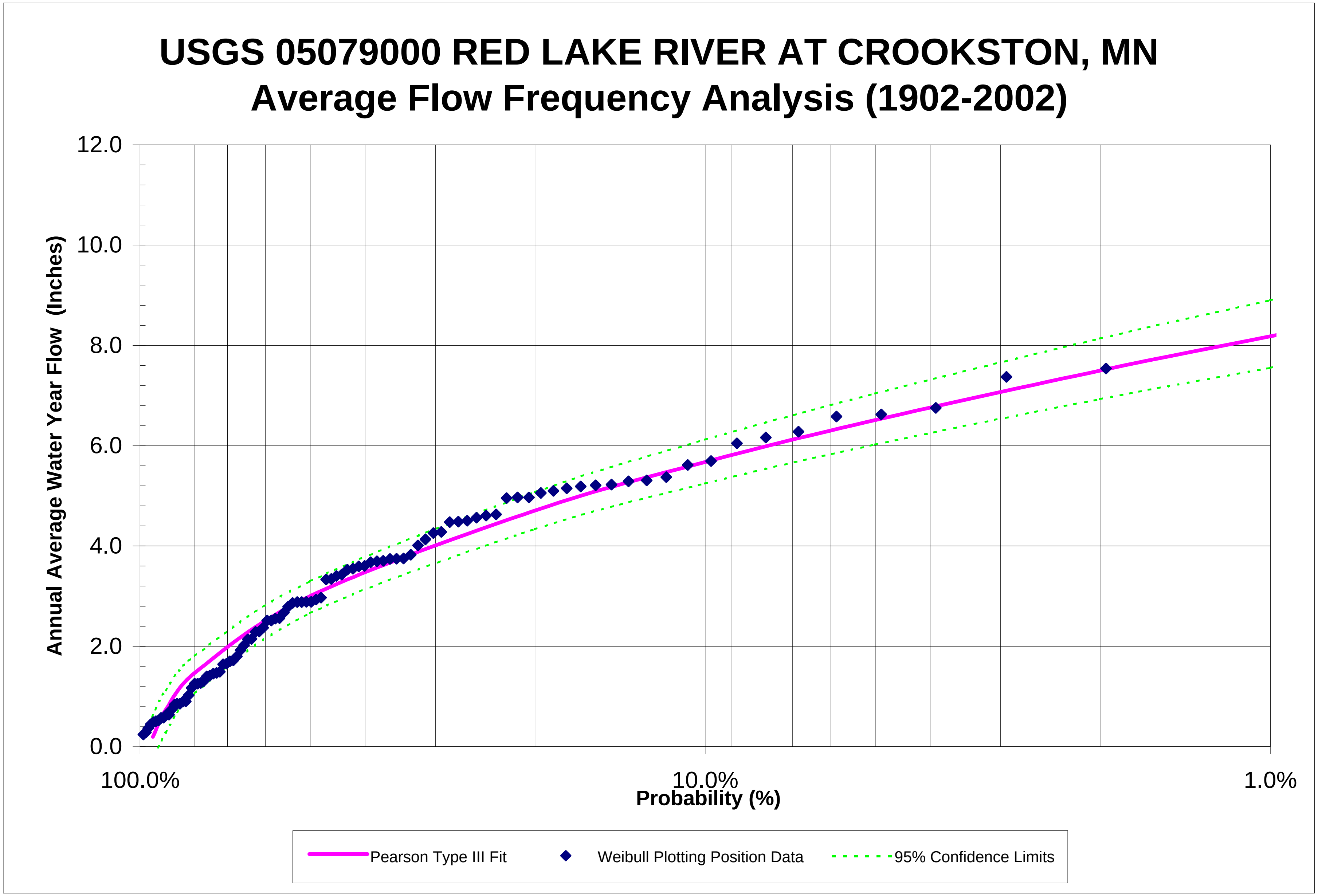
P:\23\62\853\Basin Hydrology_Mass Balance\WatershedData\USGS\DAN_Figs\ParkRiver_FrequencyAnalysis

USGS 05090000 PARK RIVER AT GRAFTON, ND
Average Flow Frequency Analysis (1979-2002)

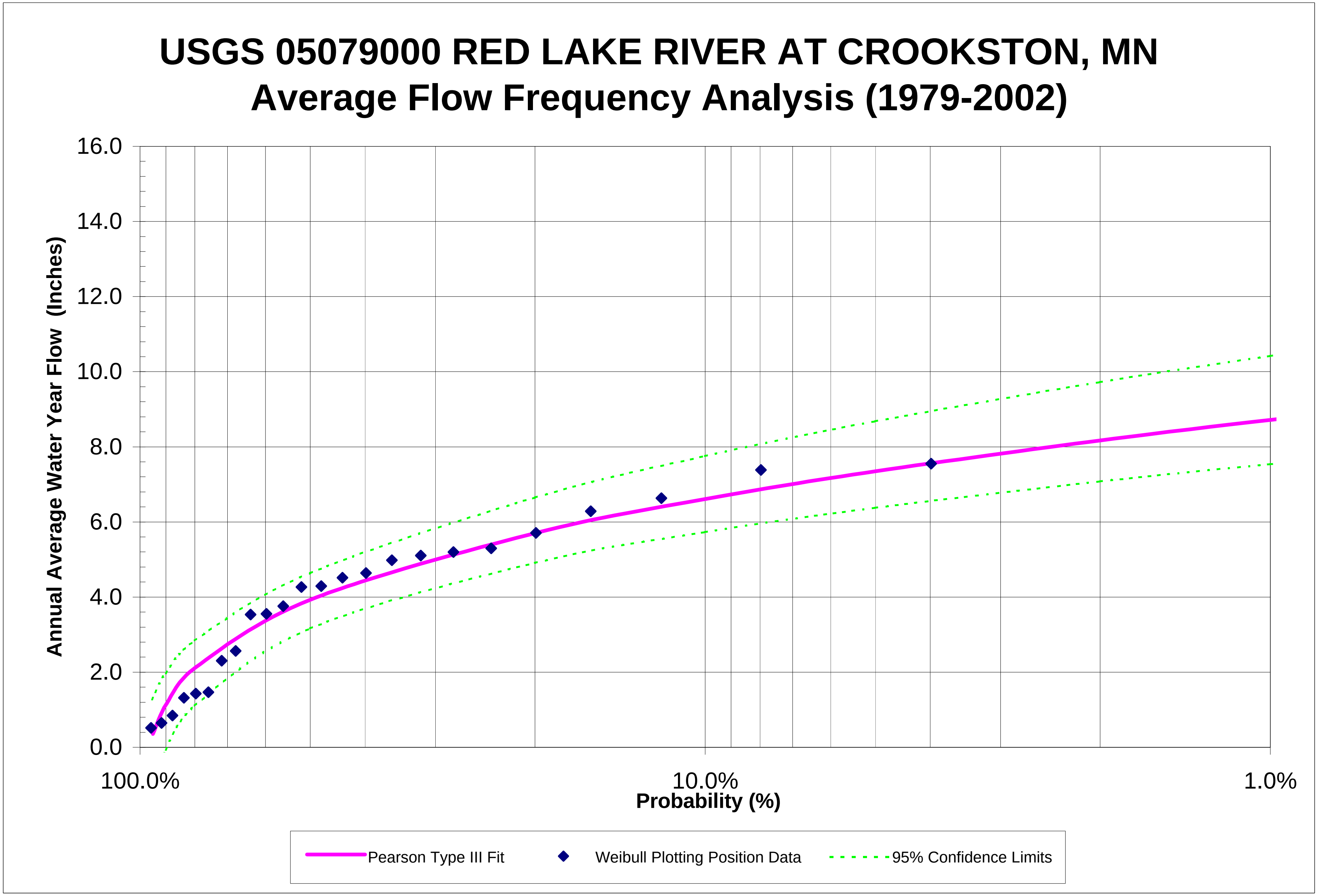


P:\23\62\853\Basin Hydrology_Mass Balance\WatershedData\USGS\DAN_Figs\ParkRiver_FrequencyAnalysis

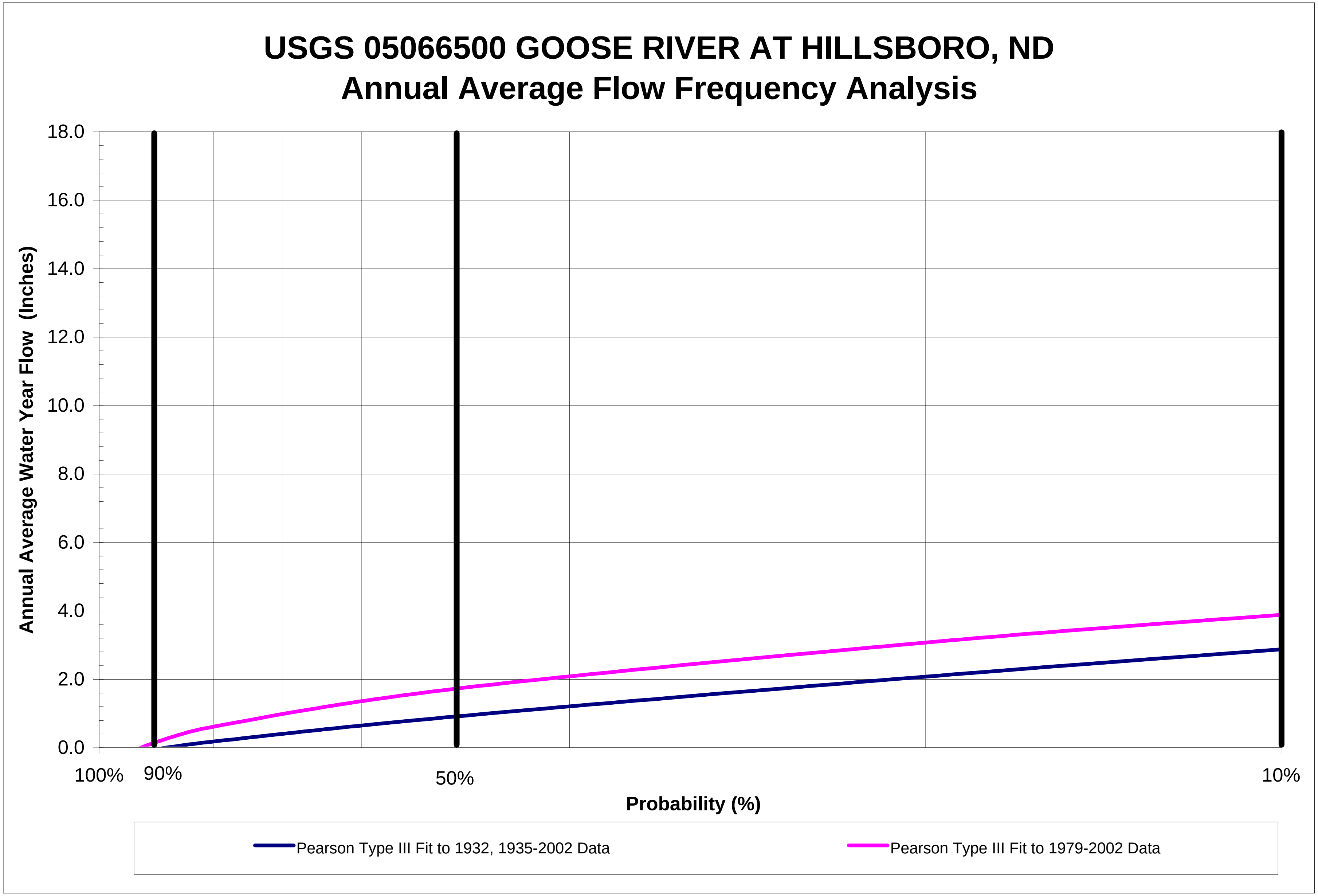

USGS 05079000 RED LAKE RIVER AT CROOKSTON, MN
Annual Average Flow Frequency Analysis
Annual Average Water Year Flow (Inches)
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
100%
90%
50%
10%
Probability (%)
Pearson Type III Fit to 1902-2002 Data
Pearson Type III Fit to 1979-2002 Data

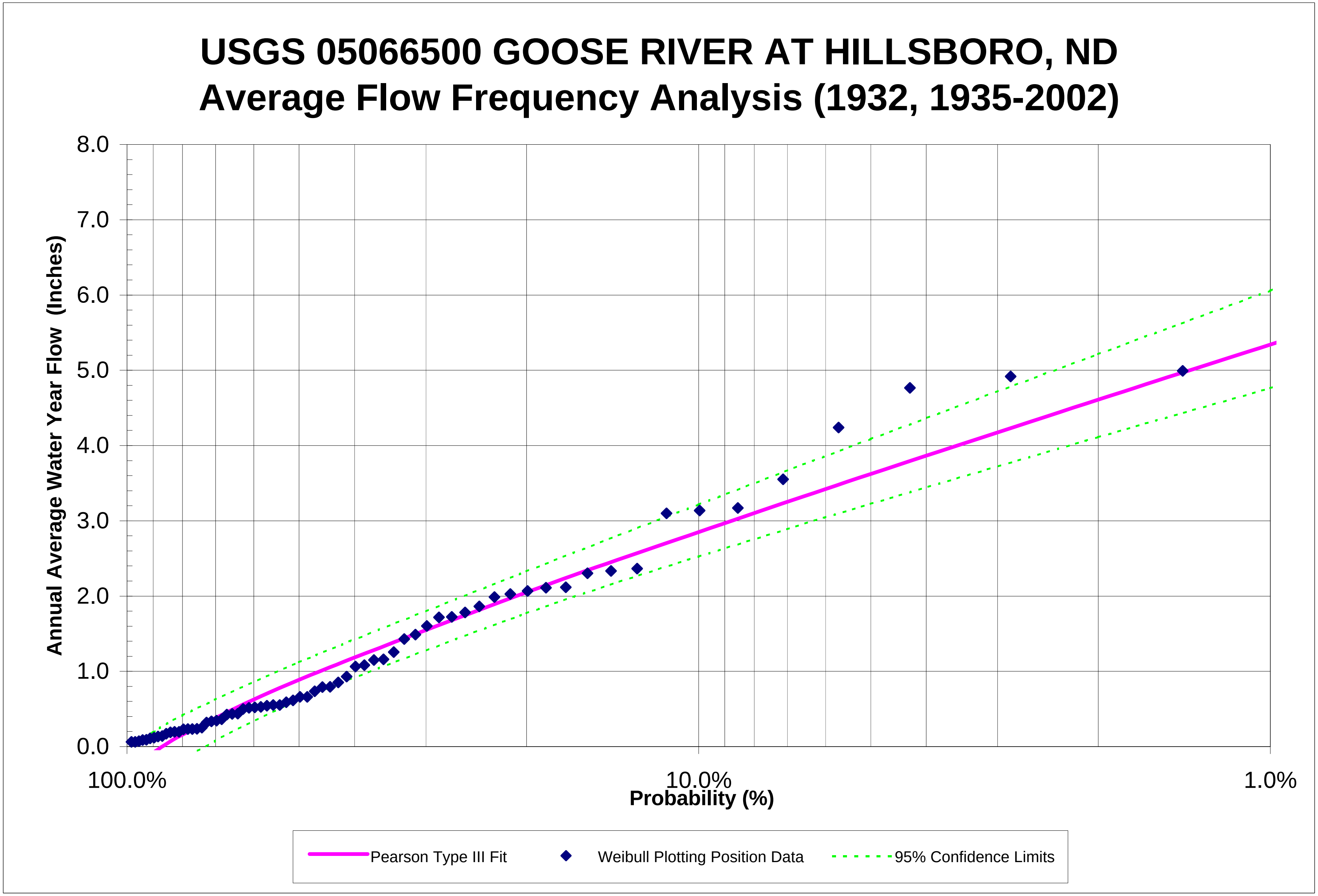


P:\23\62\853\Basin Hydrology_Mass Balance\WatershedData\USGS\DAN_Figs\RedLakeRiver@Crookston_FrequencyAnalysis

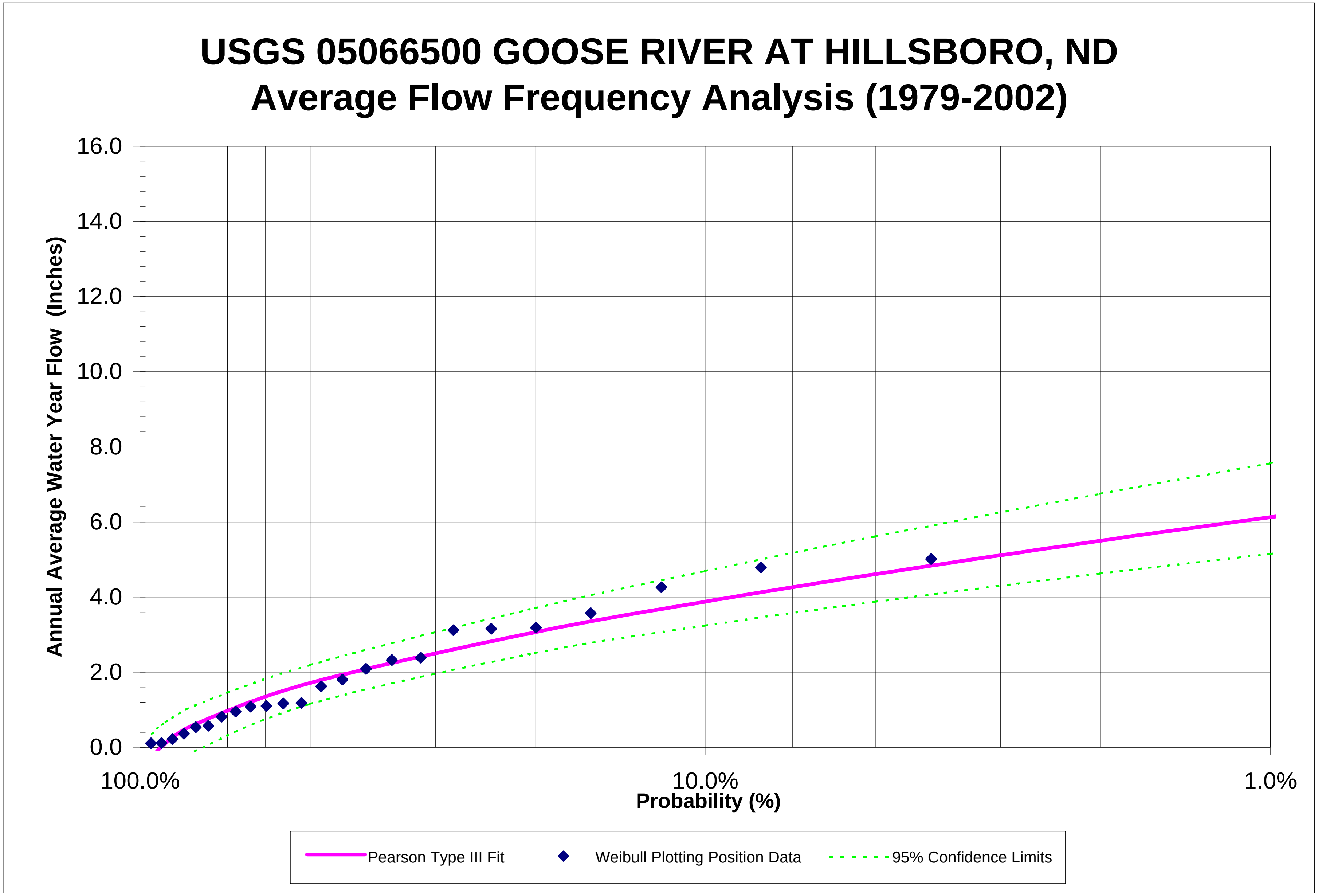


P:\23\62\853\Basin Hydrology_Mass Balance\WatershedData\USGS\DAN_Figs\RedLakeRiver@Crookston_FrequencyAnalysis

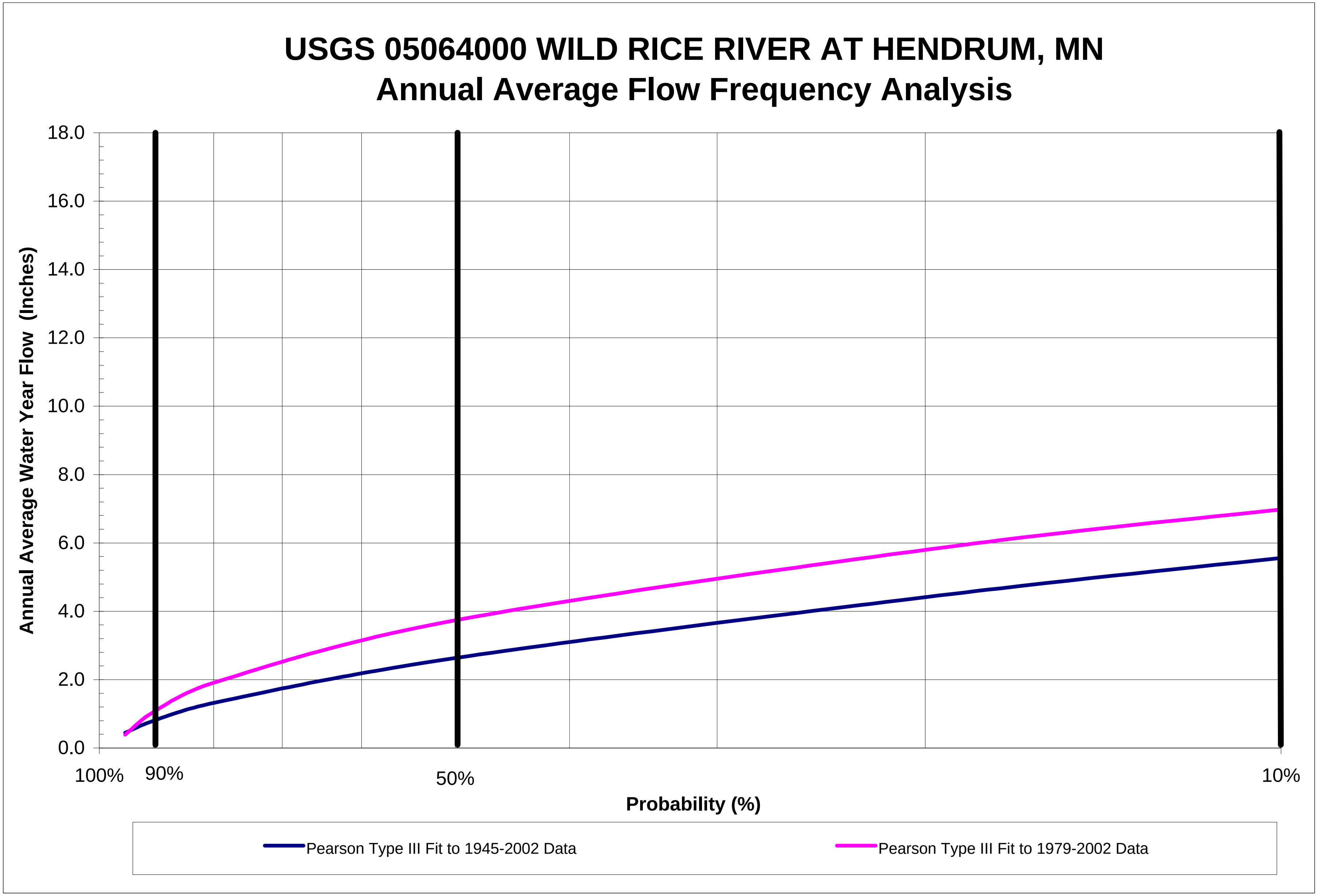

USGS 05066500 GOOSE RIVER AT HILLSBORO, ND
Annual Average Flow Frequency Analysis
Annual Average Water Year Flow (Inches)
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
100%
90%
50%
10%
Probability (%)
Pearson Type III Fit to 1932, 1935-2002 Data
Pearson Type III Fit to 1979-2002 Data

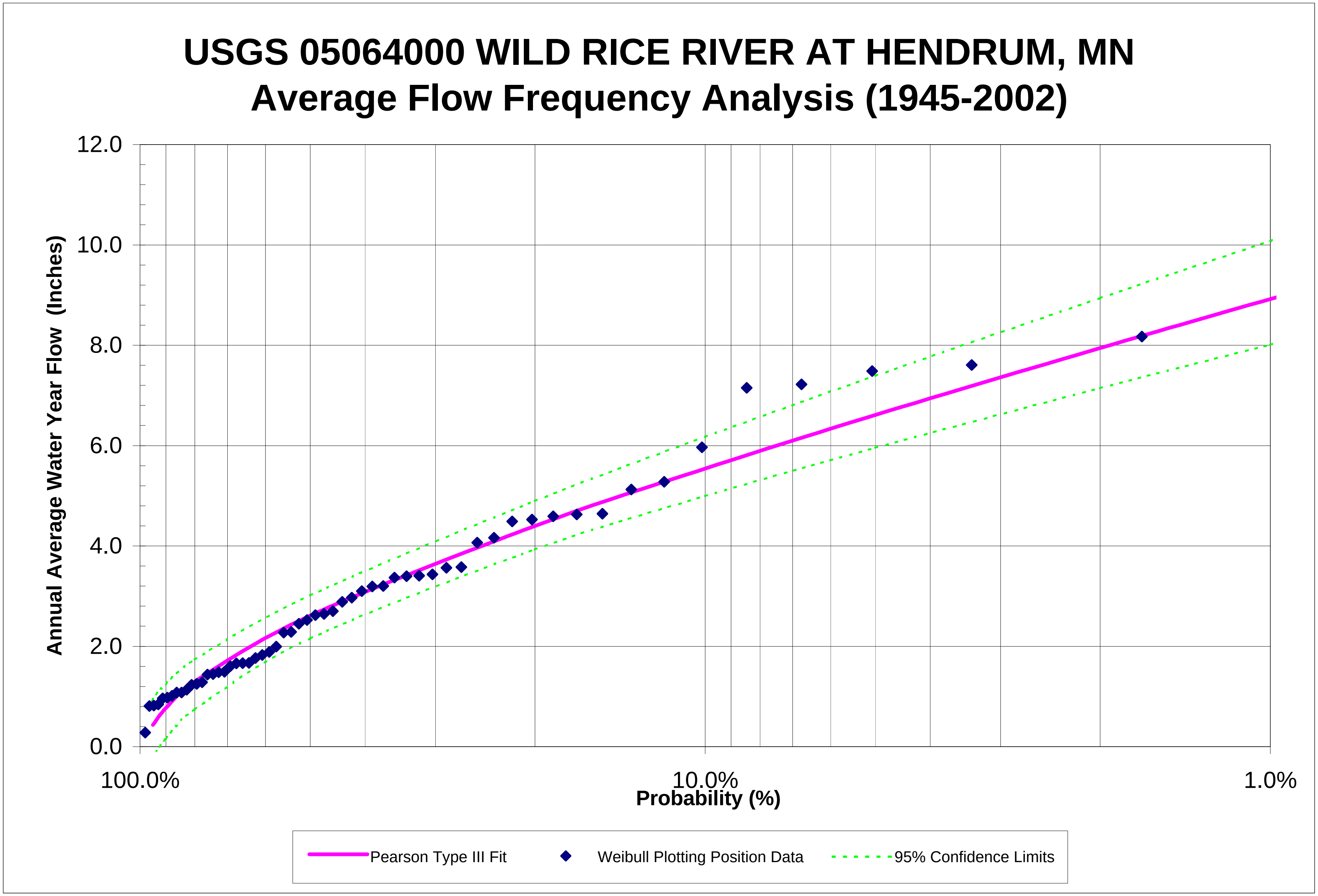


P:\23\62\853\Basin Hydrology_Mass Balance\WatershedData\USGS\DAN_Figs\GooseRiver_FrequencyAnalysis

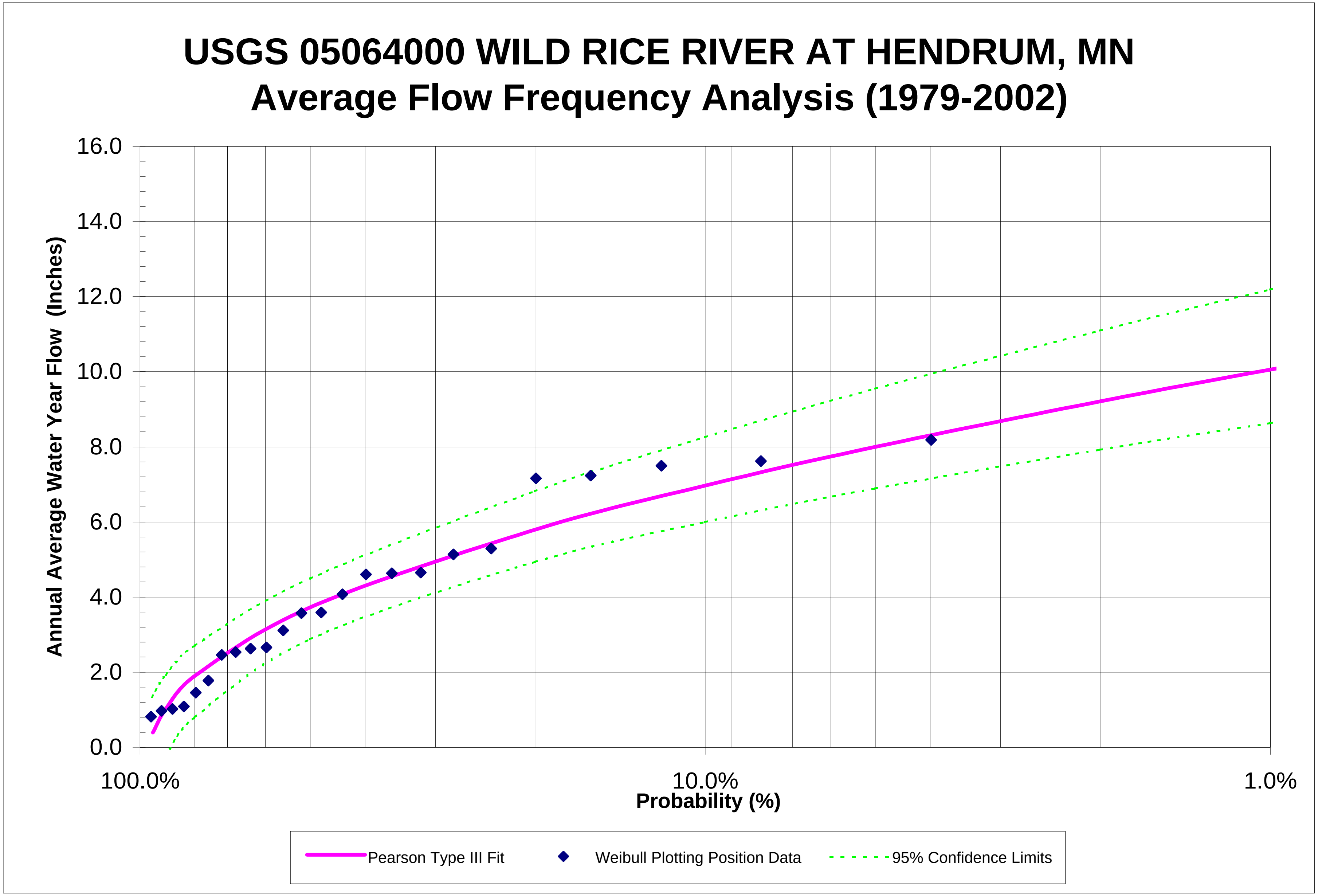


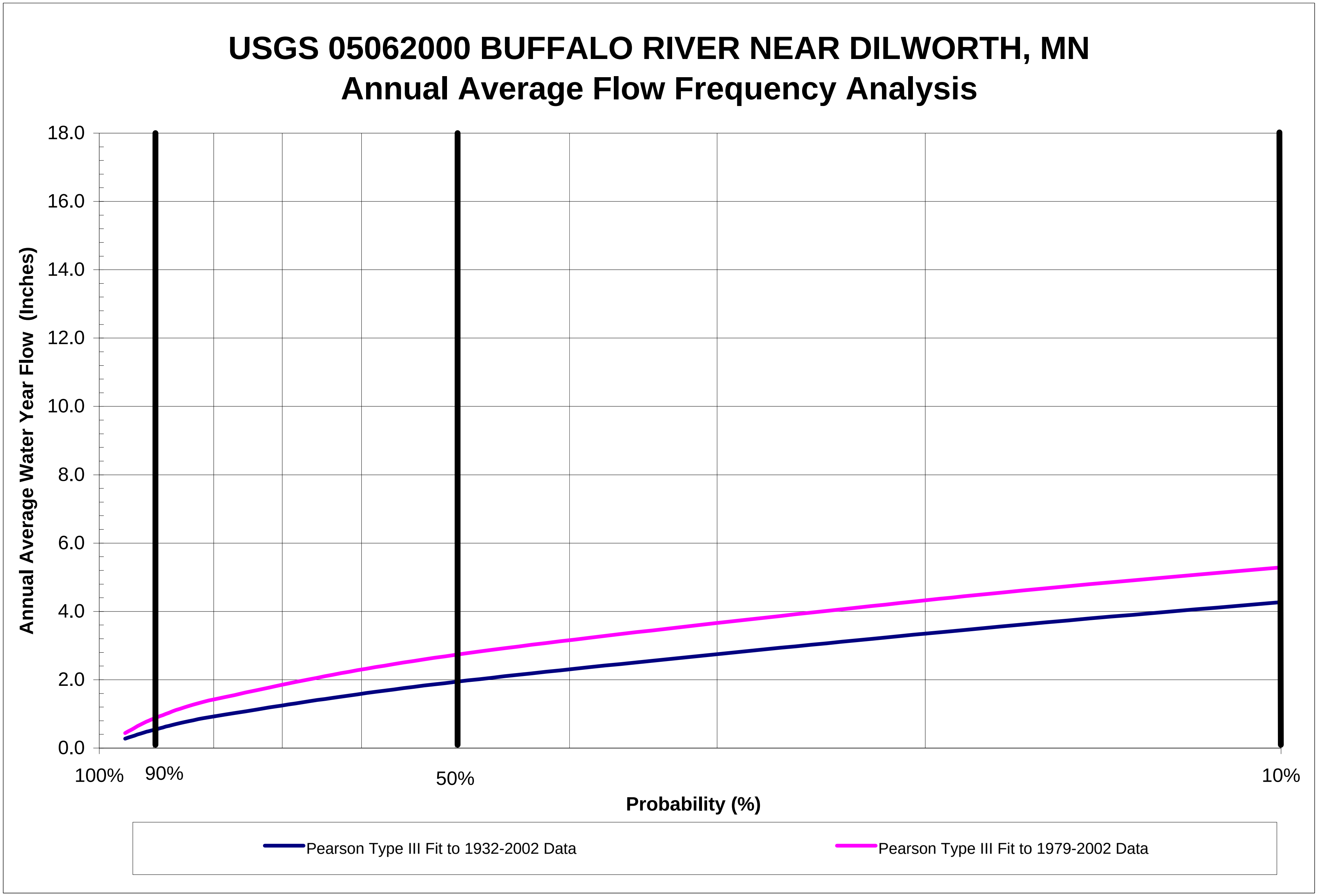
P:\23\62\853\Basin Hydrology_Mass Balance\WatershedData\USGS\DAN_Figs\GooseRiver_FrequencyAnalysis


USGS 05064000 WILD RICE RIVER AT HENDRUM, MN
Annual Average Flow Frequency Analysis
Annual Average Water Year Flow (Inches)
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
100%
90%
50%
10%
Probability (%)
Pearson Type III Fit to 1945-2002 Data
Pearson Type III Fit to 1979-2002 Data



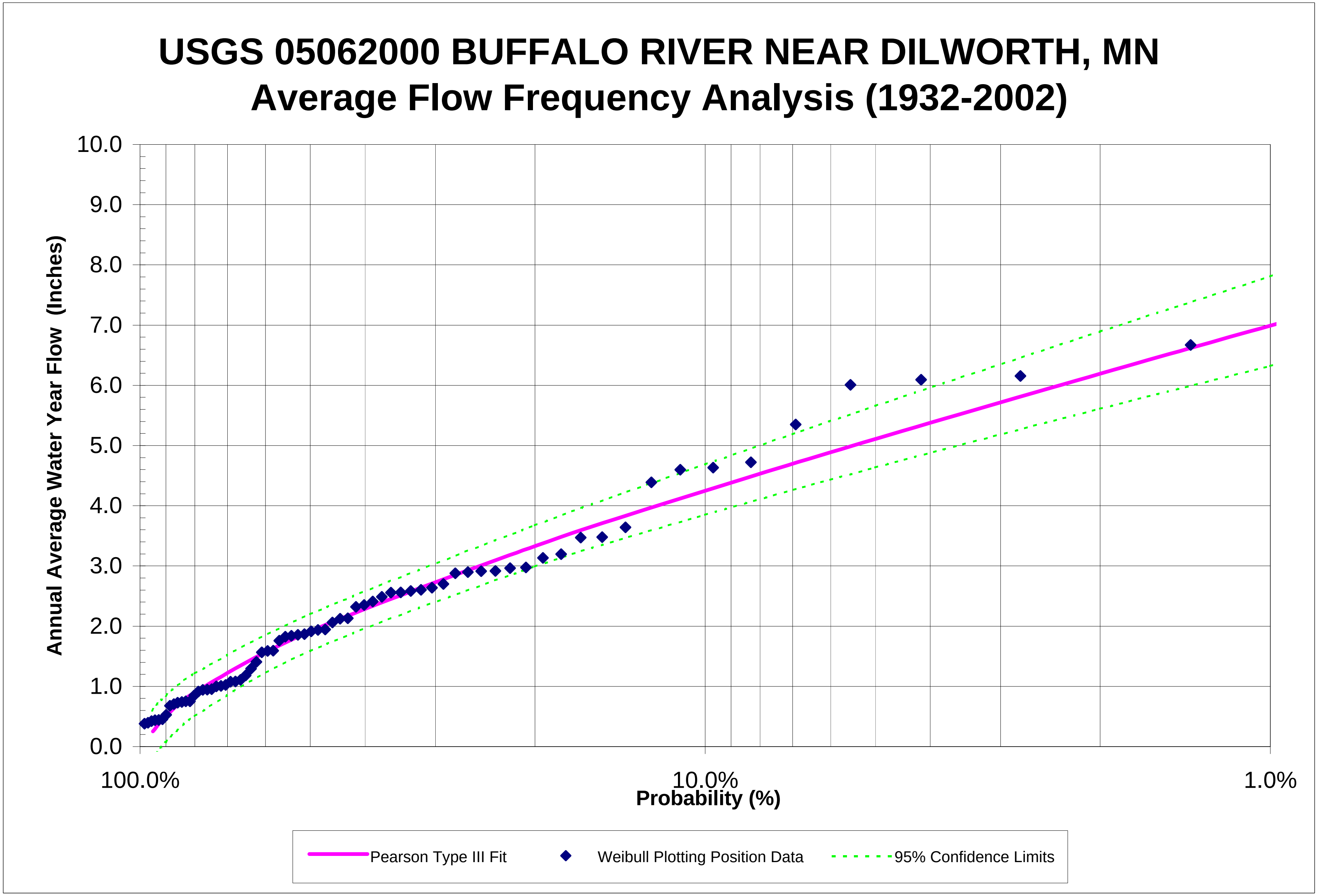
P:\23\62\853\Basin Hydrology_Mass Balance\WatershedData\USGS\DAN_Figs\WildRiceRiverr_FrequencyAnalysis


USGS 05064000 WILD RICE RIVER AT HENDRUM, MN
Average Flow Frequency Analysis (1979-2002)
Annual Average Water Year Flow (Inches)
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
100.0%
10.0%
1.0%
Probability (%)
Pearson Type III Fit
Weibull Plotting Position Data
95% Confidence Limits

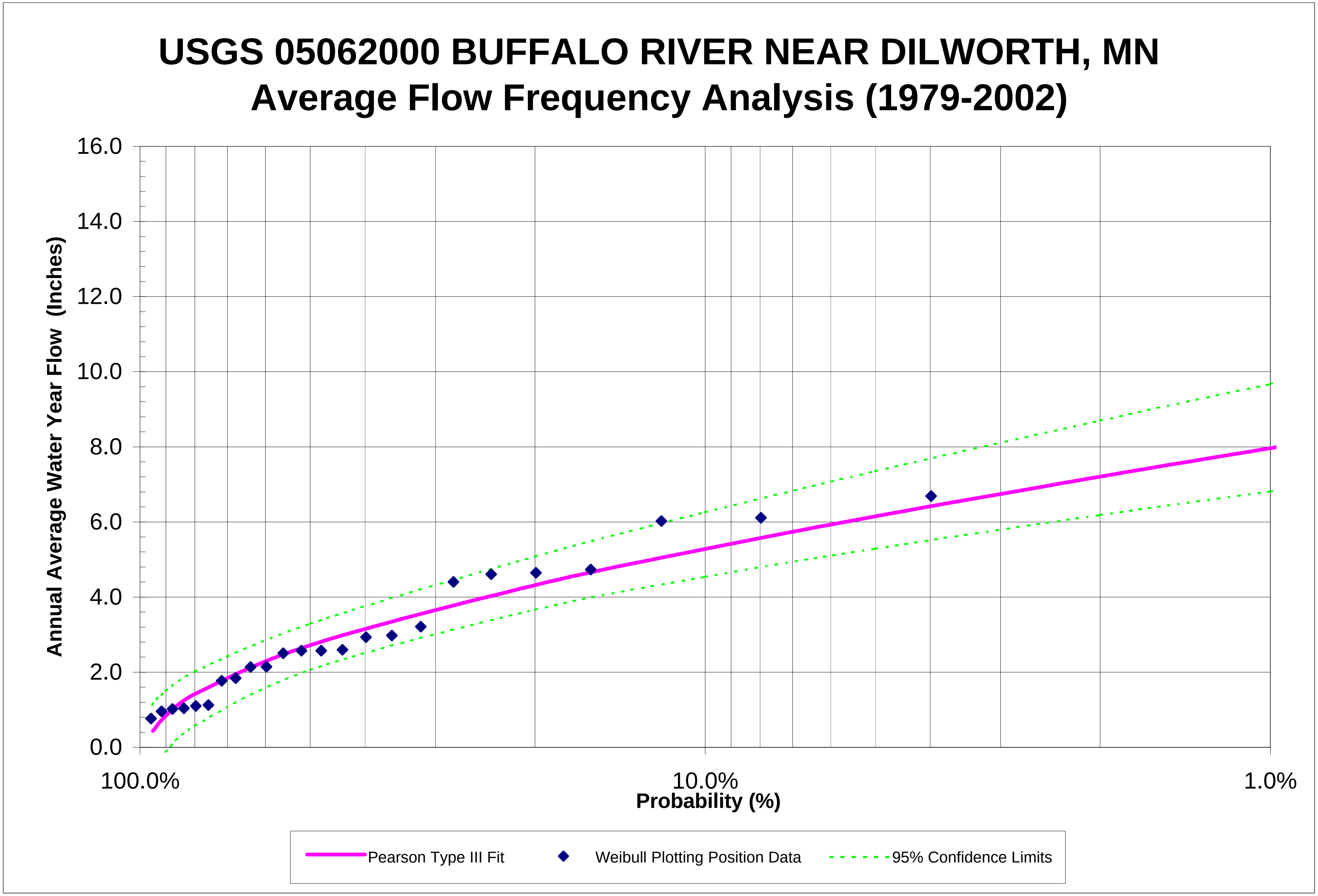


P:\23\62\853\Basin Hydrology_Mass Balance\WatershedData\USGS\DAN_Figs\BuffaloRiver_FrequencyAnalysis

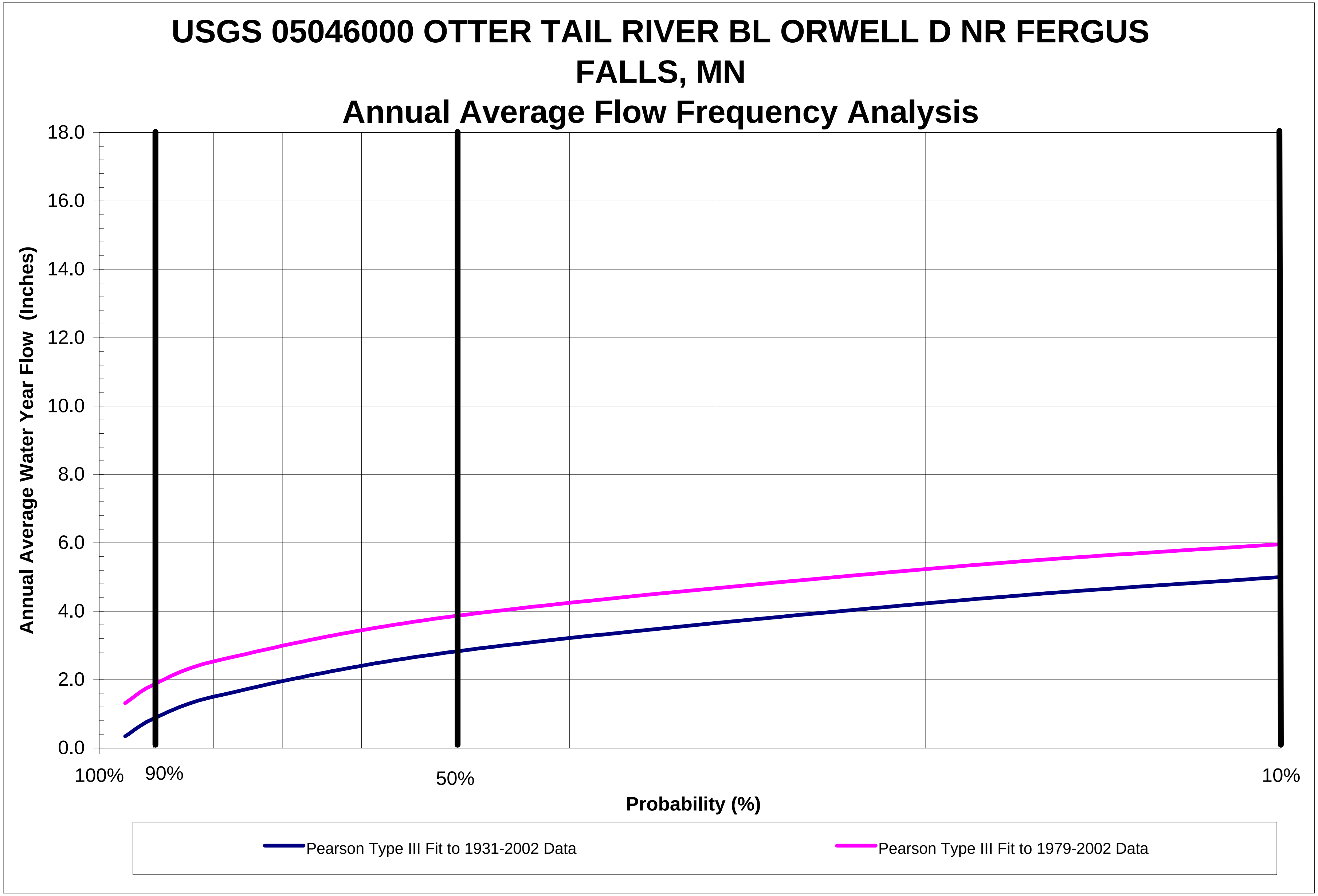
10/21/2003
9:34 AM



P:\23\62\853\Basin Hydrology_Mass Balance\WatershedData\USGS\DAN_Figs\BuffaloRiver_FrequencyAnalysis

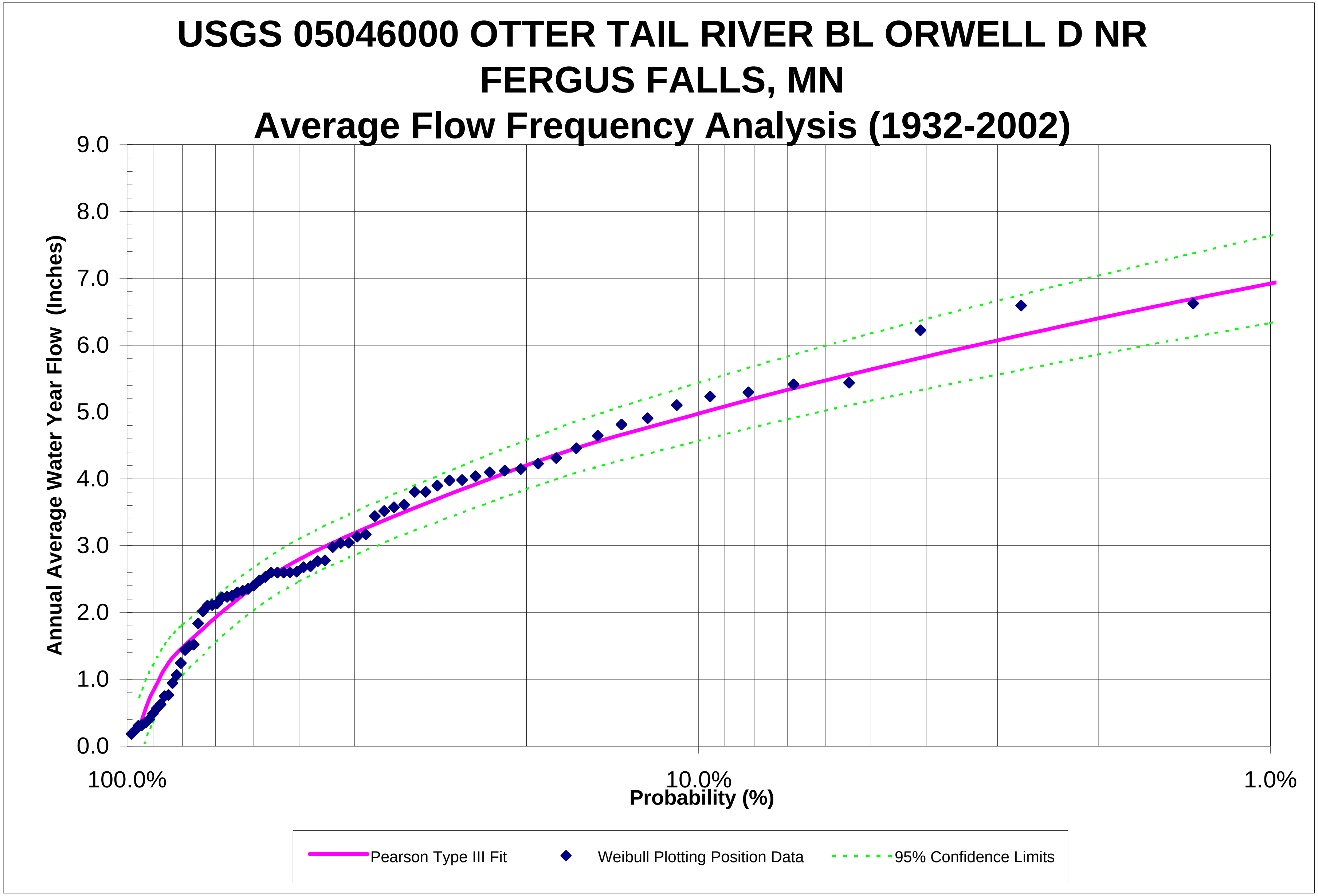


P:\23\62\853\Basin Hydrology_Mass Balance\WatershedData\USGS\DAN_Figs\BuffaloRiver_FrequencyAnalysis

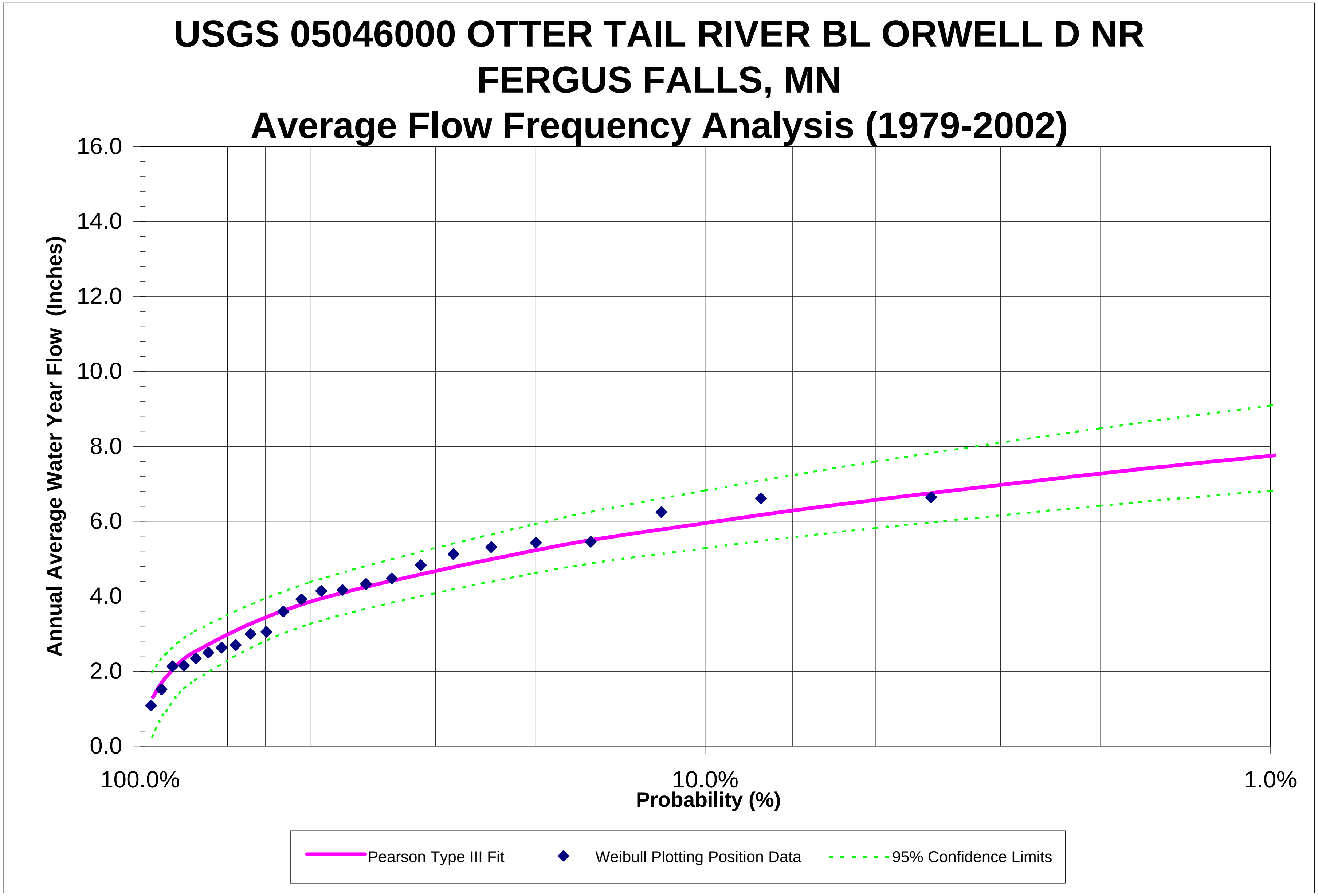


P:\23\62\853\Basin Hydrology_Mass Balance\WatershedData\USGS\DAN_Figs\OttertailRiver_FrequencyAnalysis

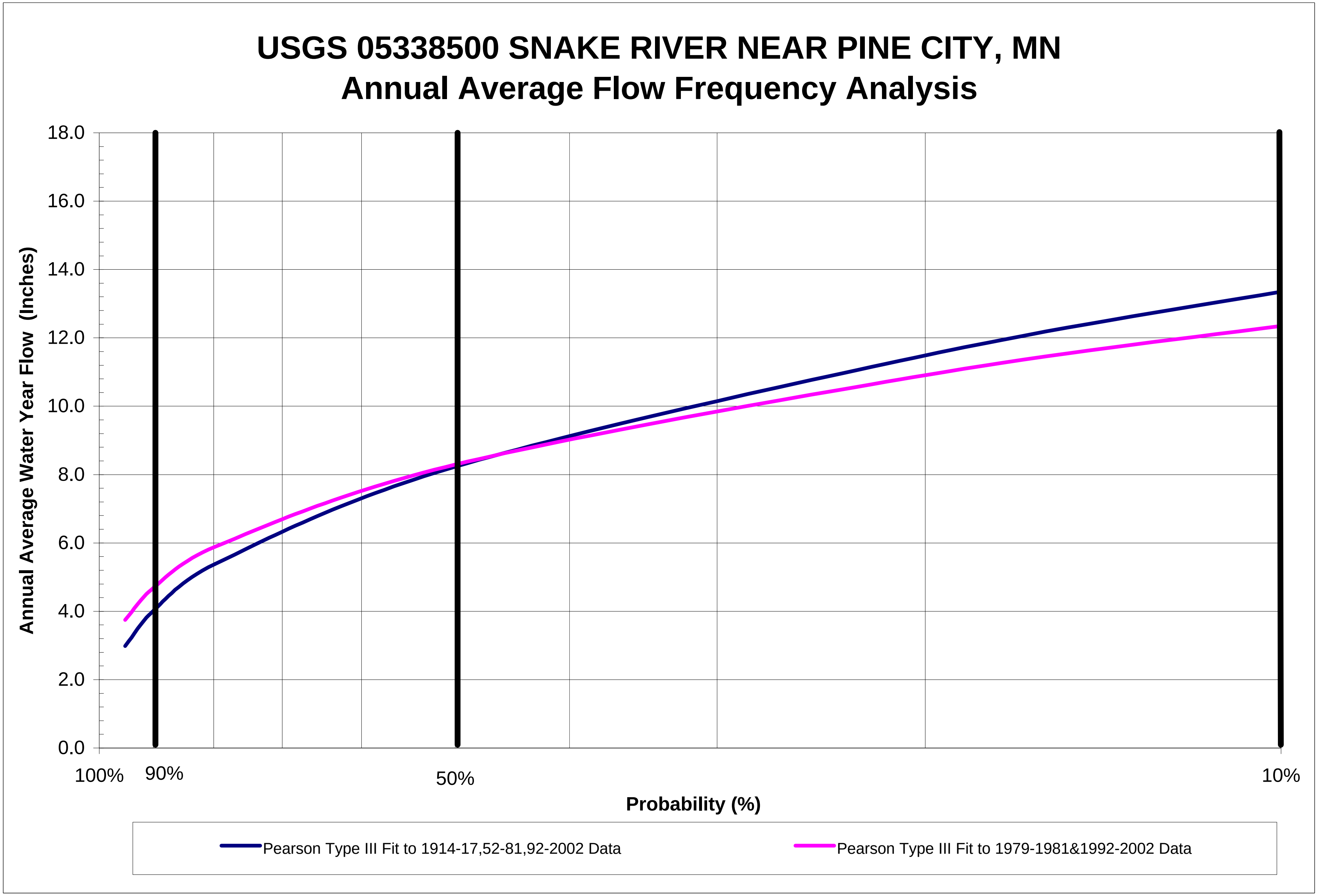
10/21/2003
9:35 AM



P:\23\62\853\Basin Hydrology_Mass Balance\WatershedData\USGS\DAN_Figs\OttertailRiver_FrequencyAnalysis



P:\23\62\853\Basin Hydrology_Mass Balance\WatershedData\USGS\DAN_Figs\OttertailRiver_FrequencyAnalysis



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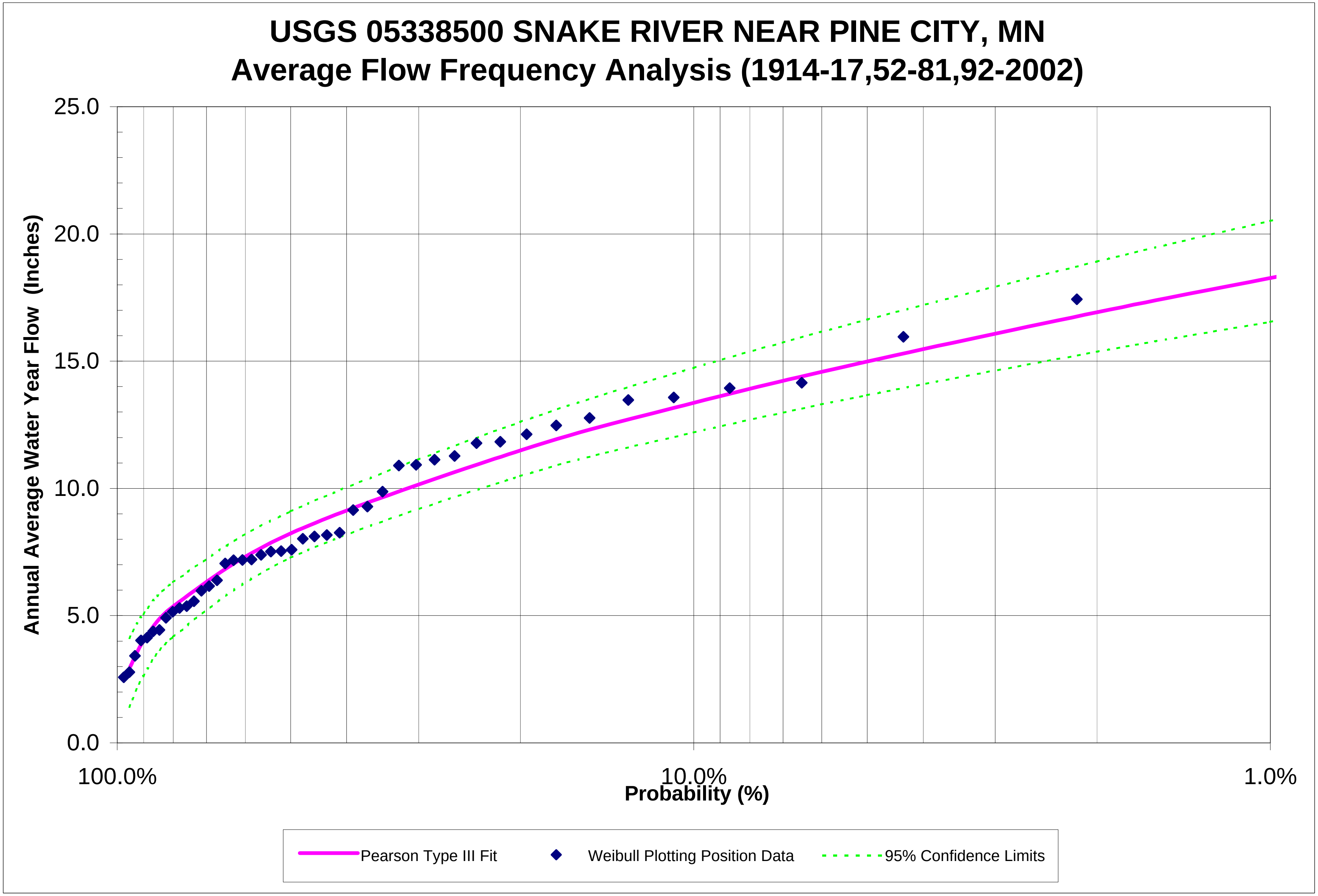
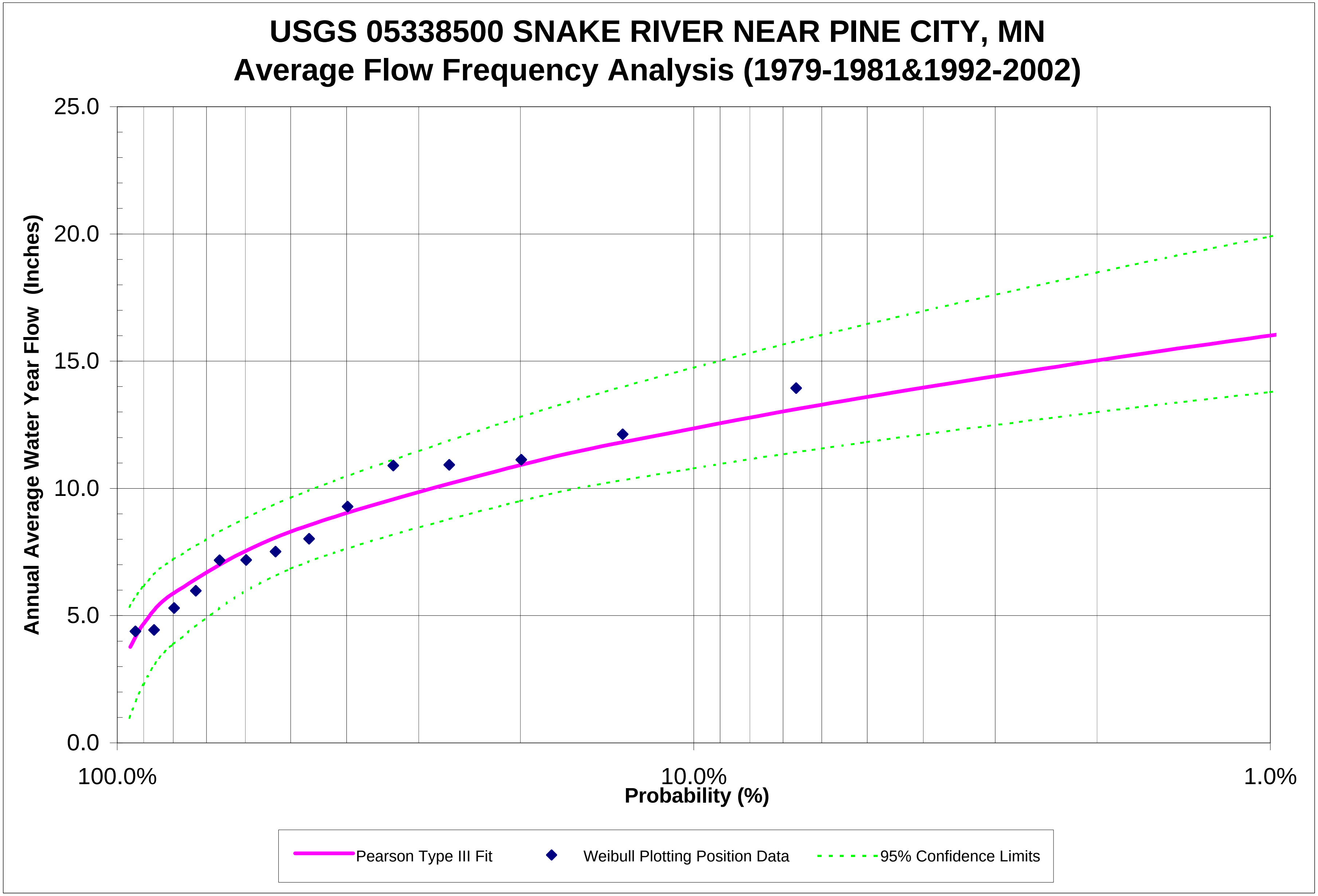
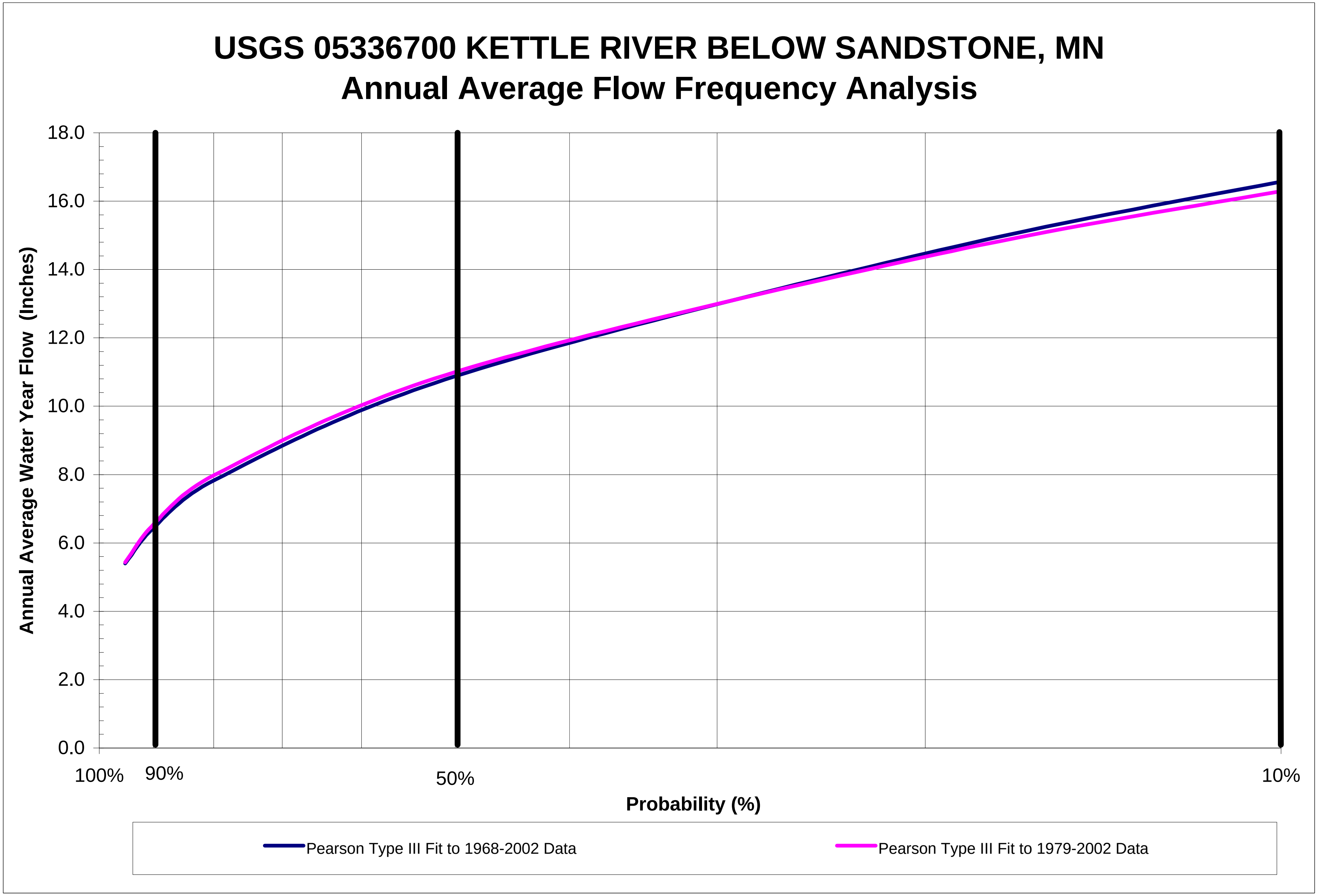
10/21/2003
9:37 AM

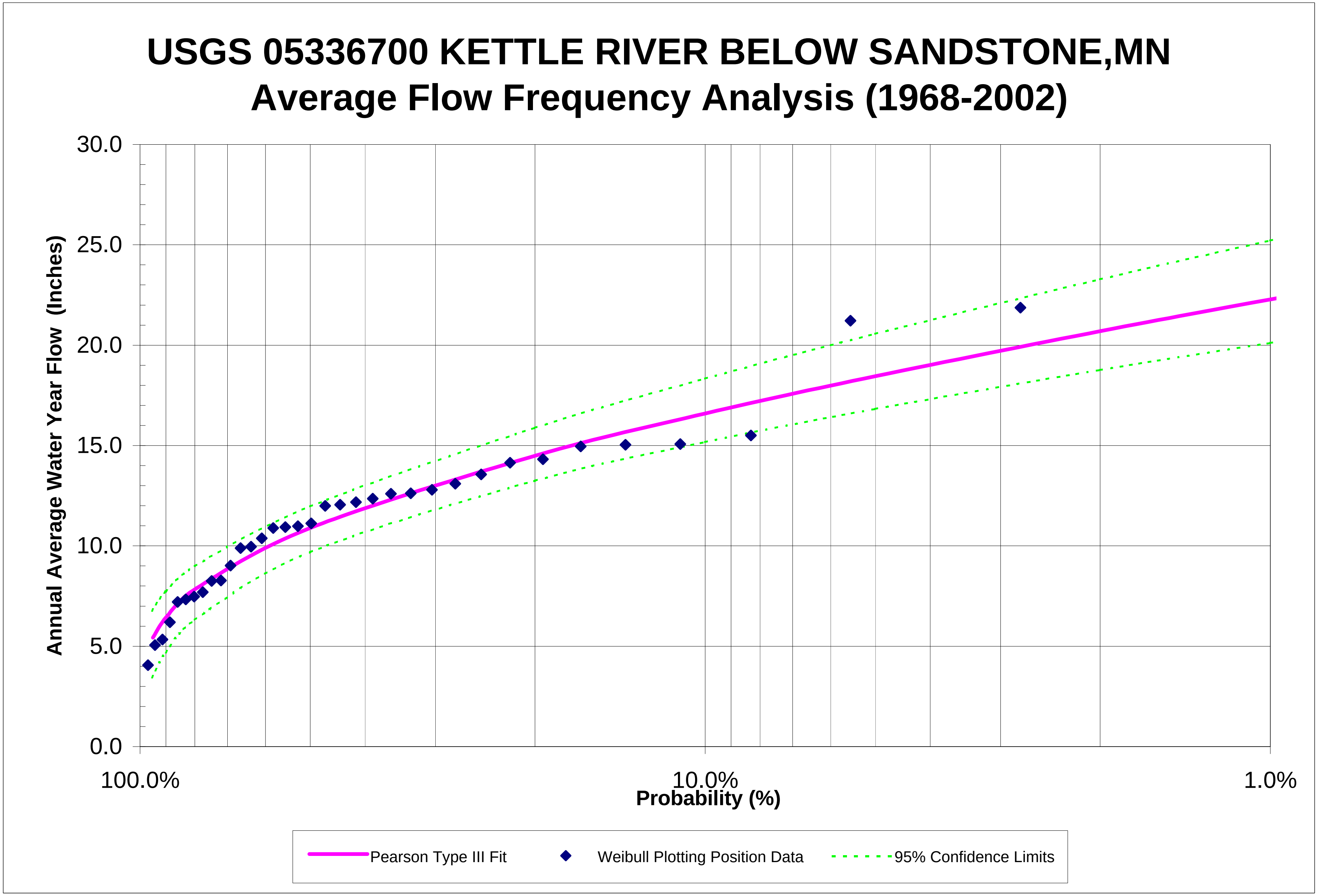


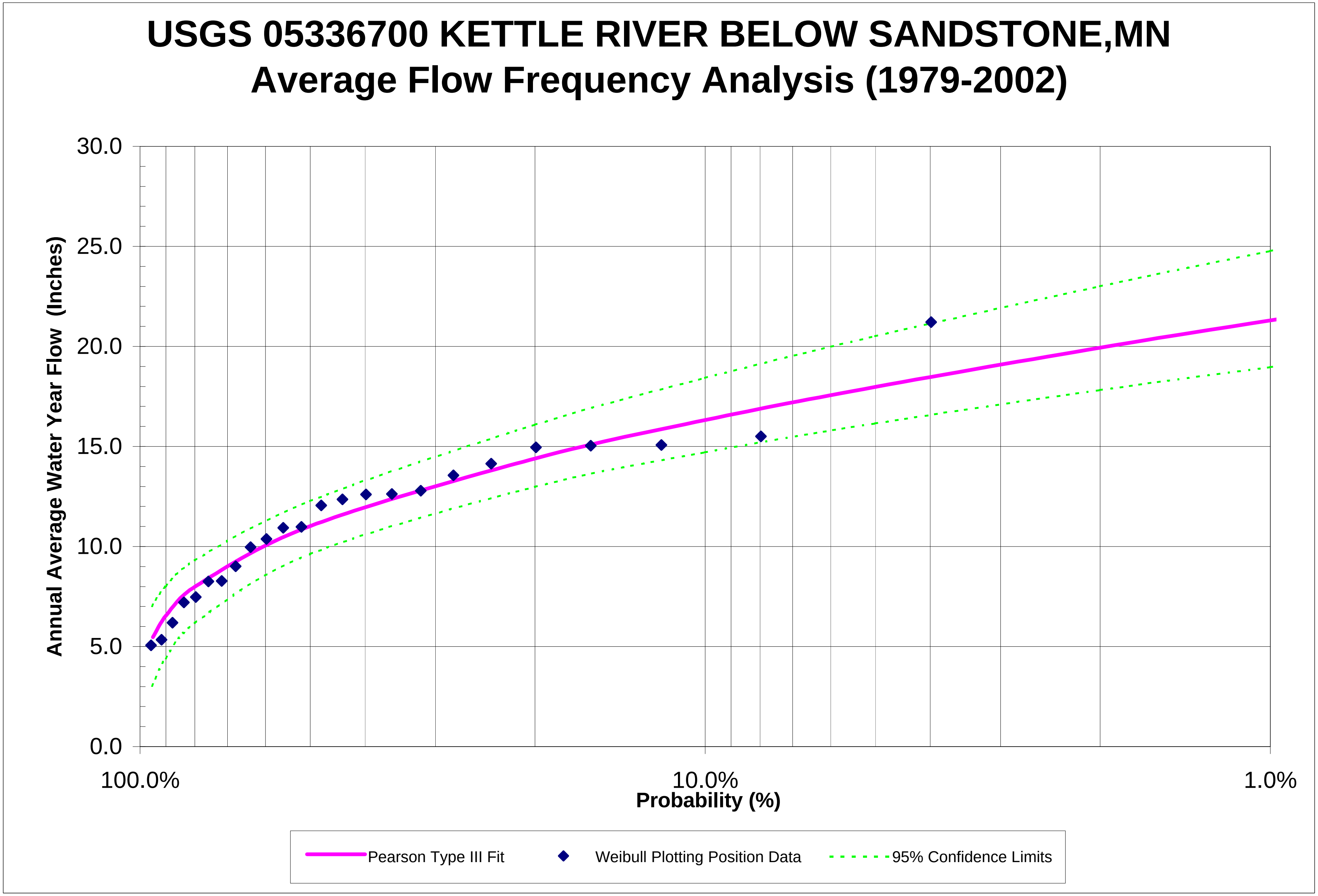
P:\23\62\853\Basin Hydrology_Mass Balance\WatershedData\USGS\DAN_Figs\SnakeRiver_FrequencyAnalysis



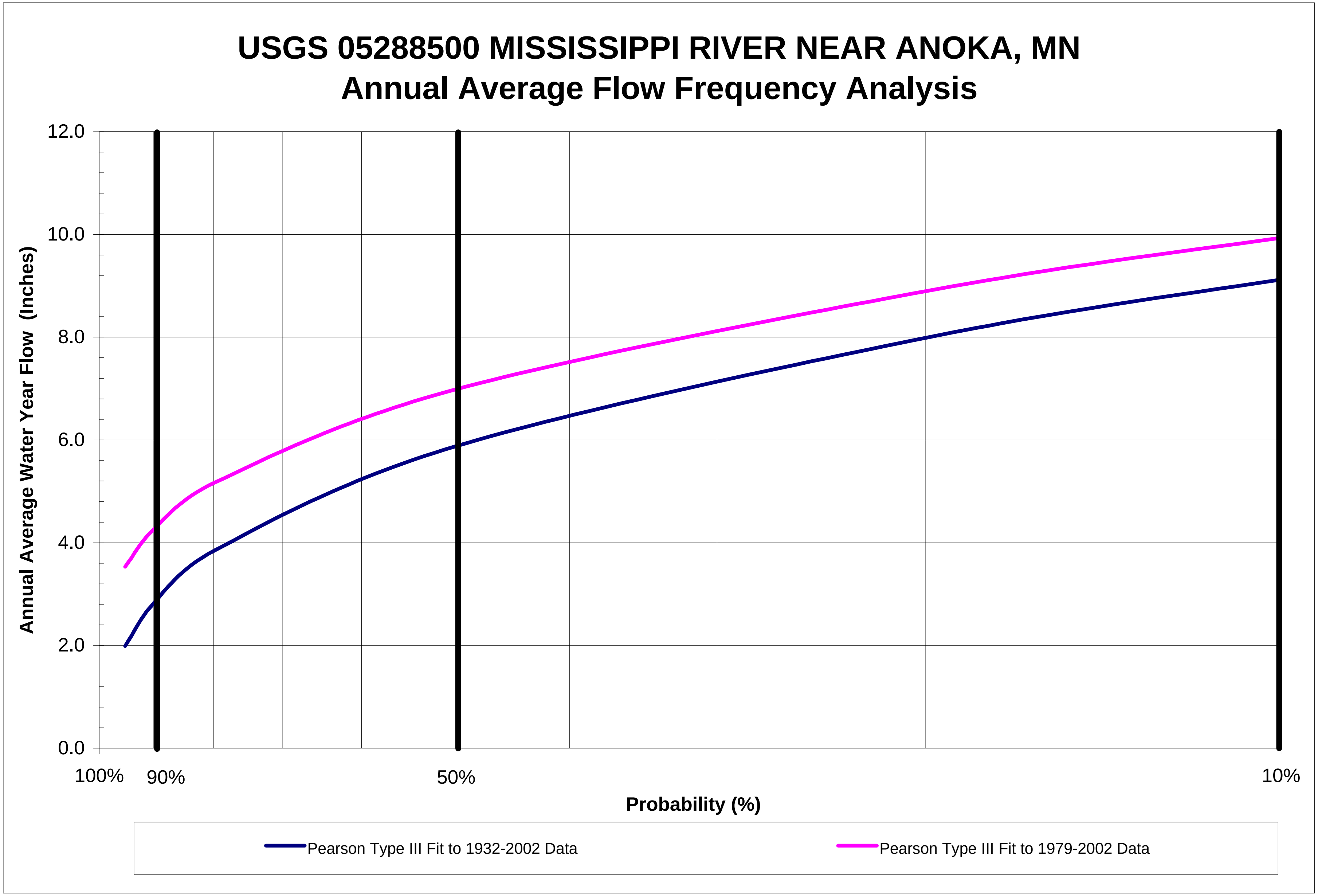
P:\23\62\853\Basin Hydrology_Mass Balance\WatershedData\USGS\DAN_Figs\SnakeRiver_FrequencyAnalysis


USGS 05336700 KETTLE RIVER BELOW SANDSTONE, MN
Annual Average Flow Frequency Analysis
Annual Average Water Year Flow (Inches)
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
100%
90%
50%
10%
Probability (%)
Pearson Type III Fit to 1968-2002 Data
Pearson Type III Fit to 1979-2002 Data


USGS 05336700 KETTLE RIVER BELOW SANDSTONE,MN
Average Flow Frequency Analysis (1968-2002)
30.0
25.0
20.0
15.0
10.0
5.0
0.0
Annual Average Water Year Flow (Inches)
100.0%
10.0%
1.0%
Probability (%)
Pearson Type III Fit
Weibull Plotting Position Data
95% Confidence Limits

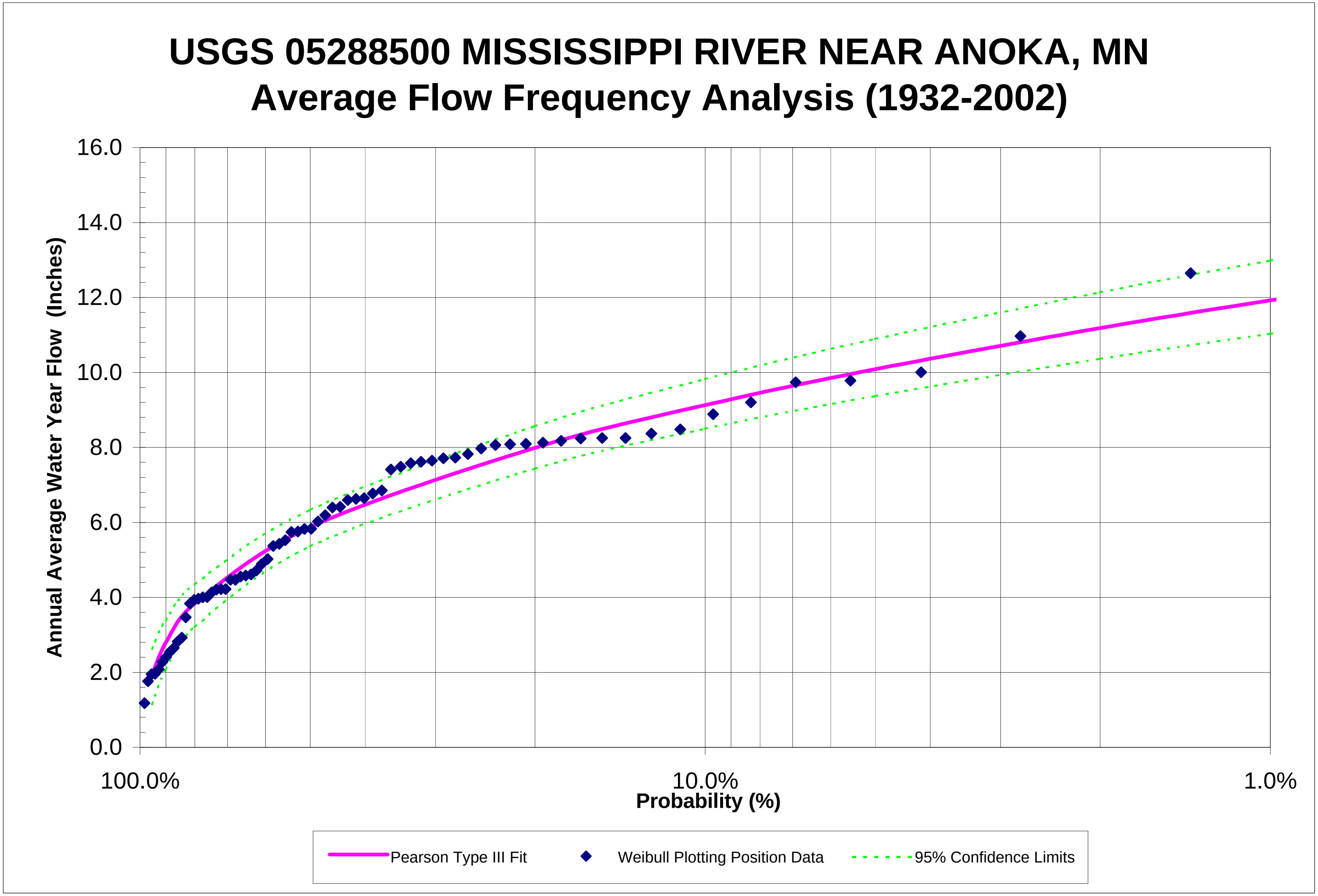


P:\23\62\853\Basin Hydrology_Mass Balance\WatershedData\USGS\DAN_Figs\KettleRiver_FrequencyAnalysis

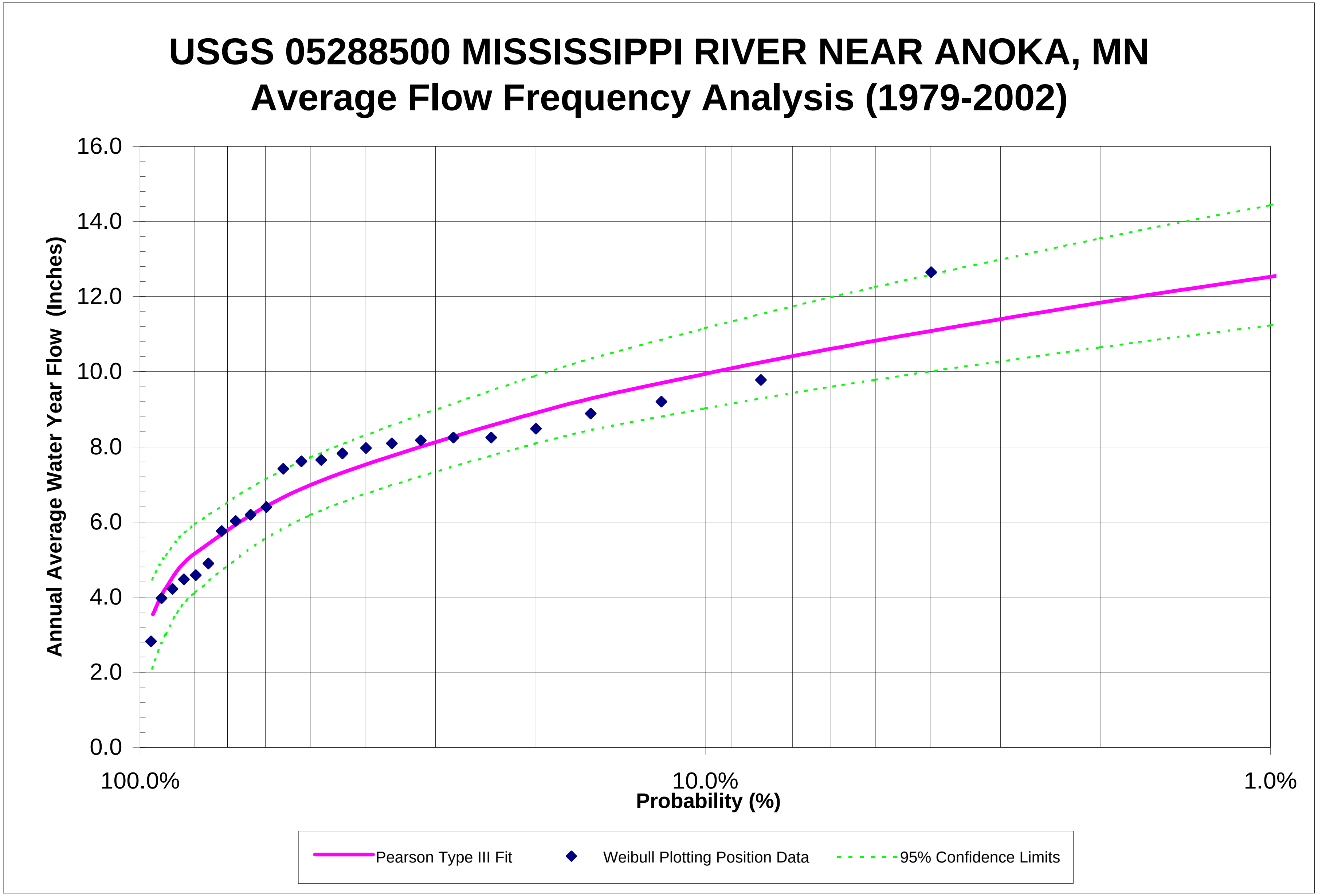


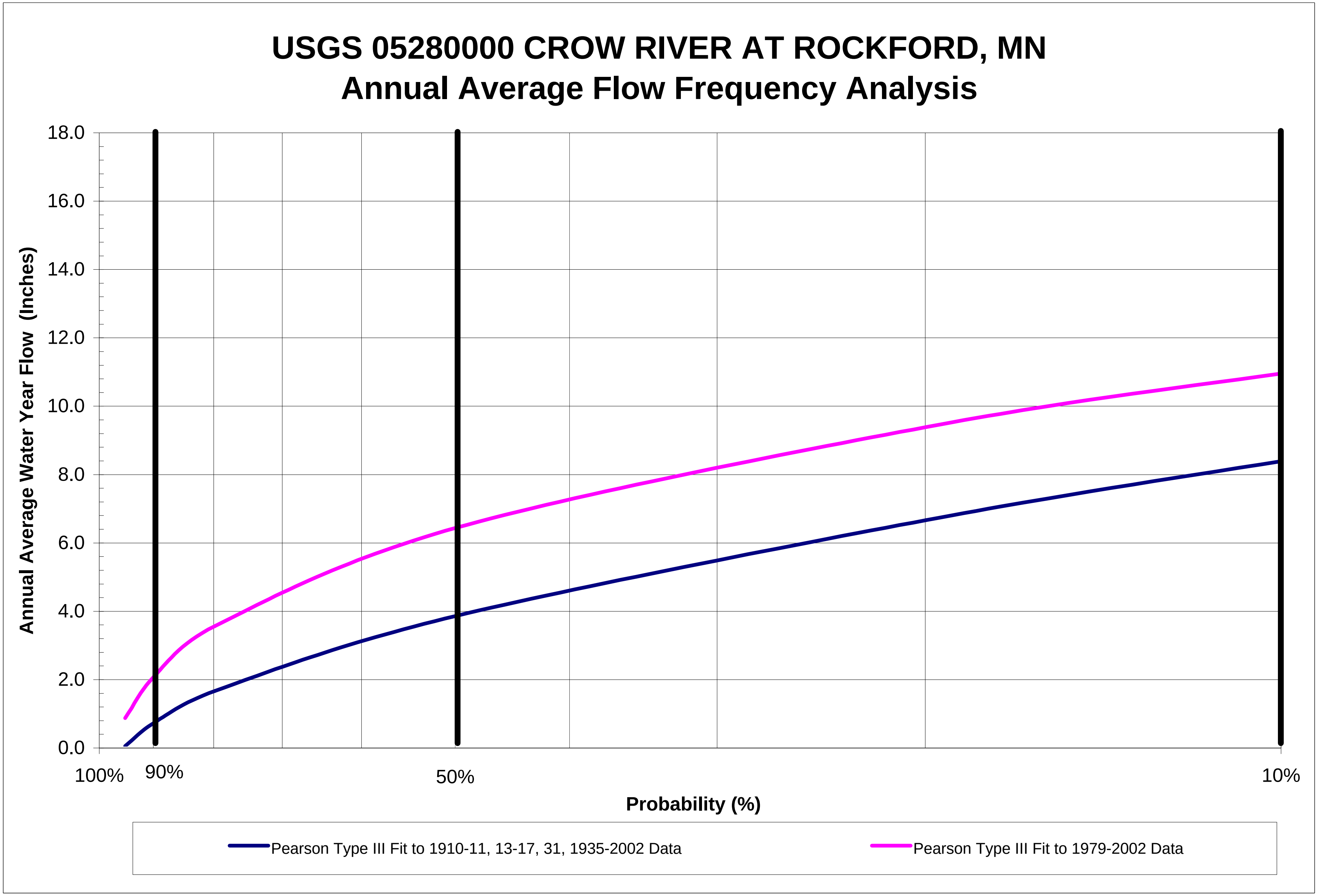
P:\23\62\853\Basin Hydrology_Mass Balance\MississippiRiver_FrequencyAnalysis.xls

10/21/2003
9:39 AM

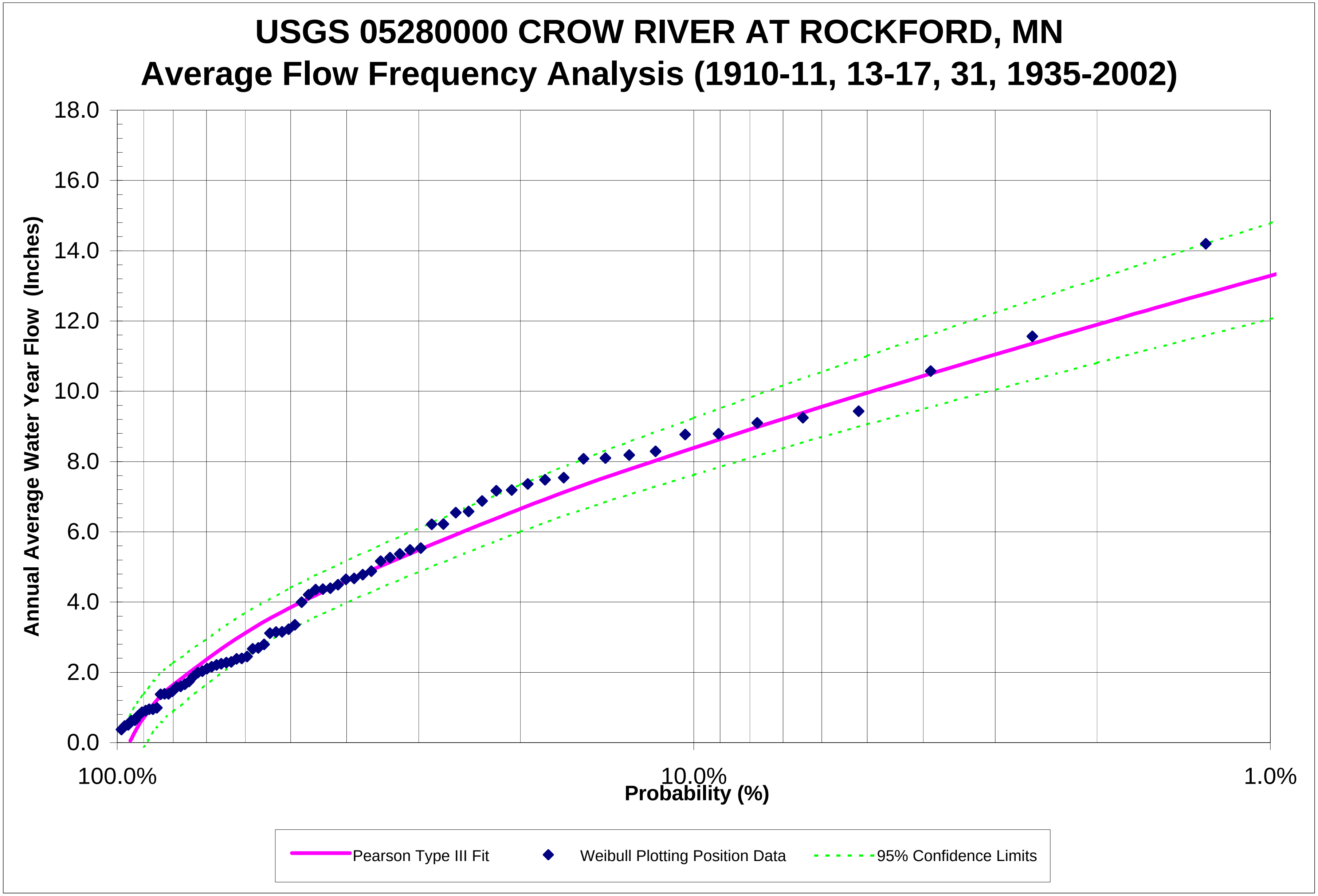


P:\23\62\853\Basin Hydrology_Mass Balance\MississippiRiver_FrequencyAnalysis

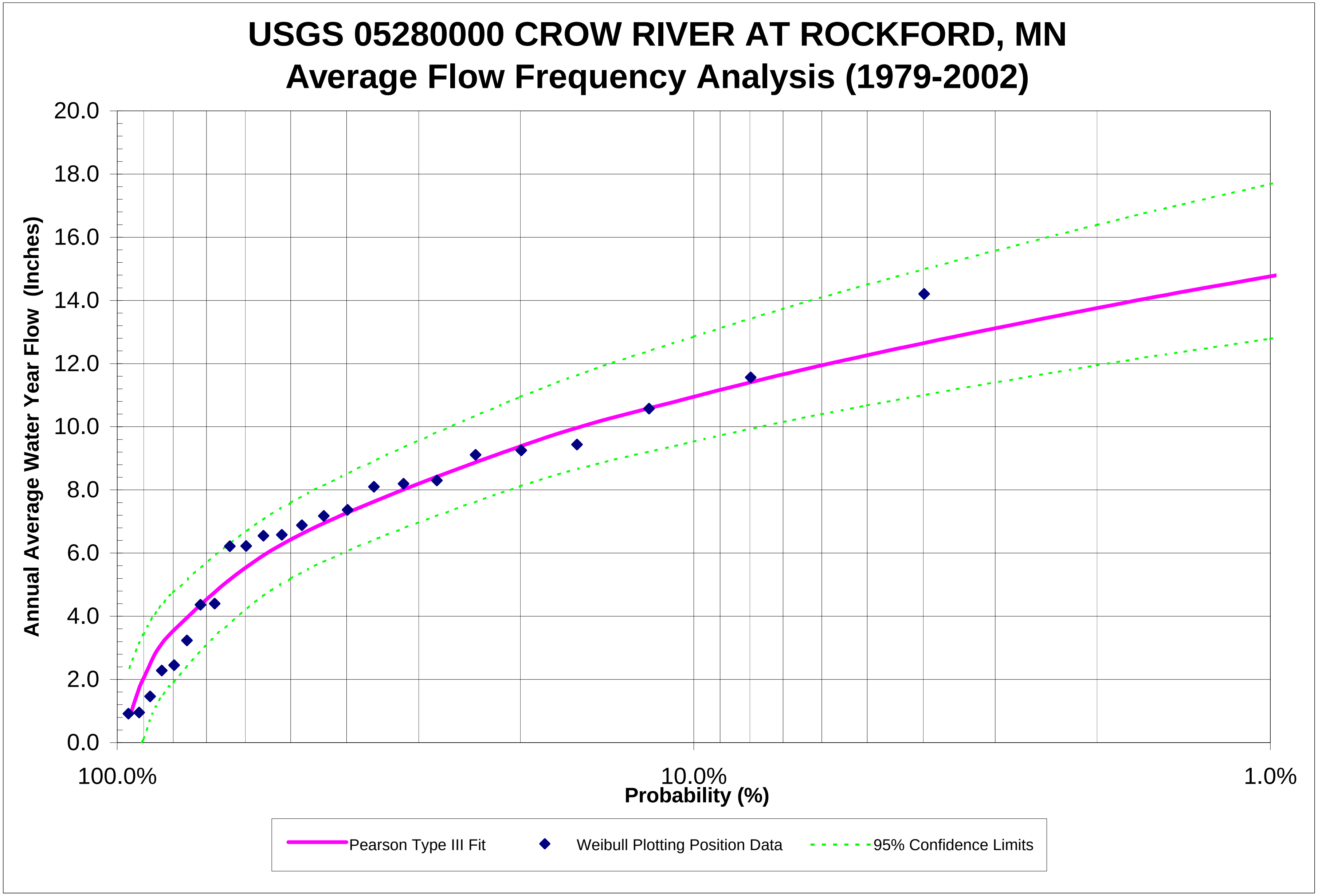

USGS 05288500 MISSISSIPPI RIVER NEAR ANOKA, MN
Average Flow Frequency Analysis (1979-2002)
Annual Average Water Year Flow (Inches)
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
100.0%
10.0%
1.0%
Probability (%)
Pearson Type III Fit
Weibull Plotting Position Data
95% Confidence Limits



USGS 05280000 CROW RIVER AT ROCKFORD, MN
Annual Average Flow Frequency Analysis
Annual Average Water Year Flow (Inches)
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
100%
90%
50%
10%
Probability (%)
Pearson Type III Fit to 1910-11, 13-17, 31, 1935-2002 Data
Pearson Type III Fit to 1979-2002 Data



P:\23\62\853\Basin Hydrology_Mass Balance\WatershedData\USGS\DAN_Figs\CrowRiver_FrequencyAnalysis



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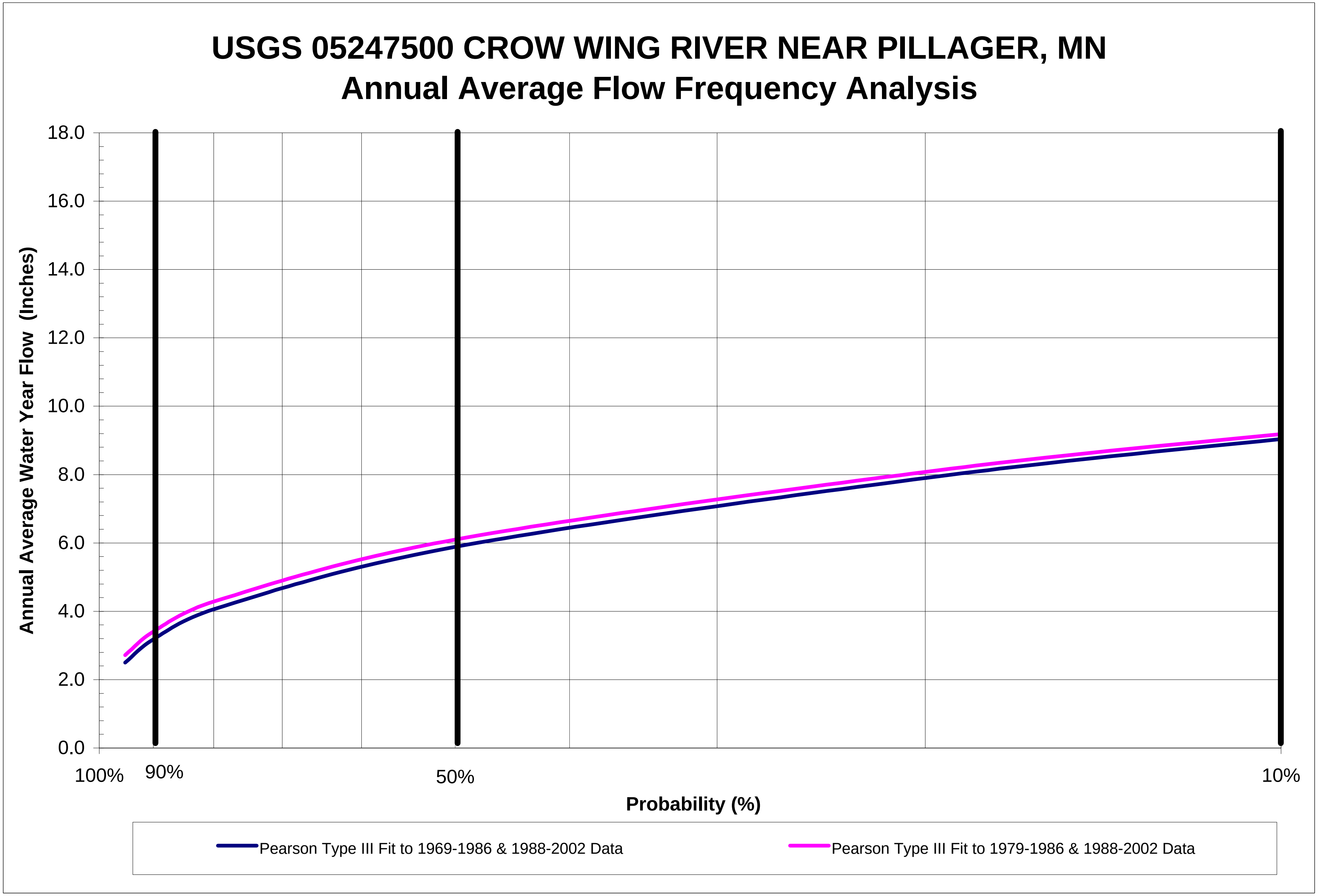
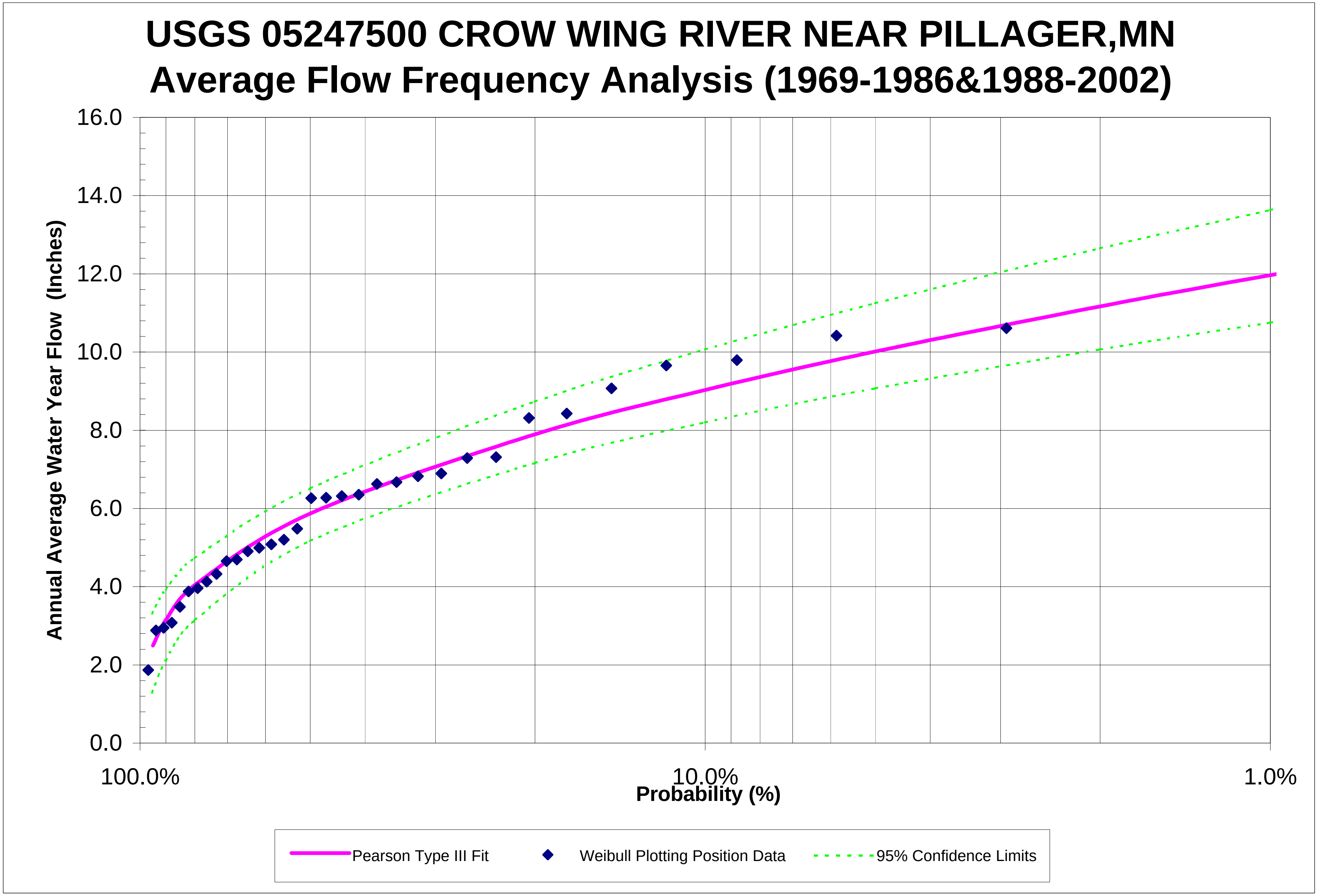
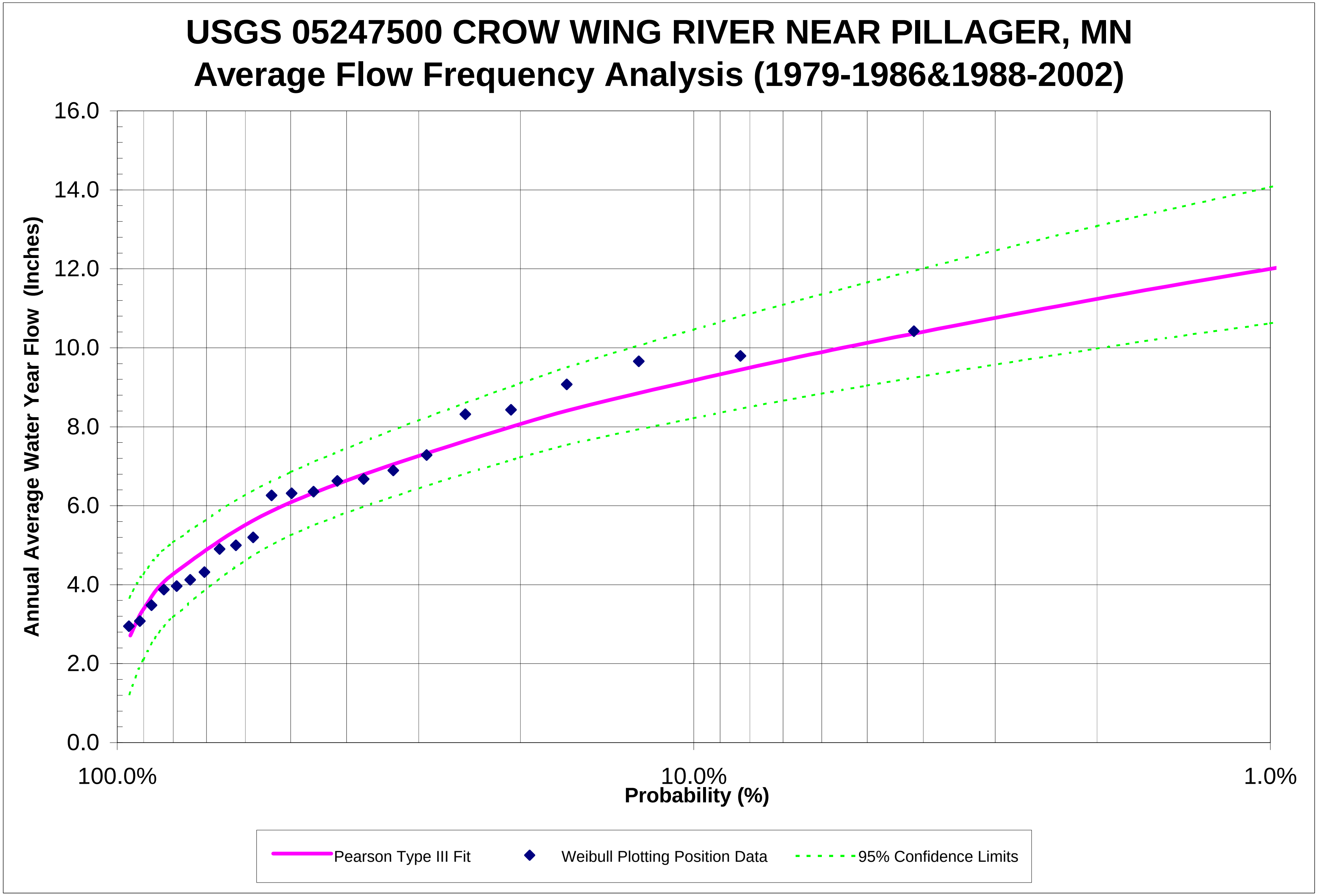


P:\23\62\853\Basin Hydrology_Mass Balance\WatershedData\USGS\DAN_Figs\CrowWingRiver_FrequencyAnalysis

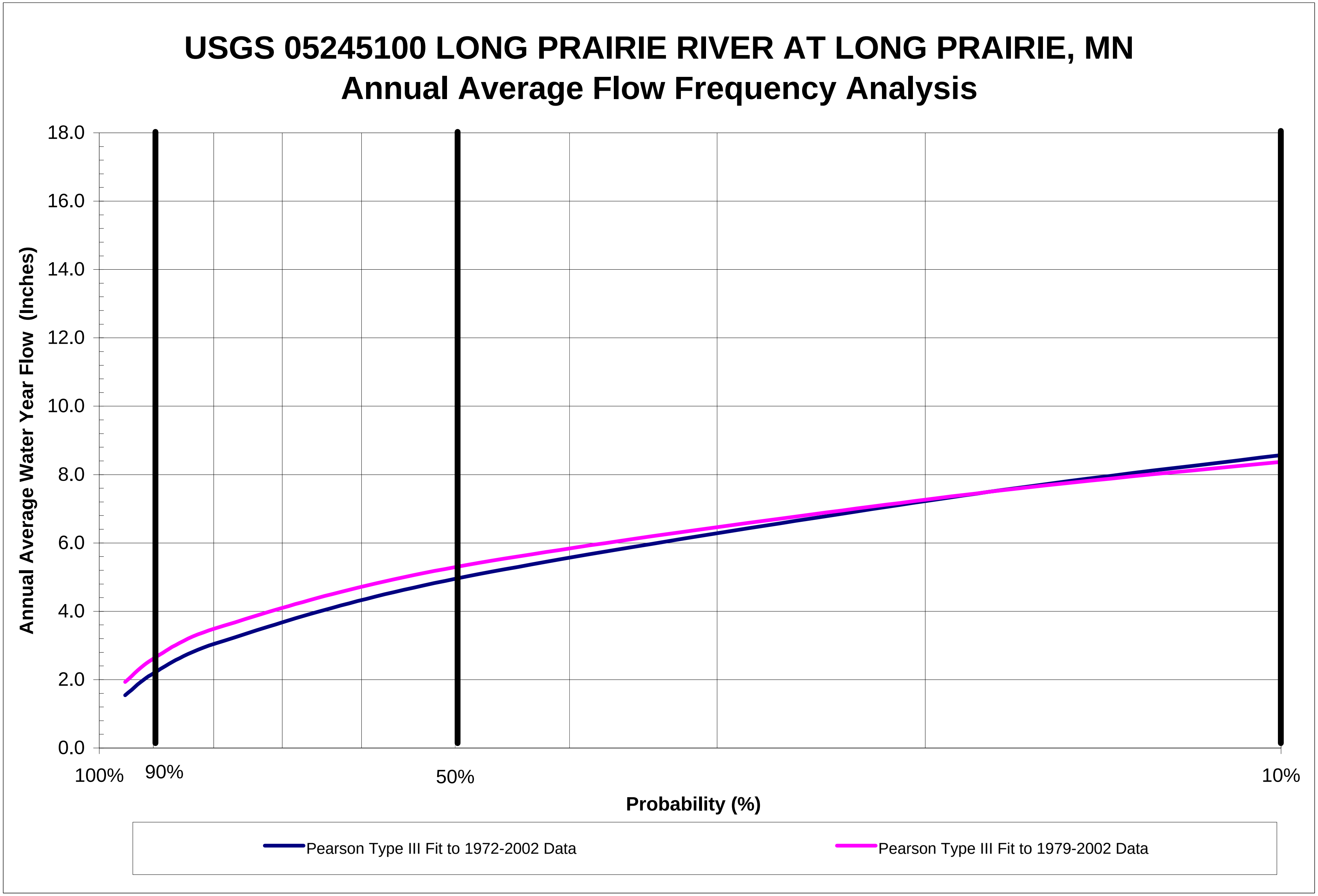
10/21/2003
9:42 AM



P:\23\62\853\Basin Hydrology_Mass Balance\WatershedData\USGS\DAN_Figs\CrowWingRiver_FrequencyAnalysis

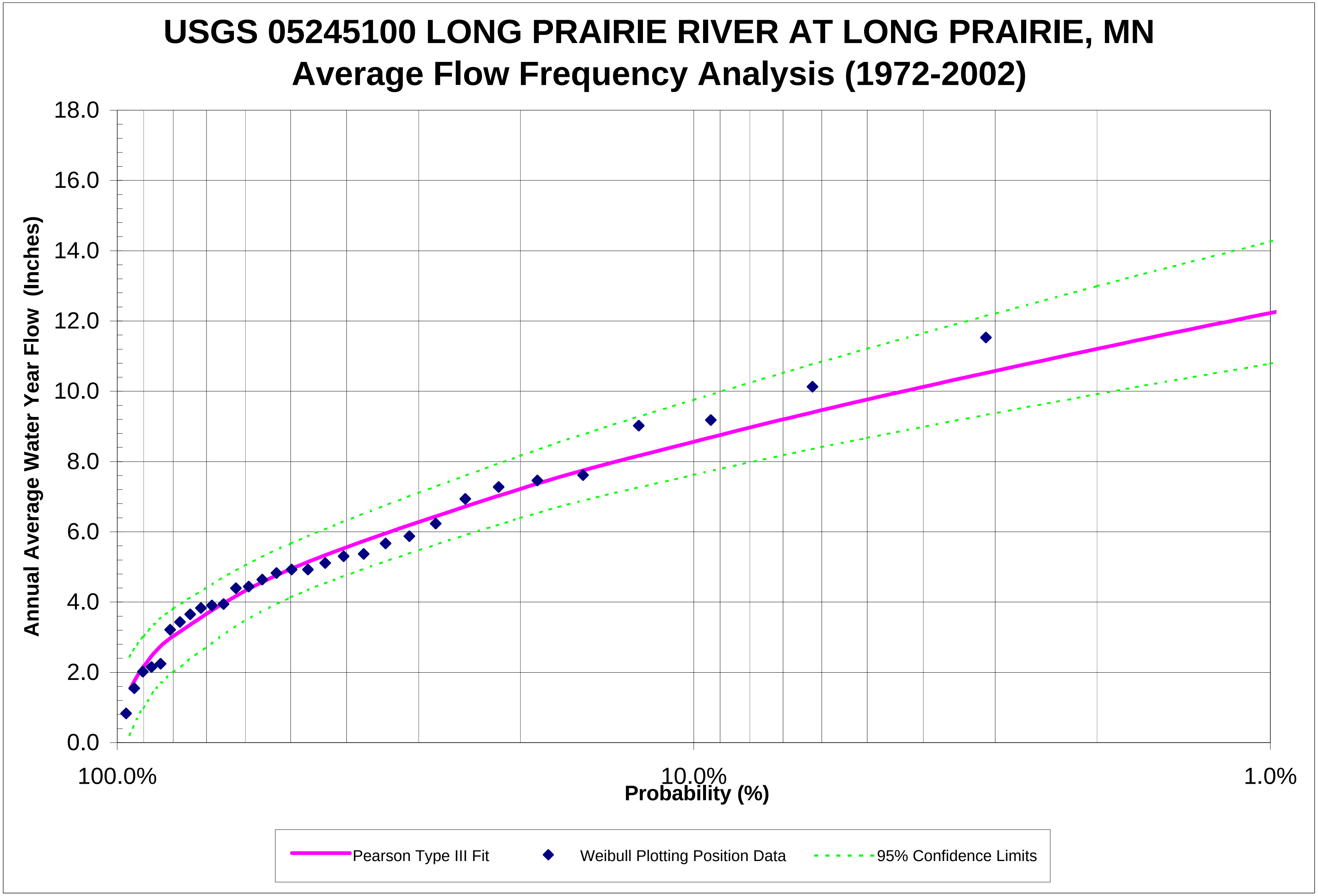


P:\23\62\853\Basin Hydrology_Mass Balance\WatershedData\USGS\DAN_Figs\CrowWingRiver_FrequencyAnalysis

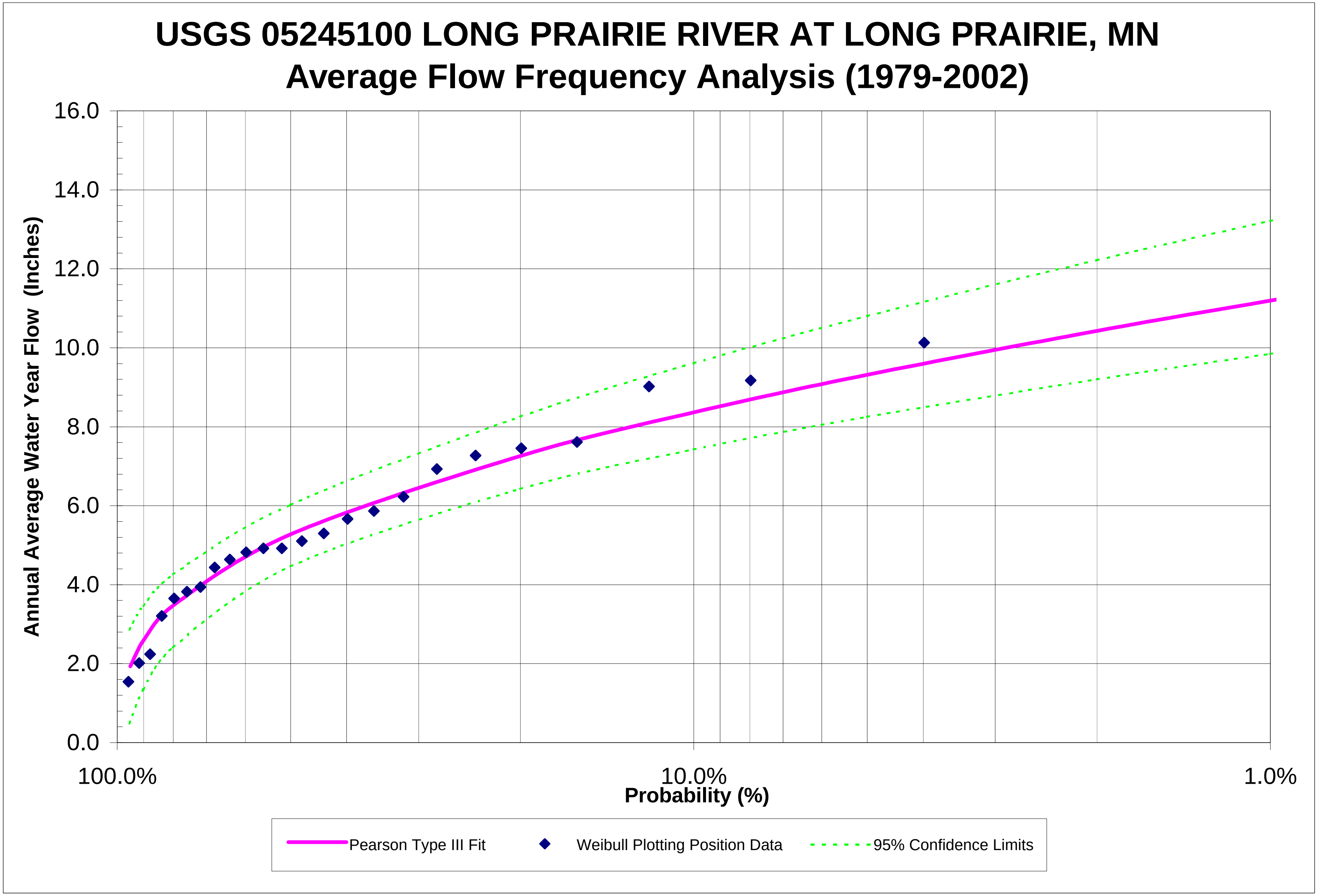


P:\23\62\853\Basin Hydrology_Mass Balance\WatershedData\USGS\DAN_Figs\LongPrairieRiver_FrequencyAnalysis

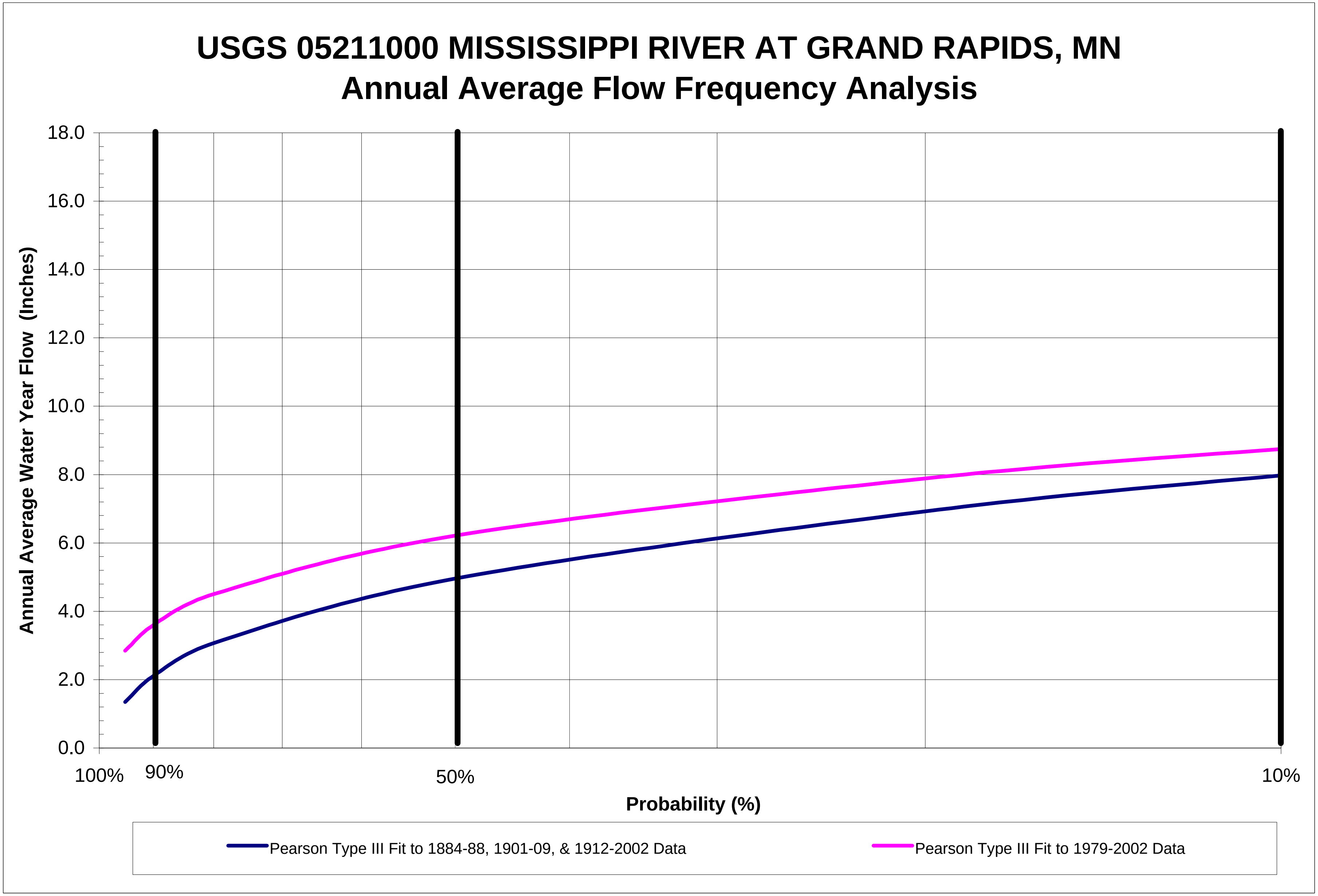
10/21/2003
9:43 AM



P:\23\62\853\Basin Hydrology_Mass Balance\WatershedData\USGS\DAN_Figs\LongPrairieRiver_FrequencyAnalysis

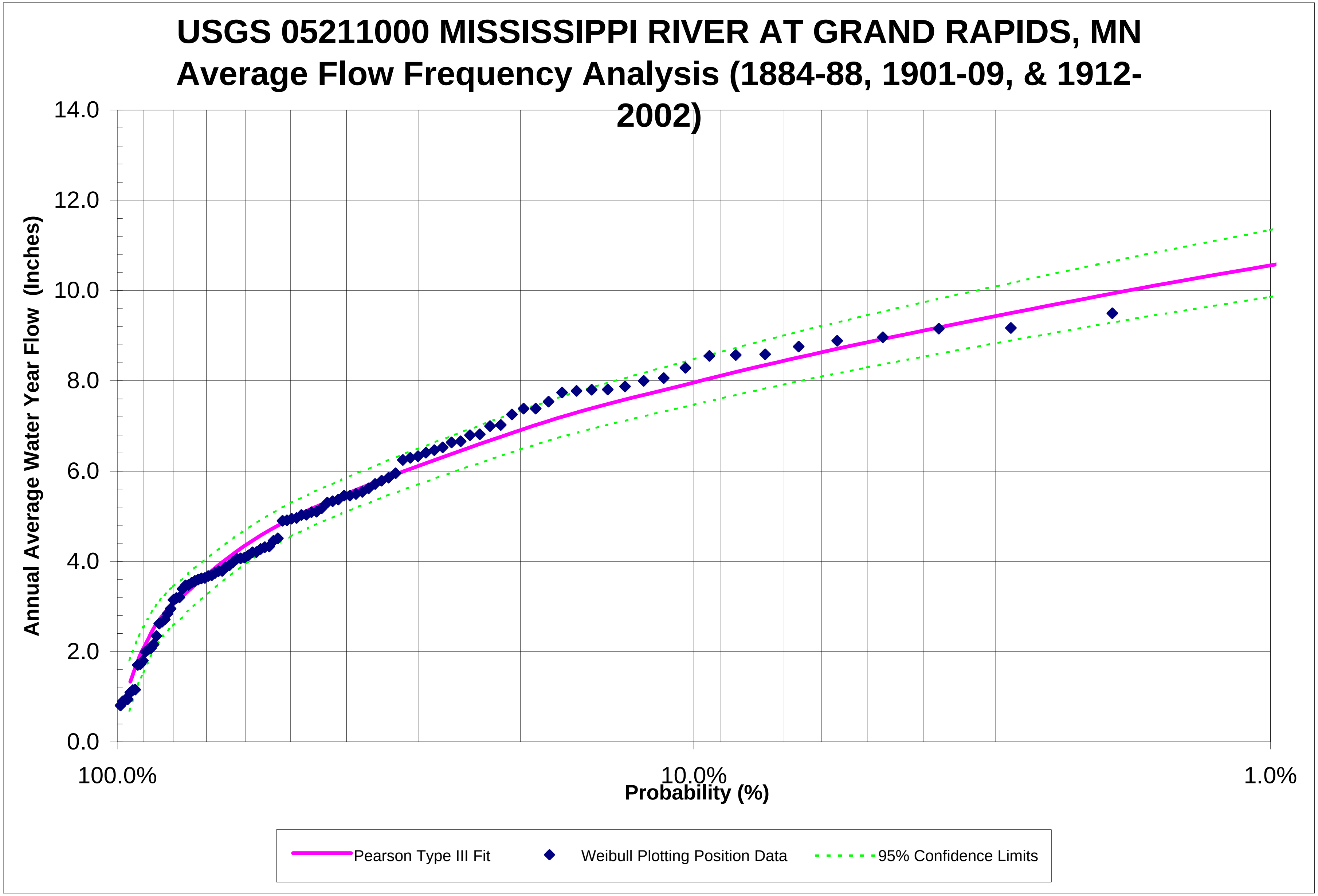


P:\23\62\853\Basin Hydrology_Mass Balance\WatershedData\USGS\DAN_Figs\LongPrairieRiver_FrequencyAnalysis

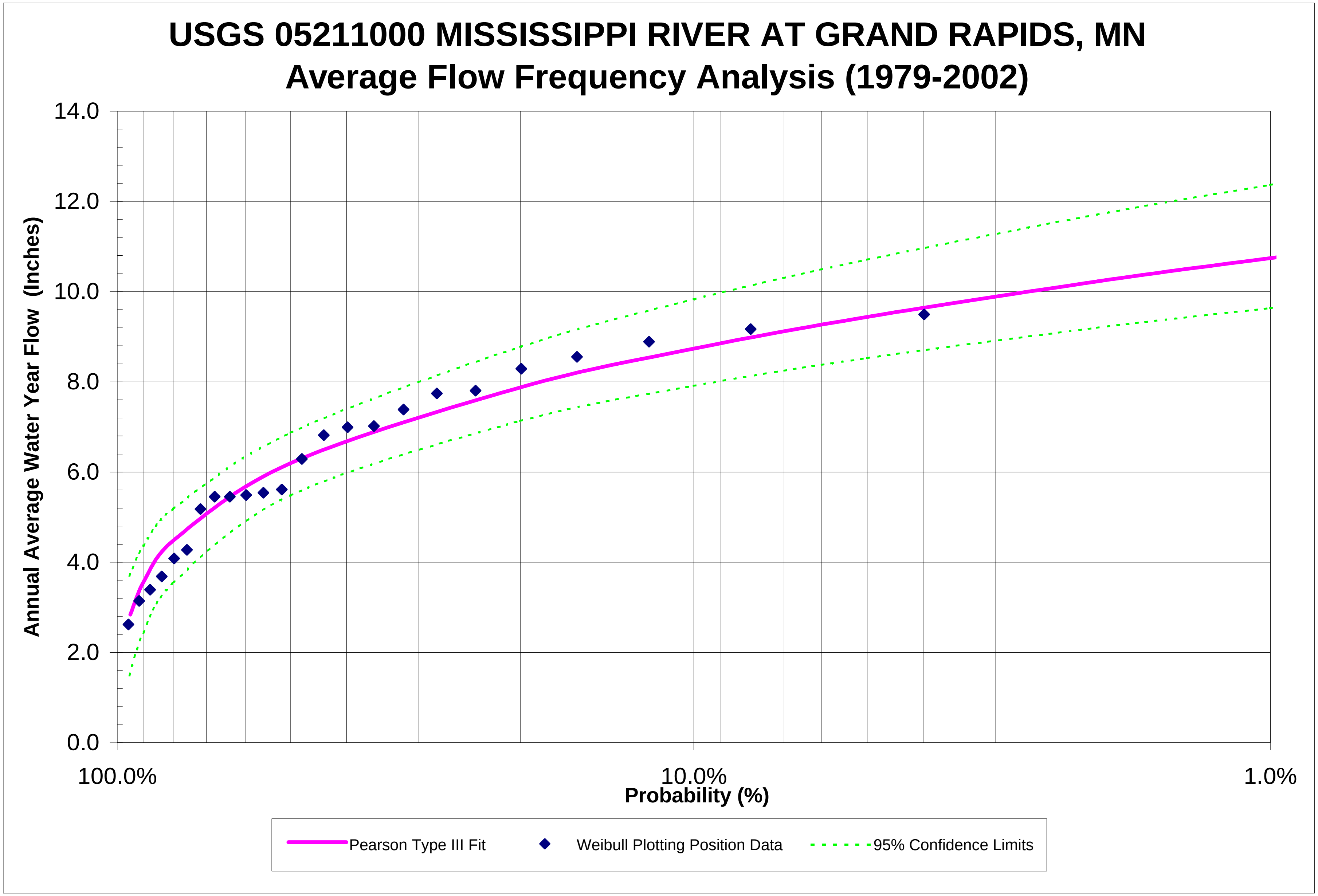


P:\23\62\853\Basin Hydrology_Mass Balance\WatershedData\USGS\DAN_Figs\MississippiRiver_FrequencyAnalysis

10/21/2003
9:45 AM

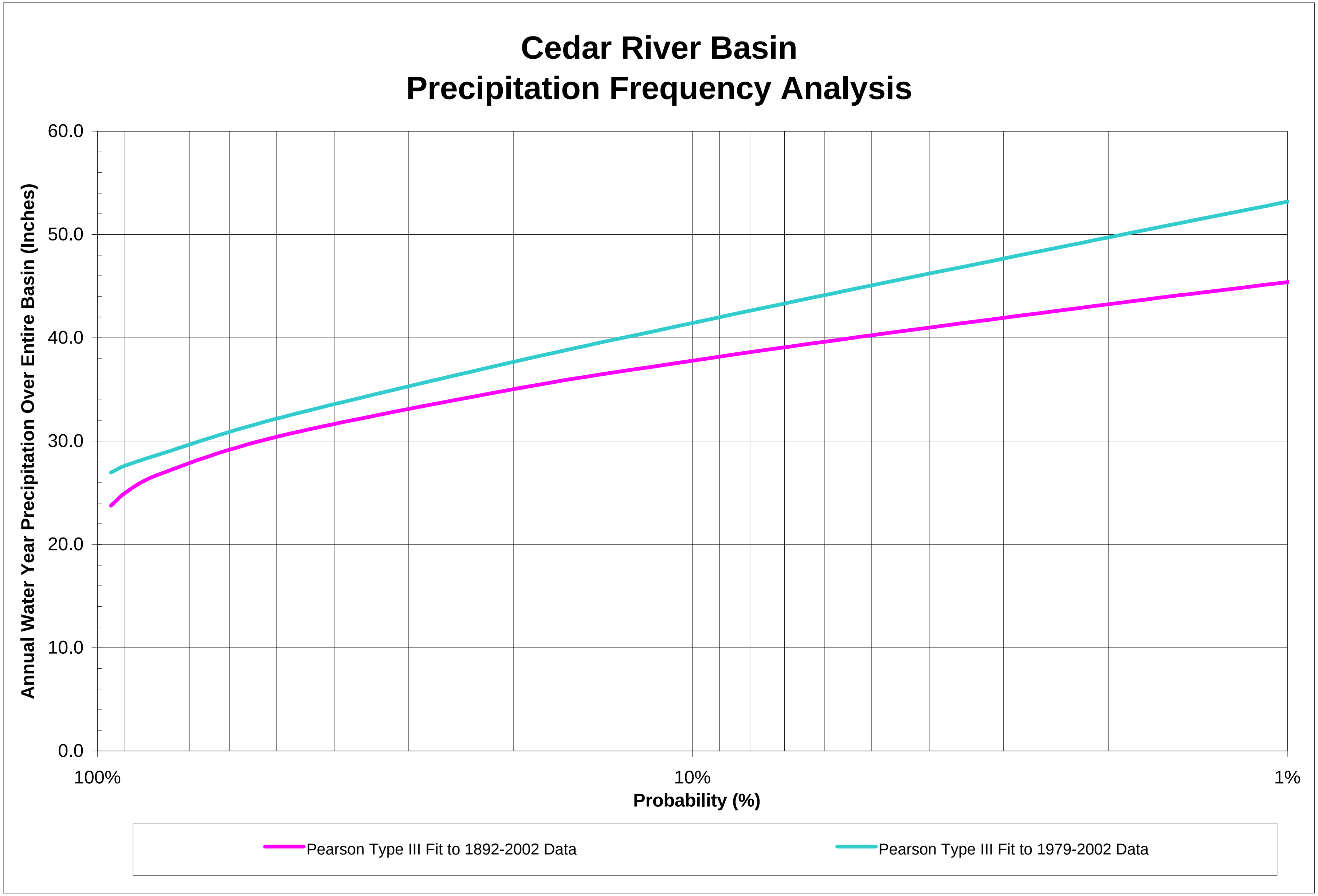


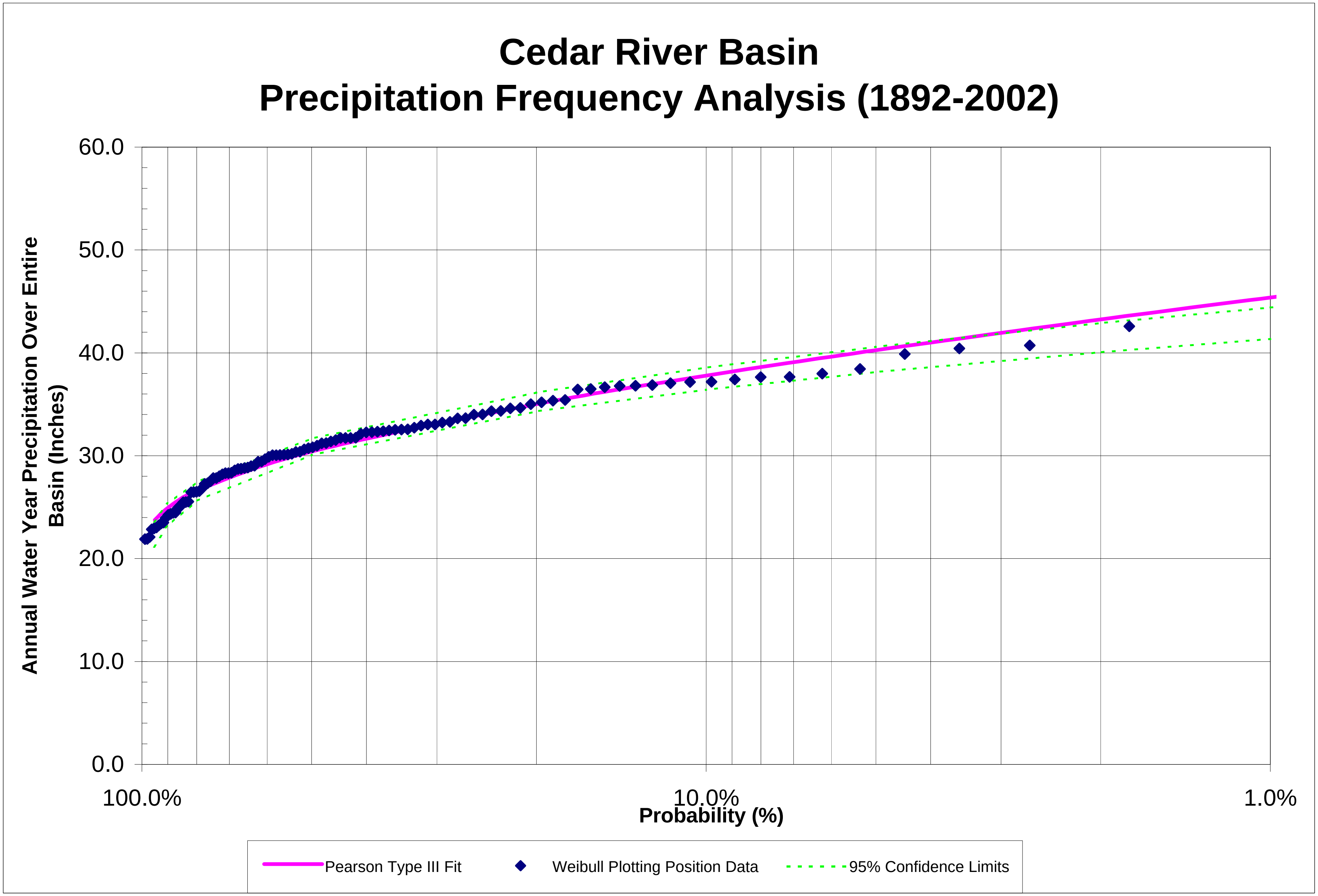
P:\23\62\853\Basin Hydrology_Mass Balance\WatershedData\USGS\DAN_Figs\MississippiRiver_FrequencyAnalysis



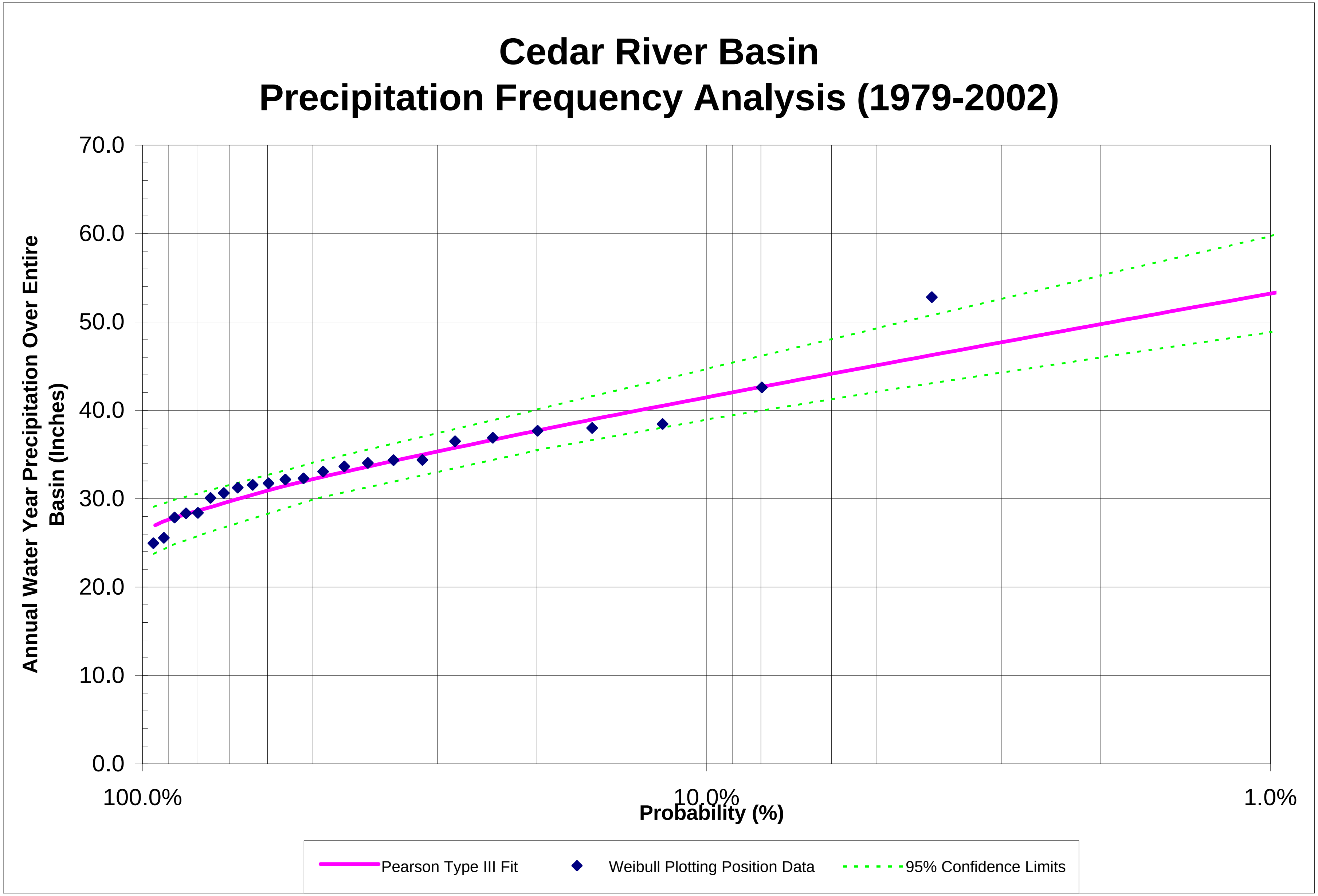
P:\23\62\853\Basin Hydrology_Mass Balance\WatershedData\USGS\DAN_Figs\MississippiRiver_FrequencyAnalysis

Appendix B: Precipitation – Frequency Curves


Cedar River Basin
Precipitation Frequency Analysis
Annual Water Year Precipitation Over Entire Basin (Inches)
60.0
50.0
40.0
30.0
20.0
10.0
0.0
100%
10%
1%
Probability (%)
Pearson Type III Fit to 1892-2002 Data
Pearson Type III Fit to 1979-2002 Data



P:\23\62\853\Basin Hydrology_Mass Balance\WatershedData\USGS\DAN_Figs\Precip\CedarBasin_FrequencyAnalysis



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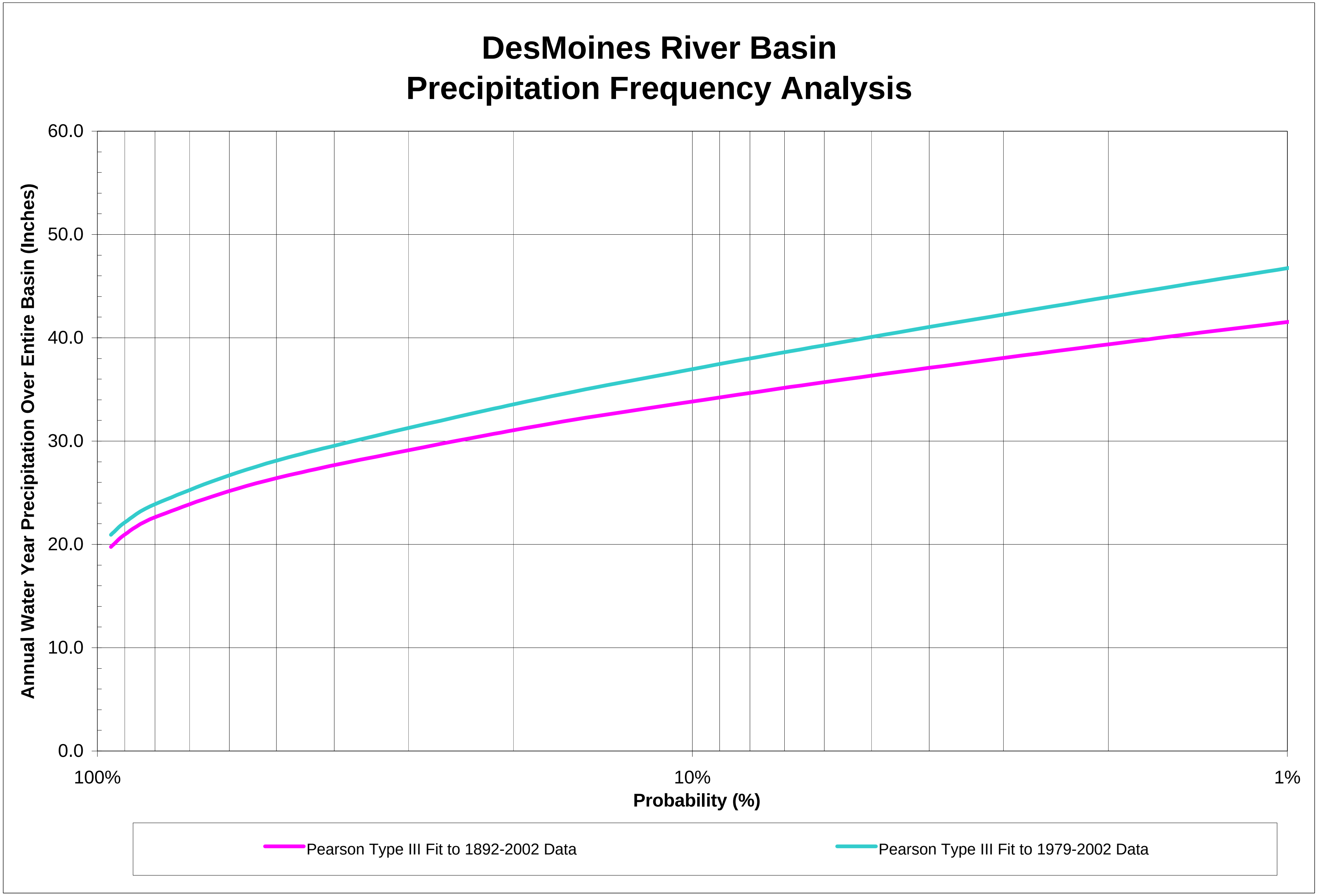
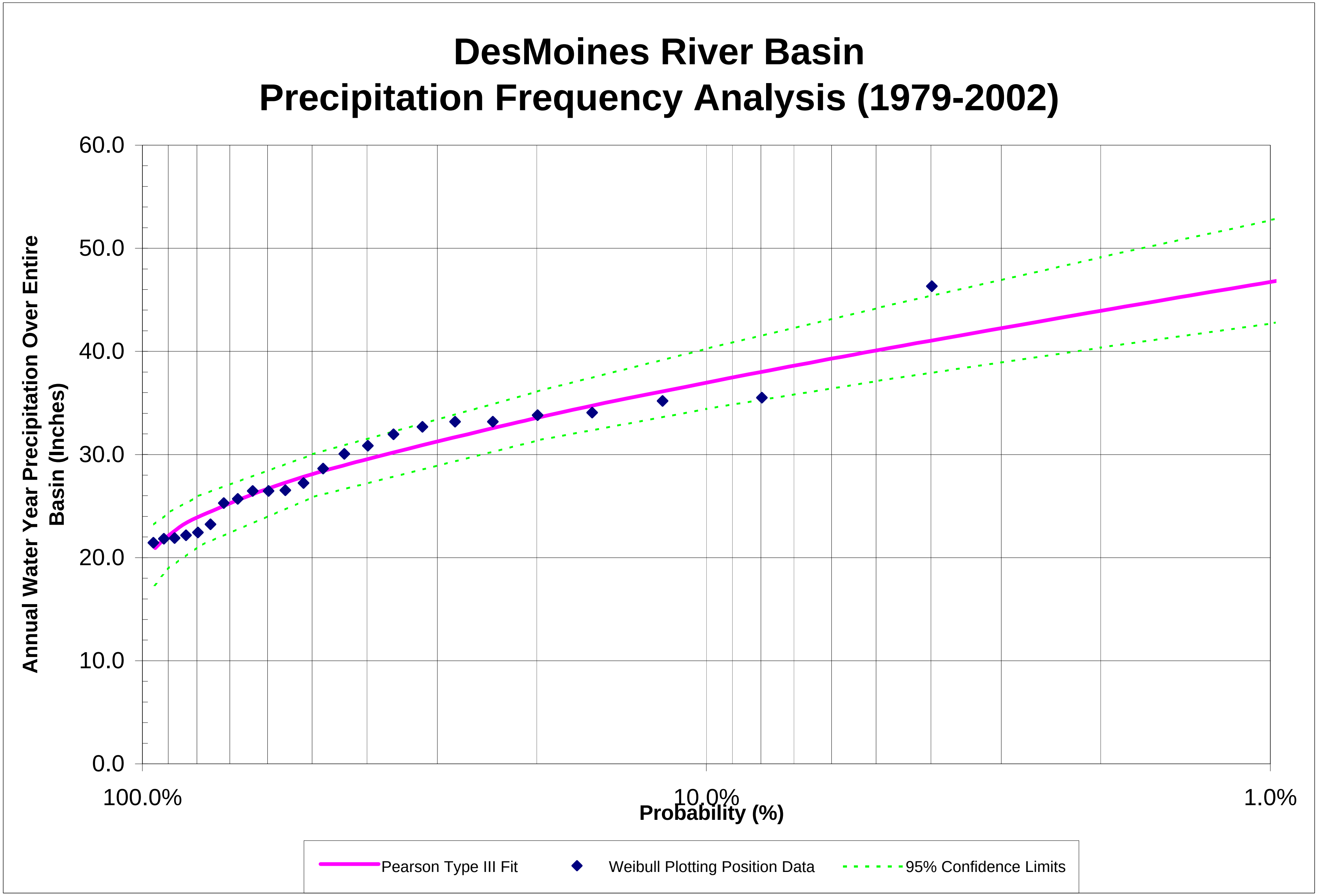
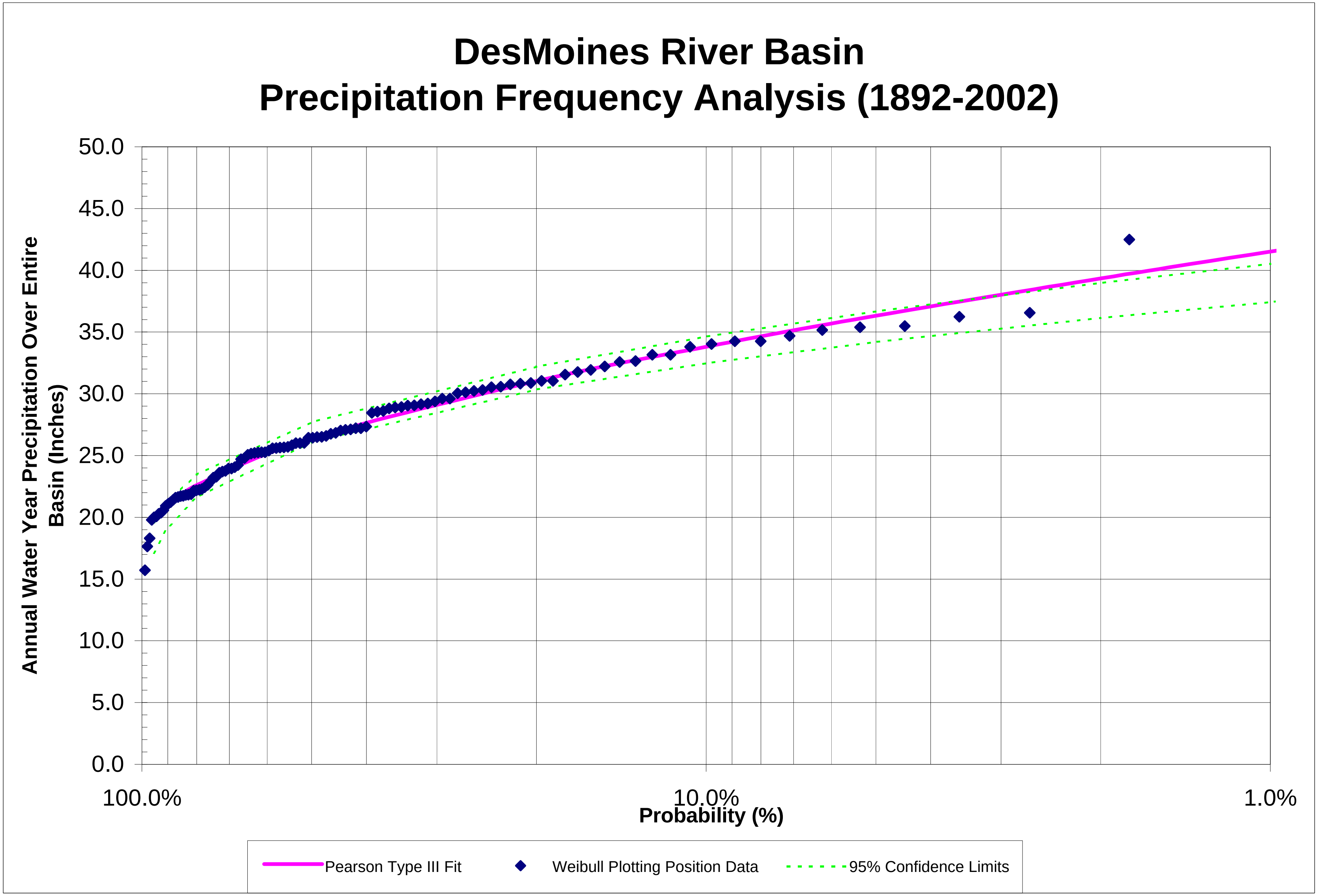
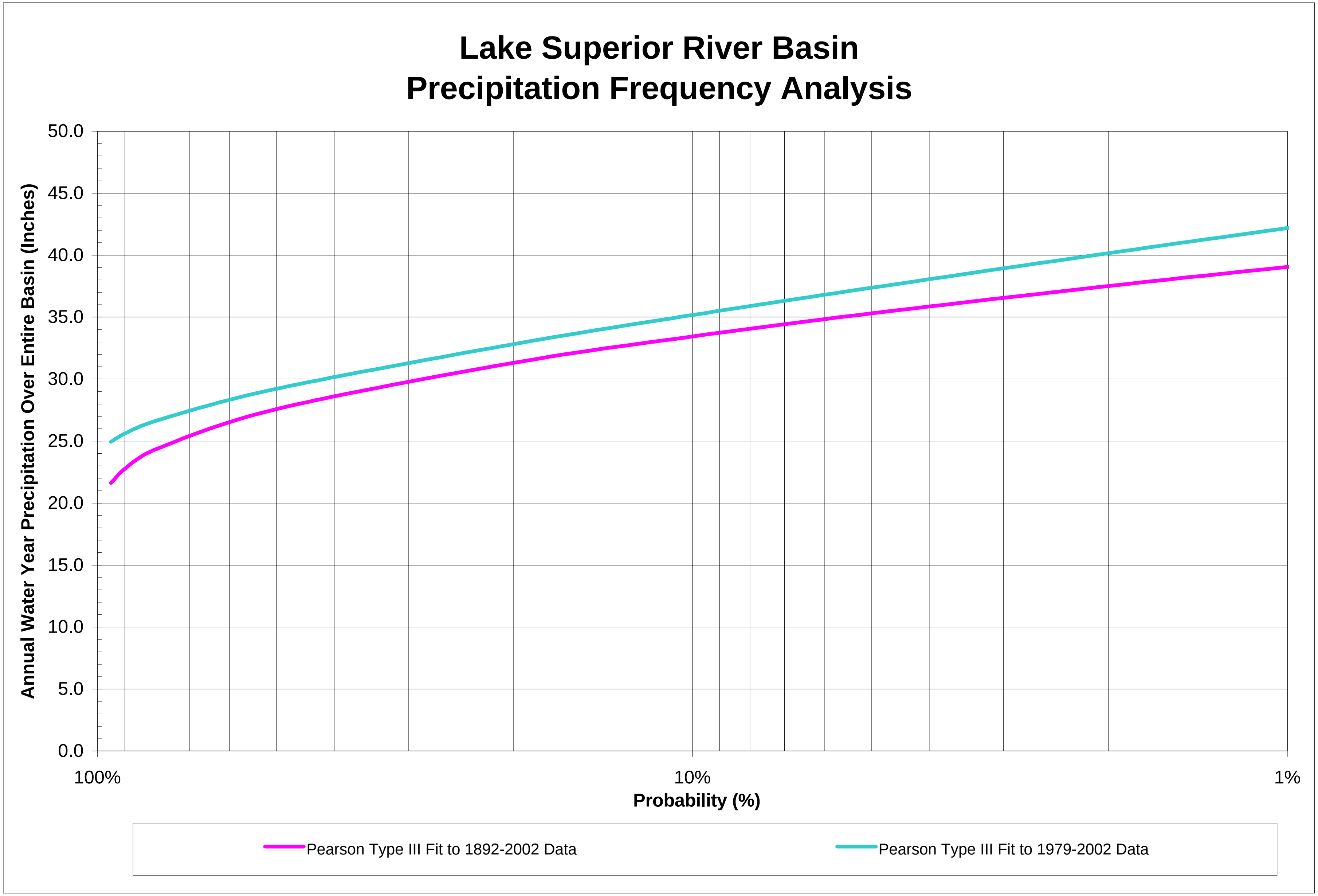

DesMoines River Basin
Precipitation Frequency Analysis
Annual Water Year Precipitation Over Entire Basin (Inches)
60.0
50.0
40.0
30.0
20.0
10.0
0.0
100%
10%
1%
Probability (%)
Pearson Type III Fit to 1892-2002 Data
Pearson Type III Fit to 1979-2002 Data

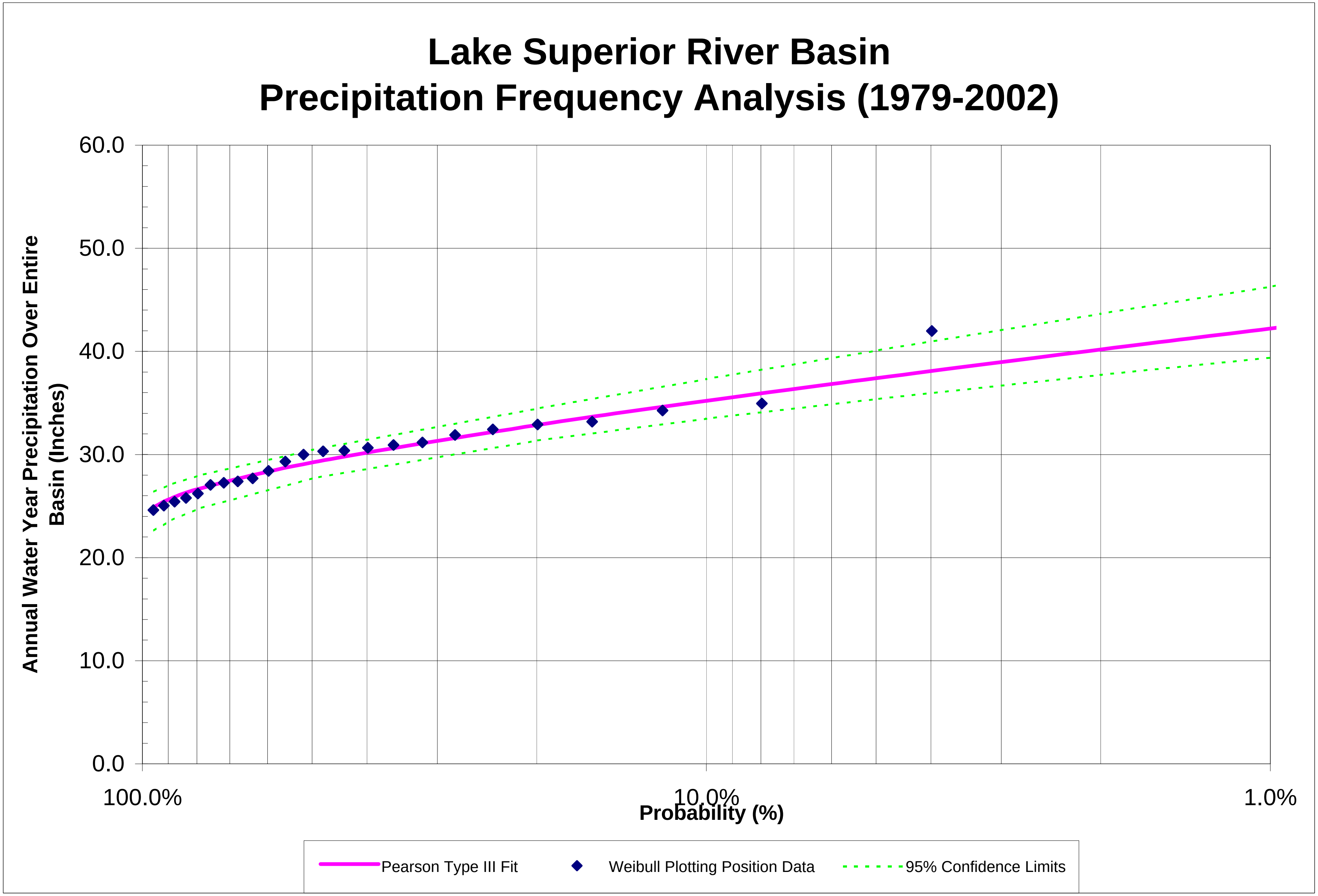


P:\23\62\853\Basin Hydrology_Mass Balance\WatershedData\USGS\DAN_Figs\Precip\DesMoinesBasin_FrequencyAnalysis

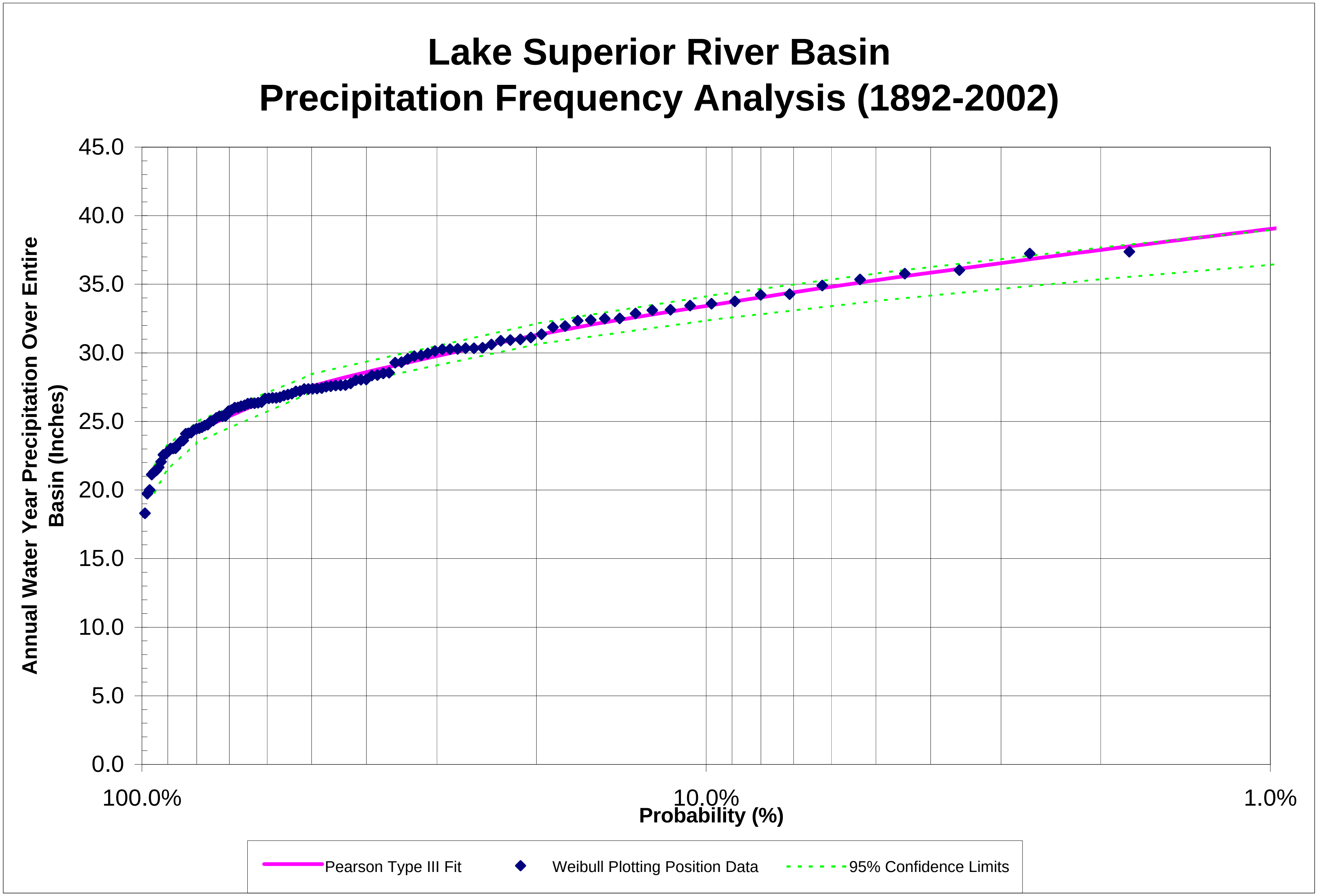


P:\23\62\853\Basin Hydrology_Mass Balance\WatershedData\USGS\DAN_Figs\Precip\DesMoinesBasin_FrequencyAnalysis

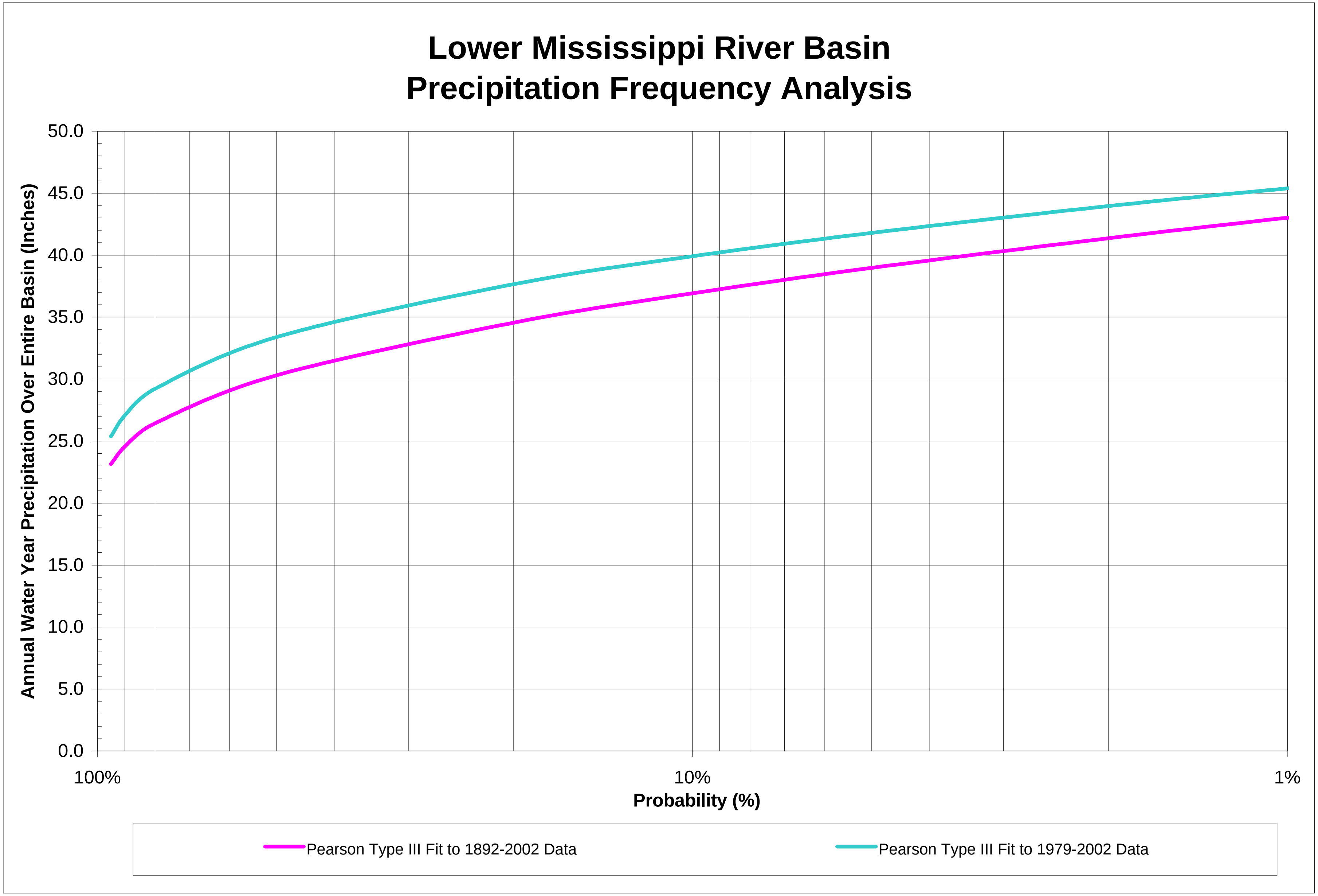

Lake Superior River Basin
Precipitation Frequency Analysis
Annual Water Year Precipitation Over Entire Basin (Inches)
50.0
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
100%
10%
1%
Probability (%)
Pearson Type III Fit to 1892-2002 Data
Pearson Type III Fit to 1979-2002 Data



P:\23\62\853\Basin Hydrology_Mass Balance\WatershedData\USGS\DAN_Figs\Precip\LakeSuperiorBasin_FrequencyAnalysis

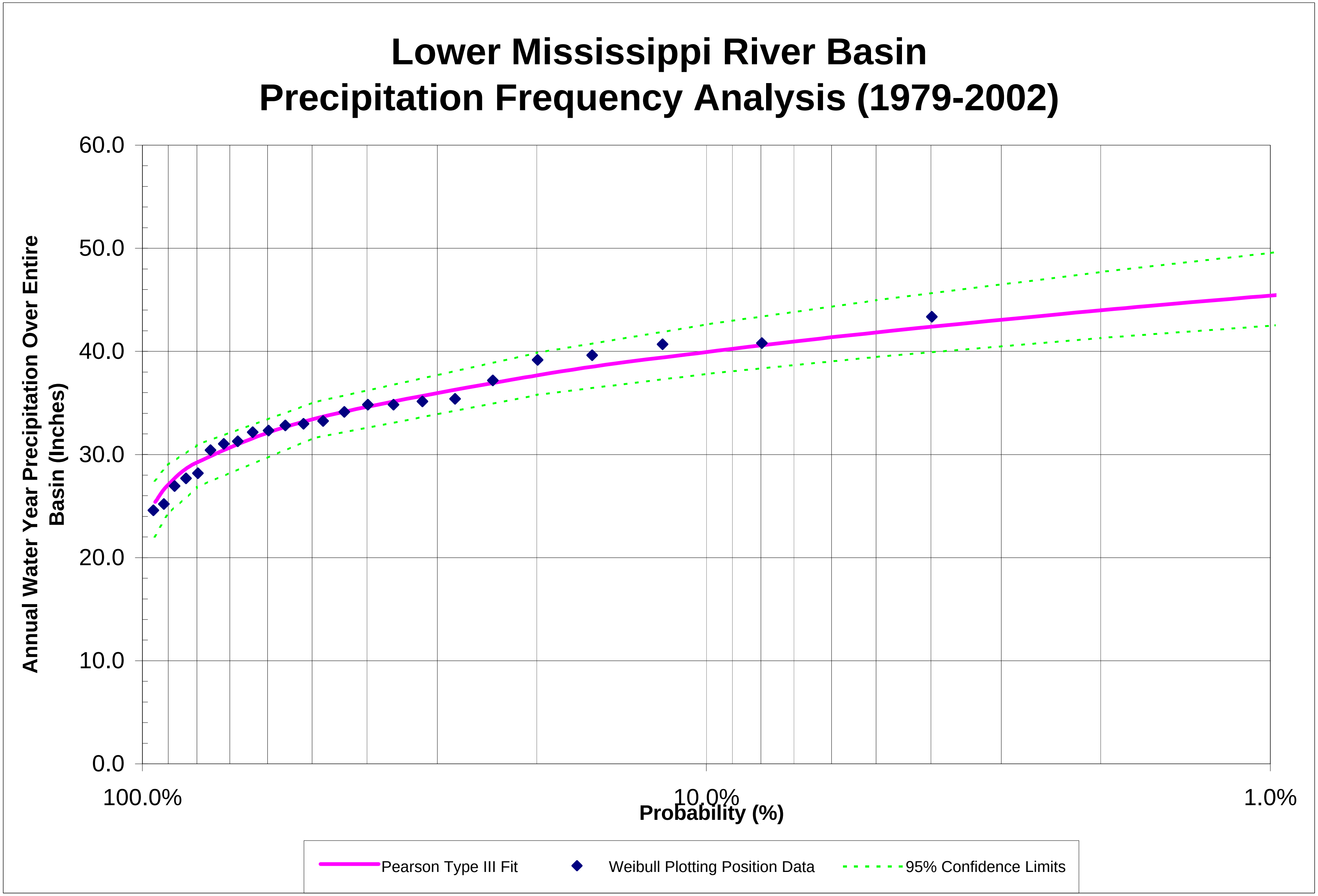


P:\23\62\853\Basin Hydrology_Mass Balance\WatershedData\USGS\DAN_Figs\Precip\LakeSuperiorBasin_FrequencyAnalysis

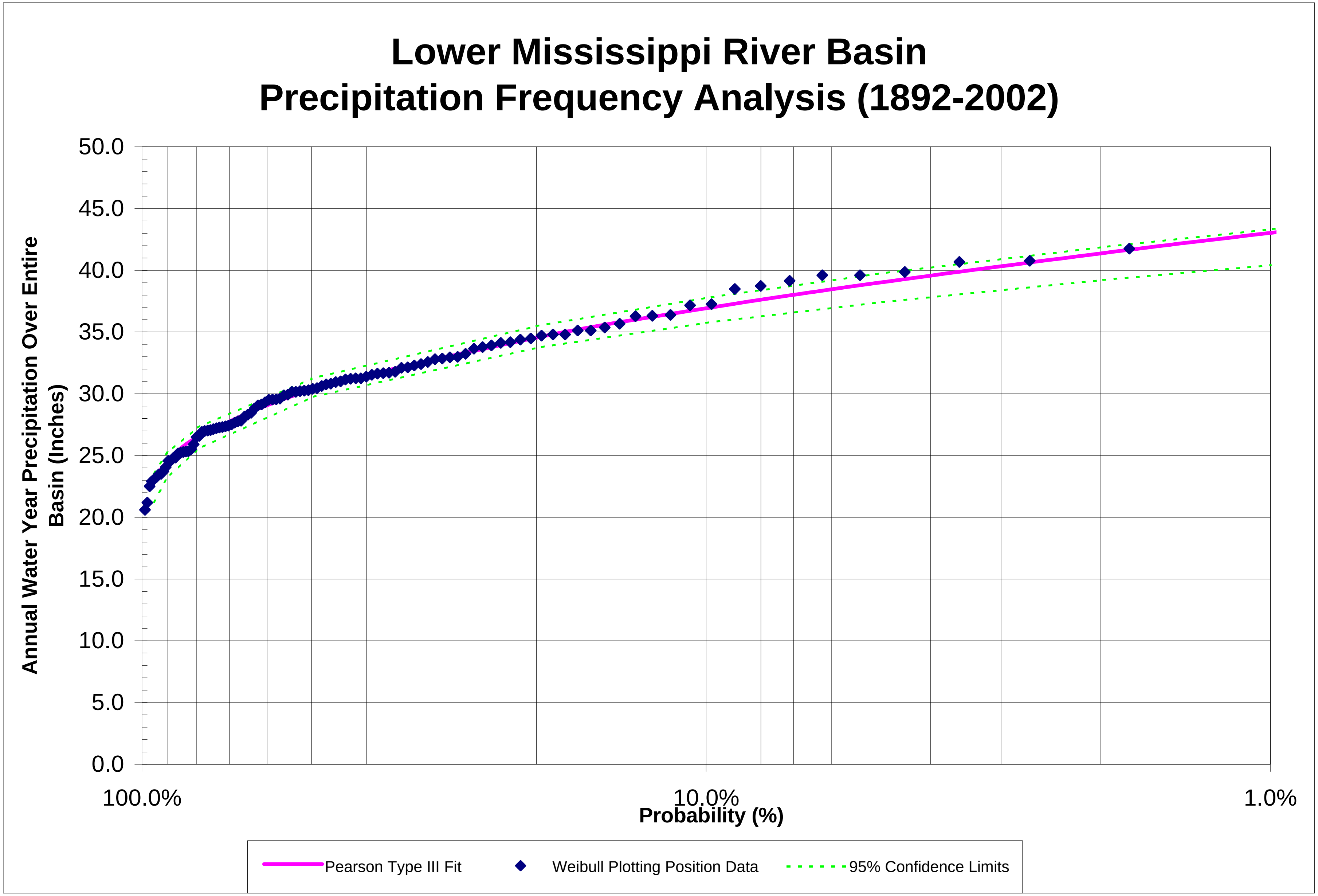


P:\23\62\853\Basin Hydrology_Mass Balance\MNRiver_FrequencyAnalysis.xls

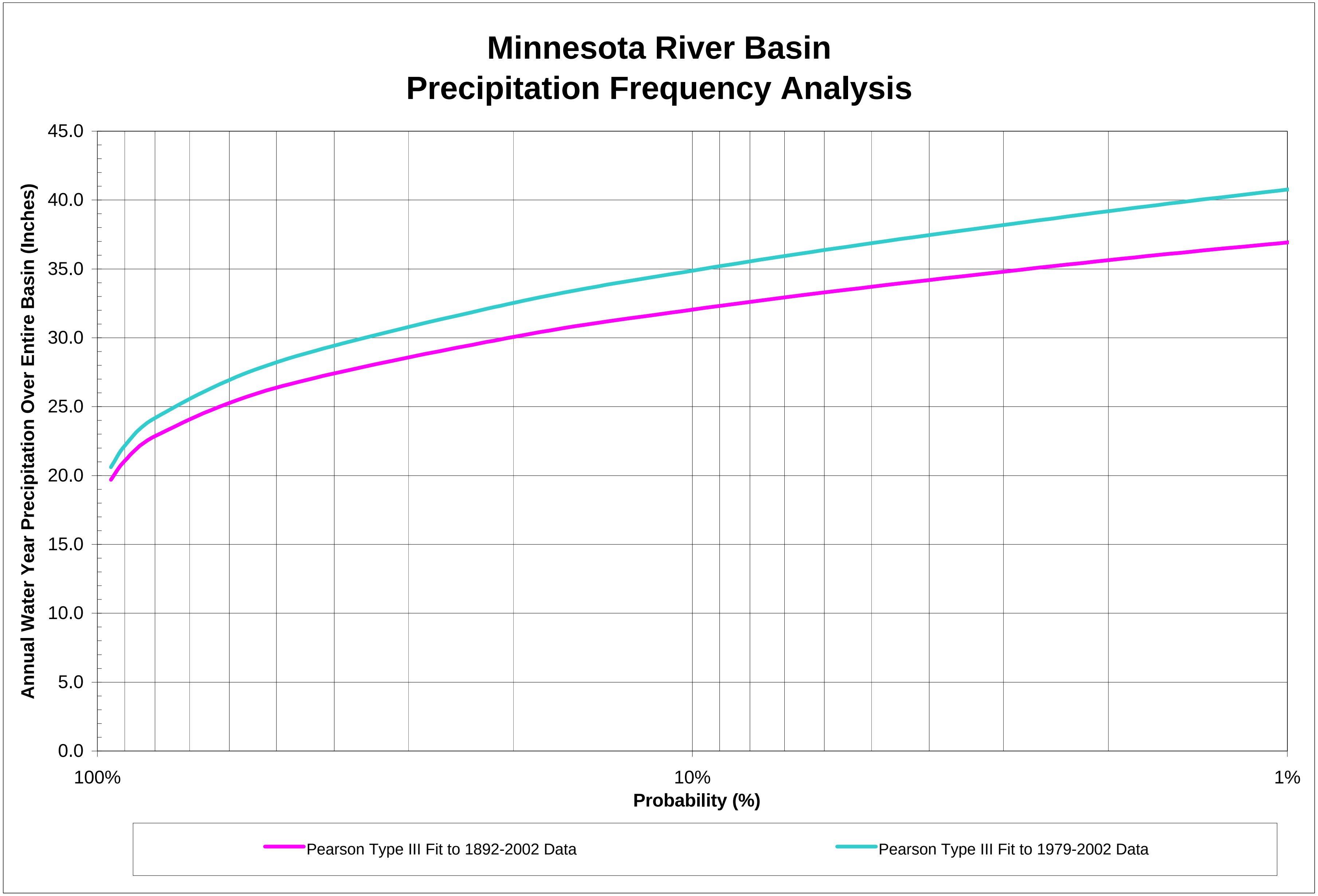
10/21/2003
9:52 AM



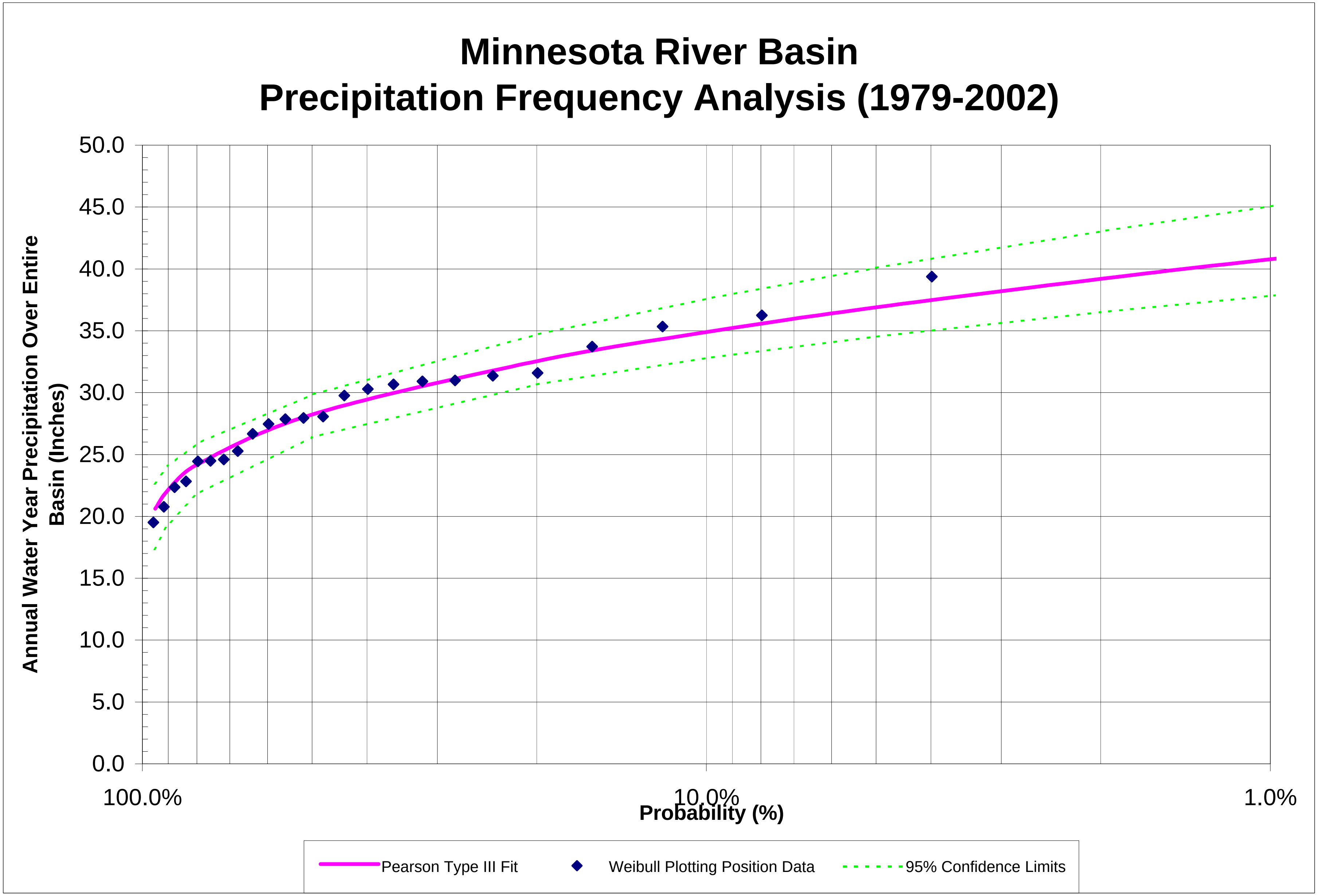
P:\23\62\853\Basin Hydrology_Mass Balance\WatershedData\USGS\DAN_Figs\Precip\LowerMissBasin_FrequencyAnalysis



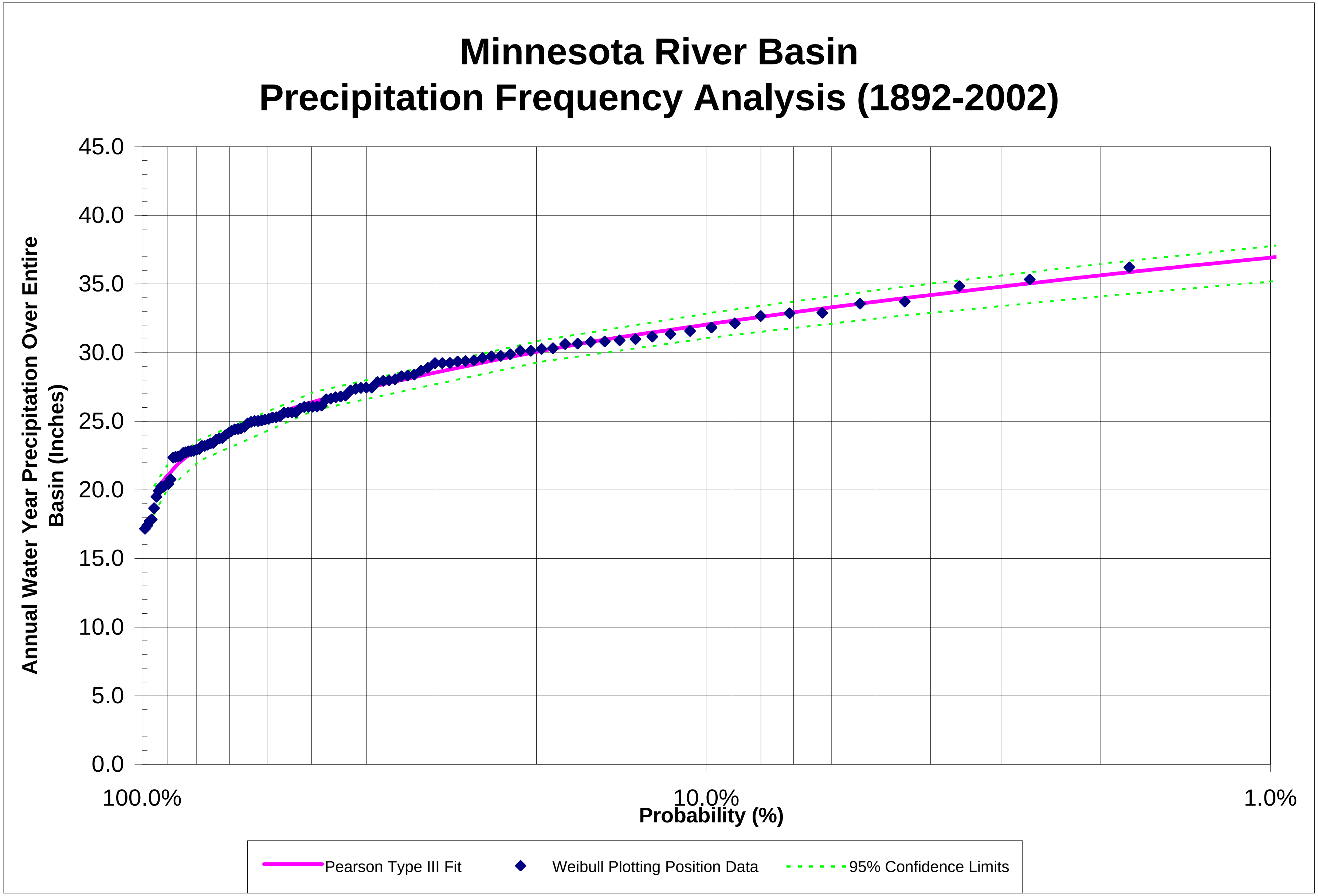
P:\23\62\853\Basin Hydrology_Mass Balance\WatershedData\USGS\DAN_Figs\Precip\LowerMissBasin_FrequencyAnalysis



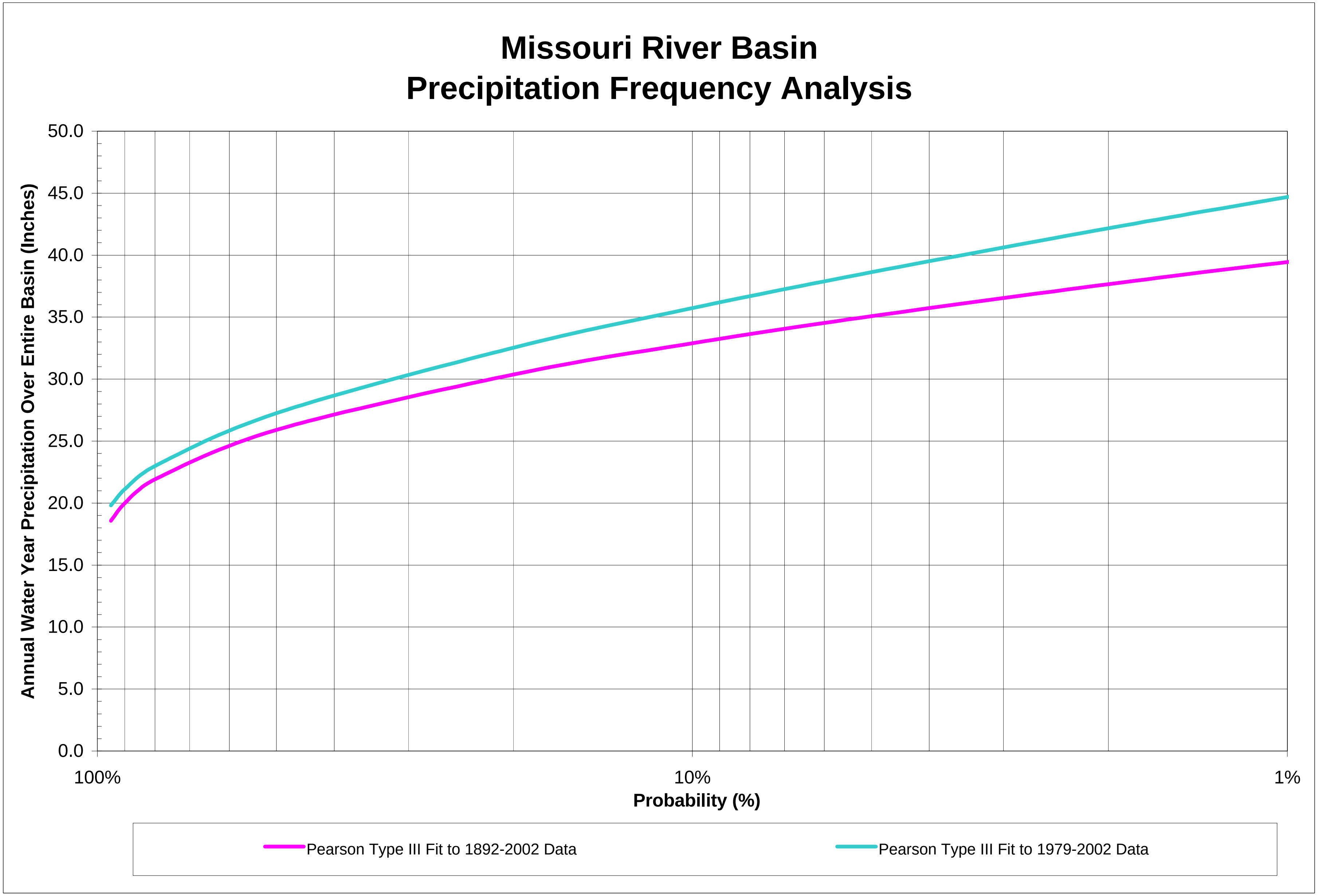
Minnesota River Basin
Precipitation Frequency Analysis
Annual Water Year Precipitation Over Entire Basin (Inches)
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
100%
10%
1%
Probability (%)
Pearson Type III Fit to 1892-2002 Data
Pearson Type III Fit to 1979-2002 Data



P:\23\62\853\Basin Hydrology_Mass Balance\WatershedData\USGS\DAN_Figs\Precip\MinnesotaBasin_FrequencyAnalysis

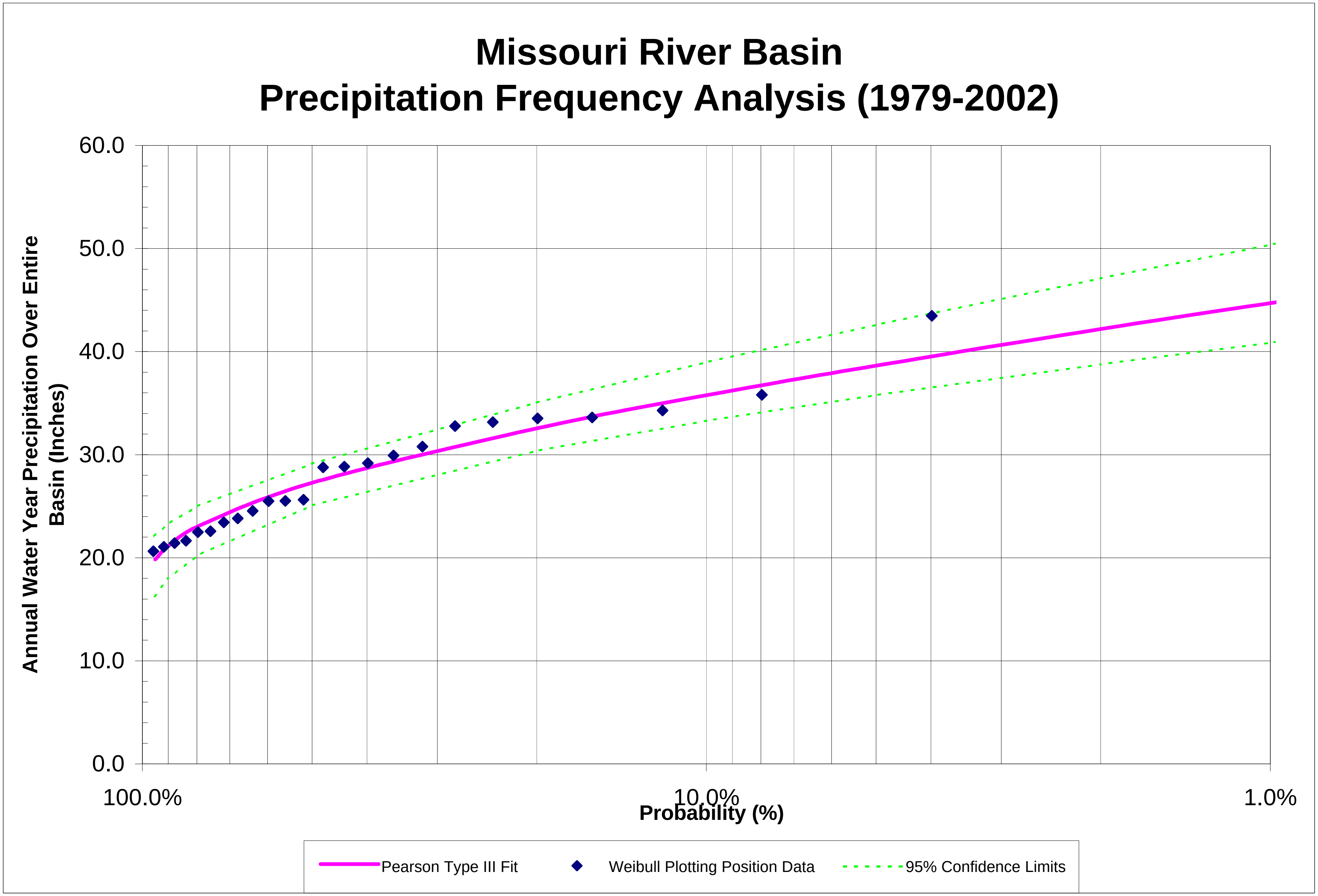


P:\23\62\853\Basin Hydrology_Mass Balance\WatershedData\USGS\DAN_Figs\Precip\MinnesotaBasin_FrequencyAnalysis

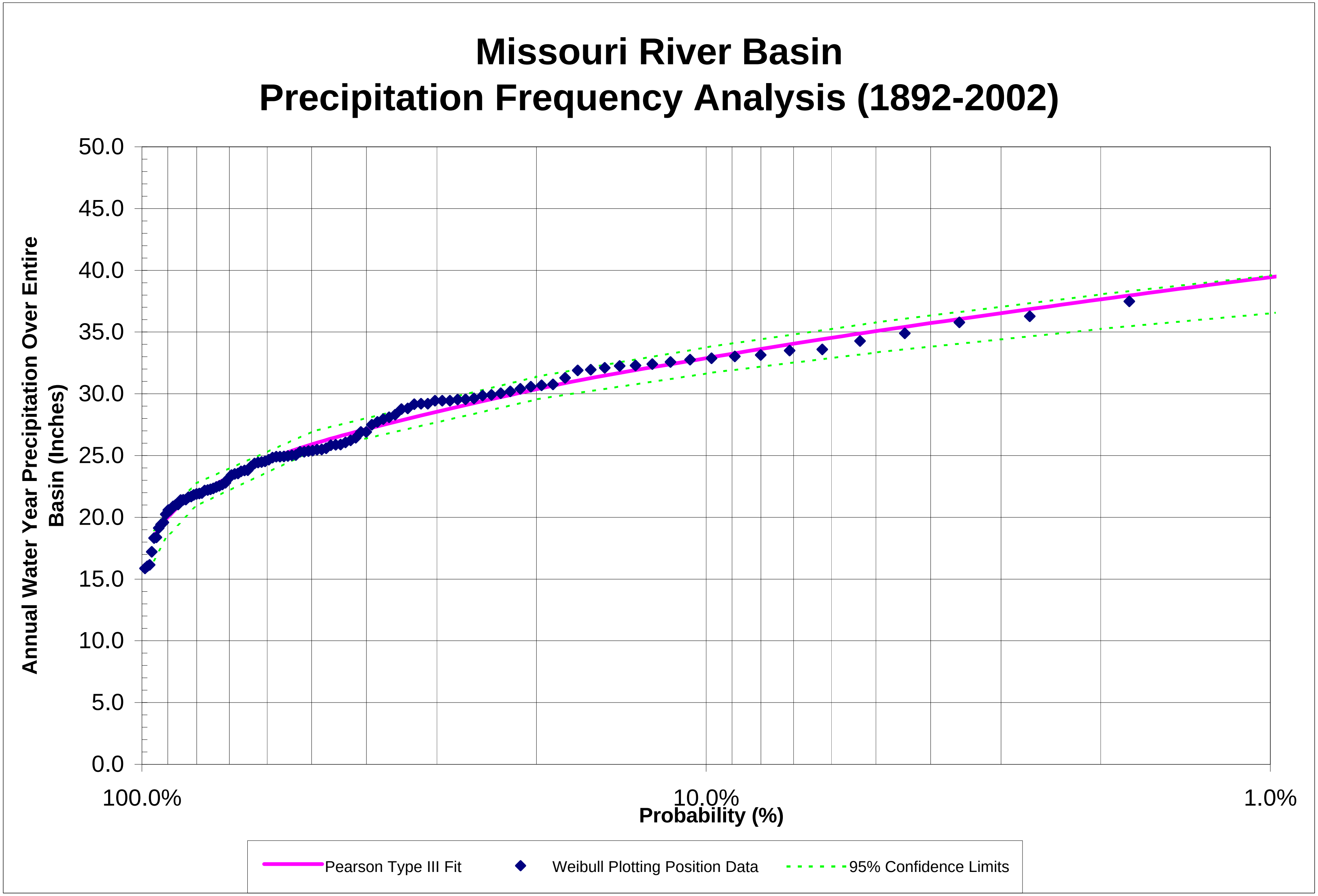


P:\23\62\853\Basin Hydrology_Mass Balance\MNRiver_FrequencyAnalysis.xls

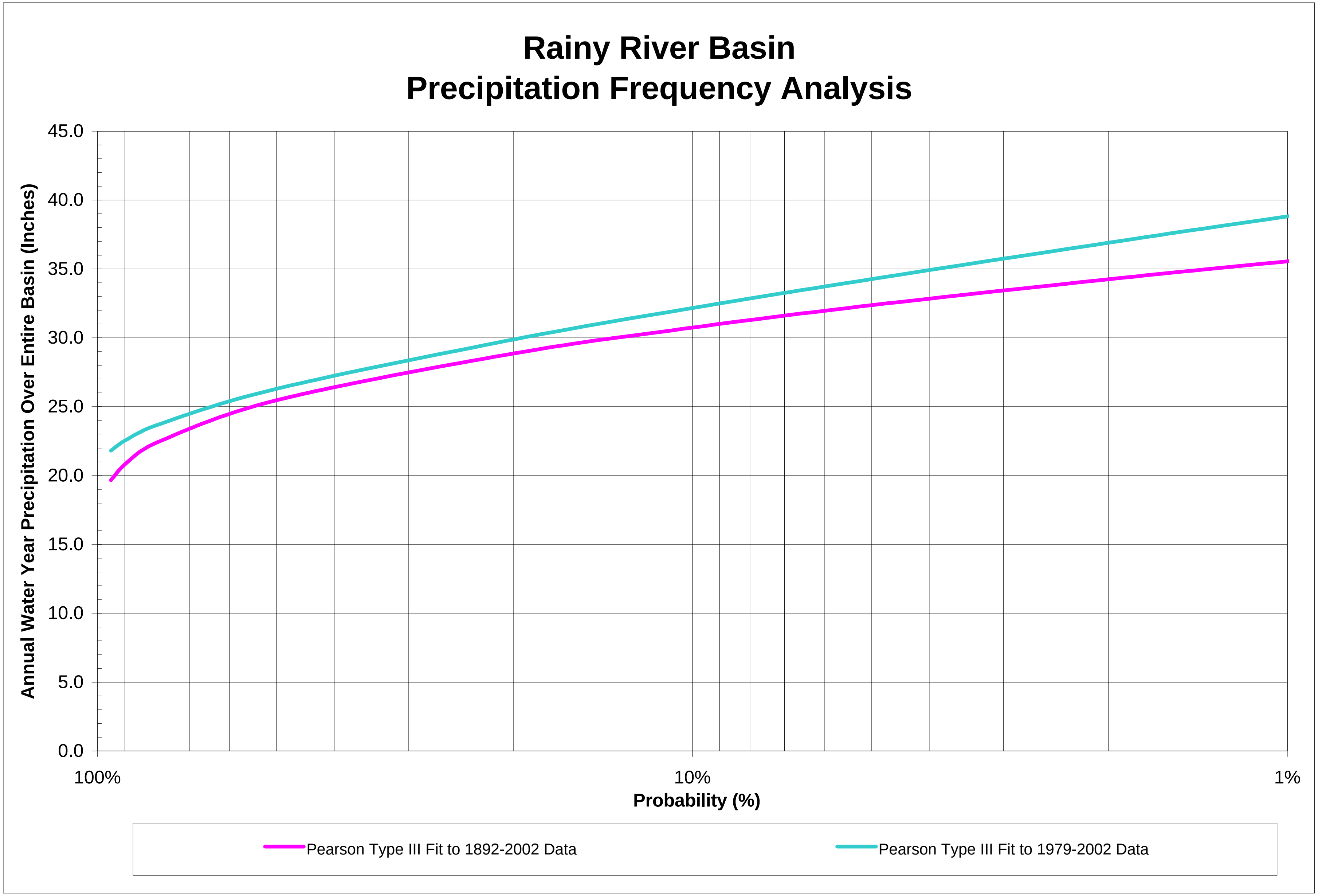
10/21/2003
9:54 AM

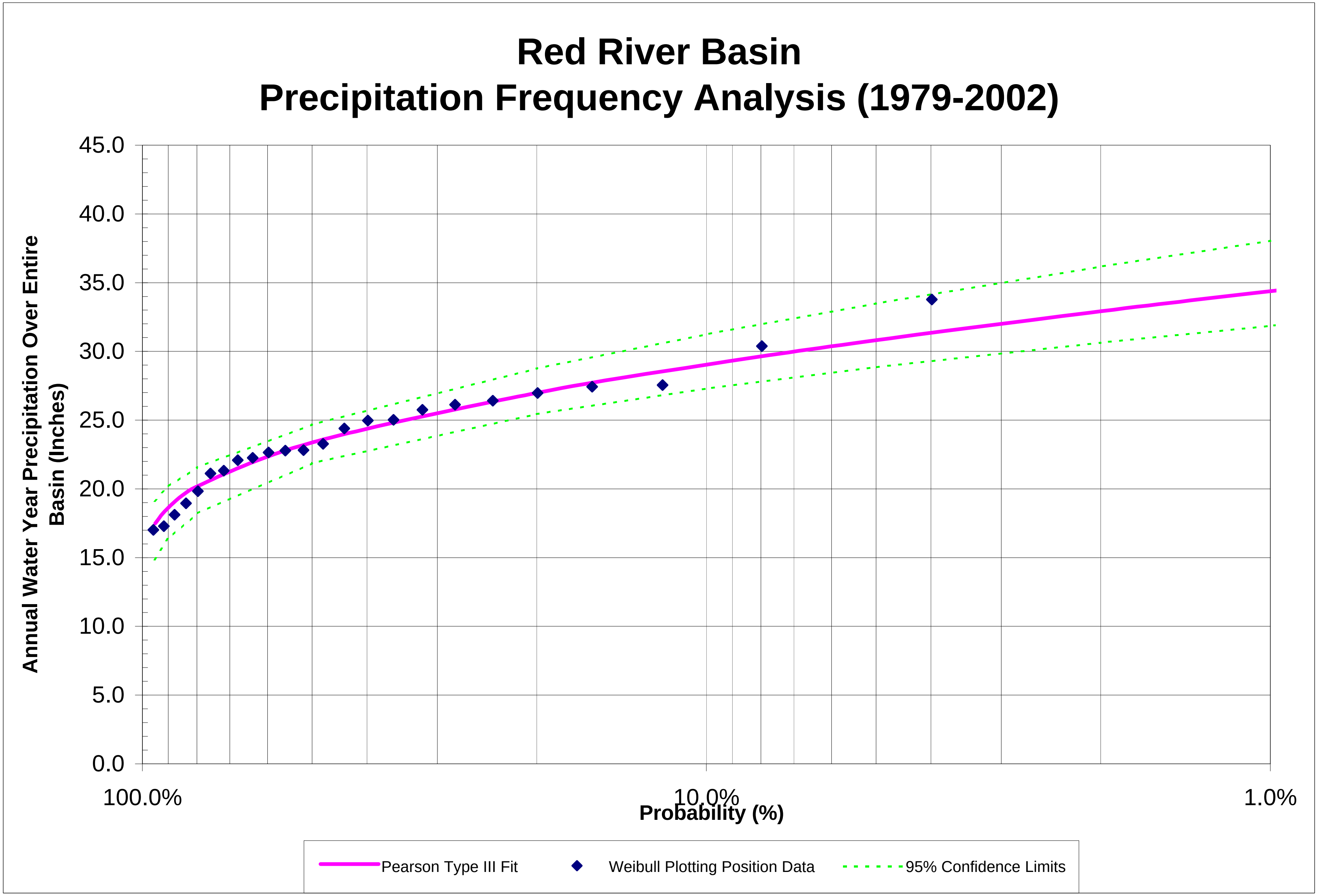


P:\23\62\853\Basin Hydrology_Mass Balance\WatershedData\USGS\DAN_Figs\Precip\MissouriBasin_FrequencyAnalysis

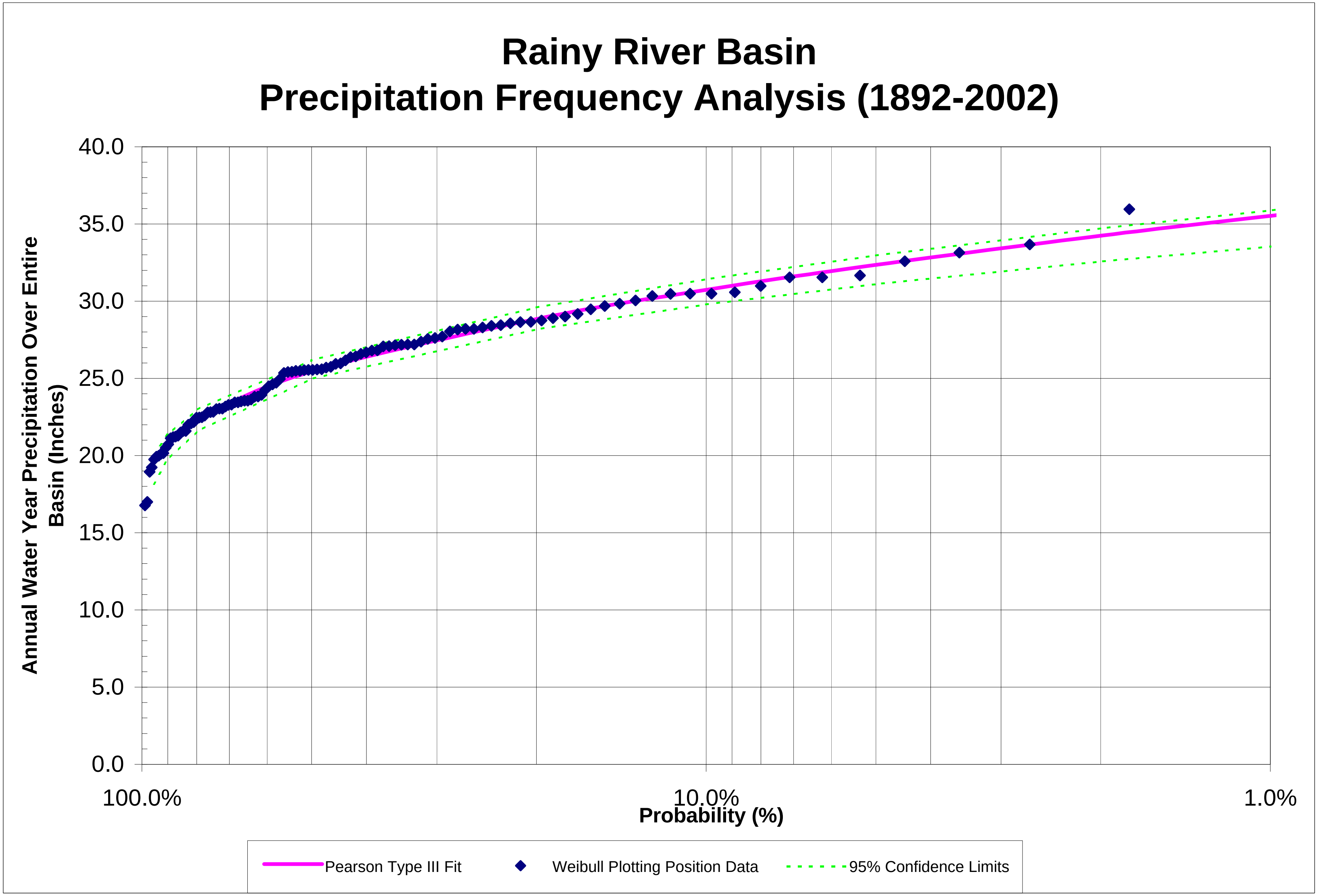


Missouri River Basin
Precipitation Frequency Analysis (1892-2002)
Annual Water Year Precipitation Over Entire Basin (Inches)
50.0
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
100.0%
10.0%
1.0%
Probability (%)
Pearson Type III Fit
Weibull Plotting Position Data
95% Confidence Limits

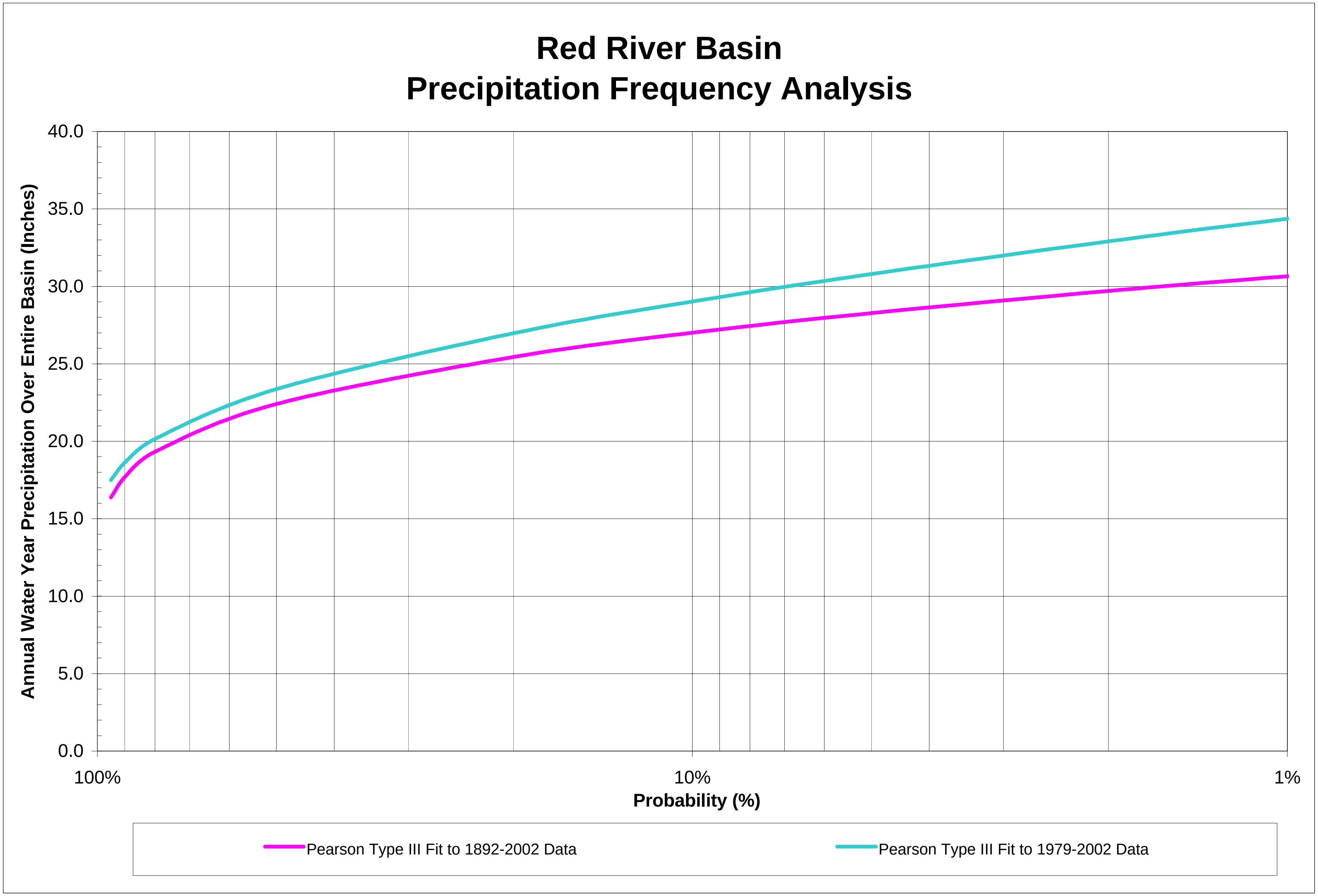

Rainy River Basin
Precipitation Frequency Analysis
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
Annual Water Year Precipitation Over Entire Basin (Inches)
100%
10%
1%
Probability (%)
Pearson Type III Fit to 1892-2002 Data
Pearson Type III Fit to 1979-2002 Data



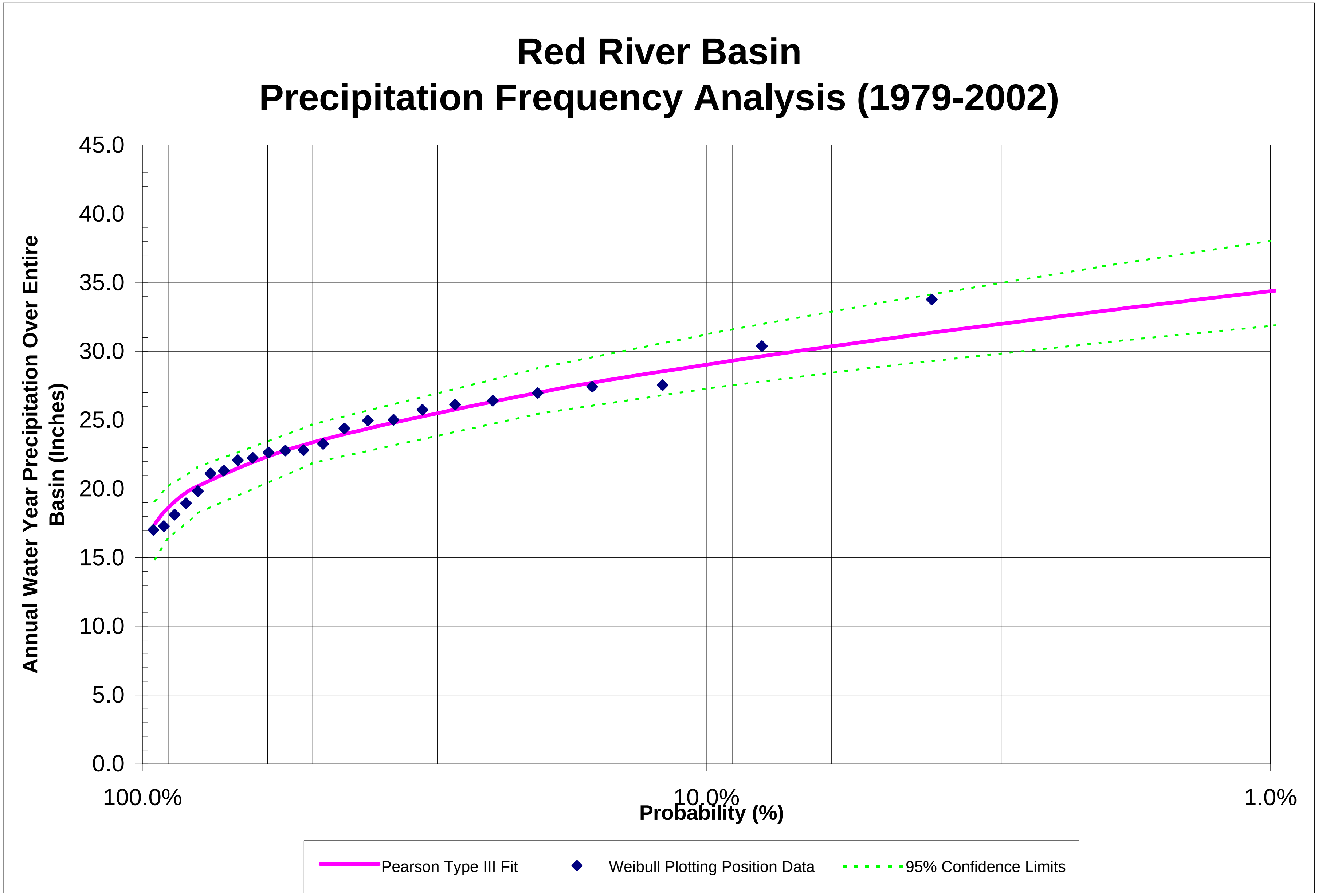
P:\23\62\853\Basin Hydrology_Mass Balance\WatershedData\USGS\DAN_Figs\Precip\RedBasin_FrequencyAnalysis



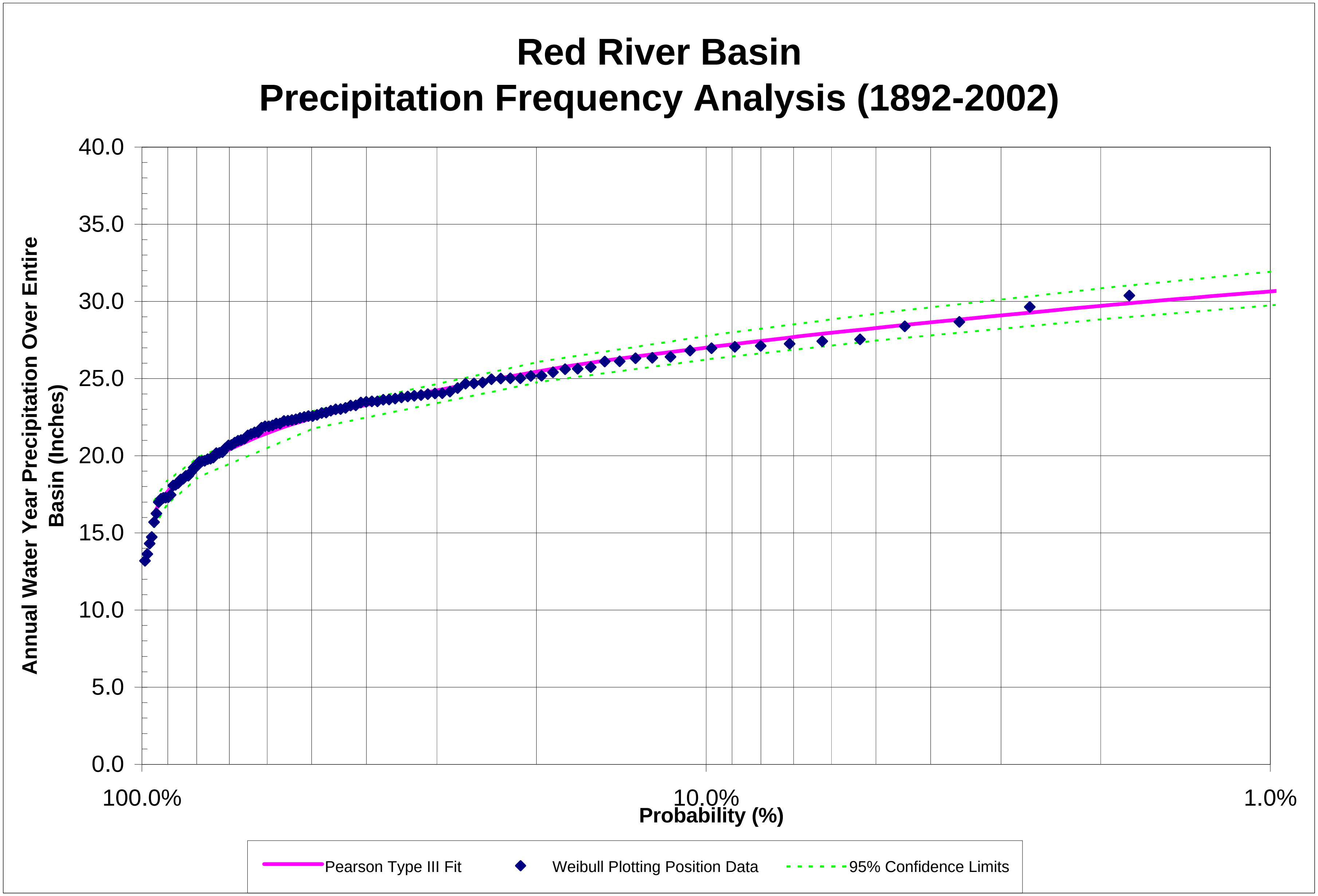
P:\23\62\853\Basin Hydrology_Mass Balance\WatershedData\USGS\DAN_Figs\Precip\RainyBasin_FrequencyAnalysis



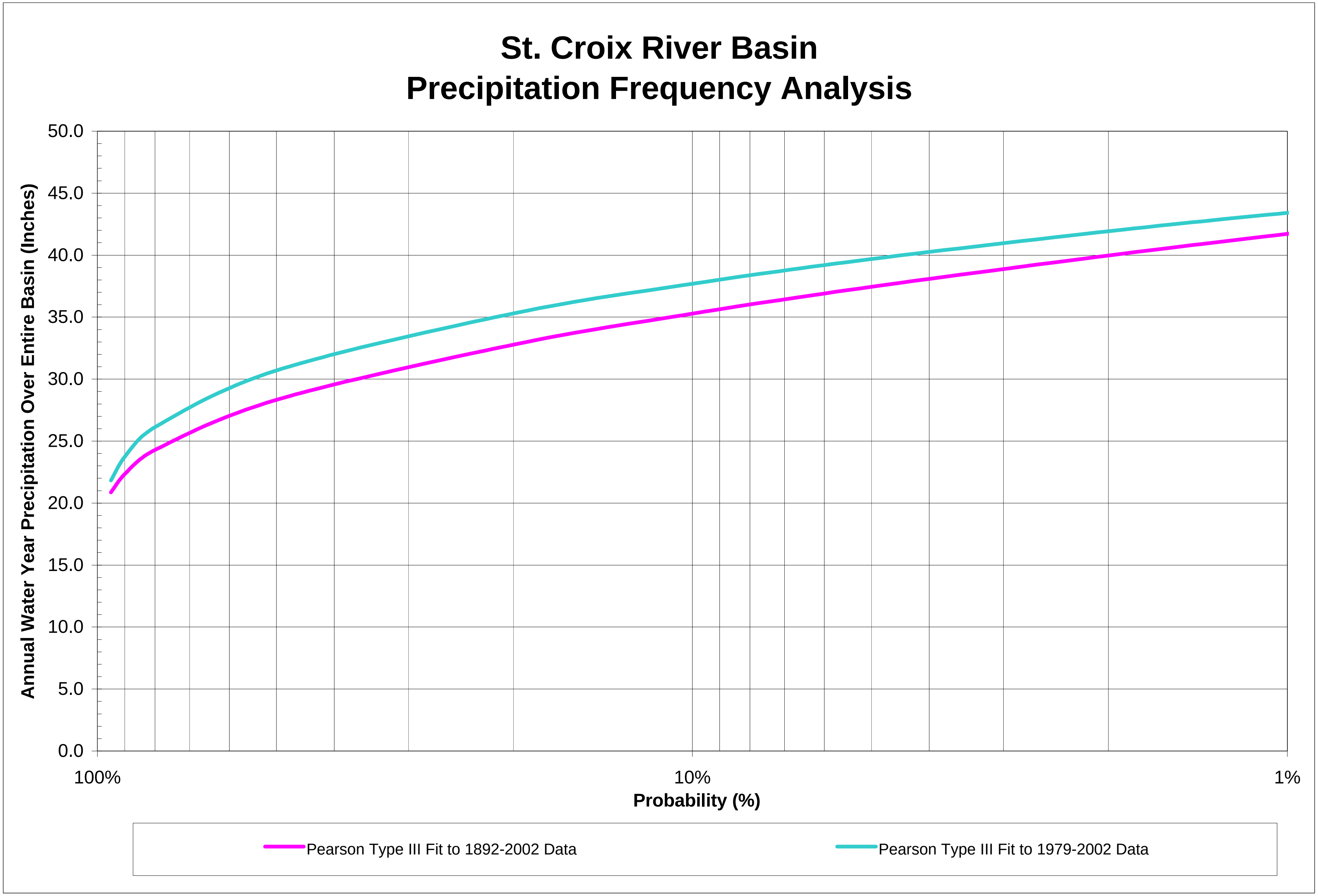
Red River Basin
Precipitation Frequency Analysis
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
Annual Water Year Precipitation Over Entire Basin (Inches)
100%
10%
1%
Probability (%)
Pearson Type III Fit to 1892-2002 Data
Pearson Type III Fit to 1979-2002 Data



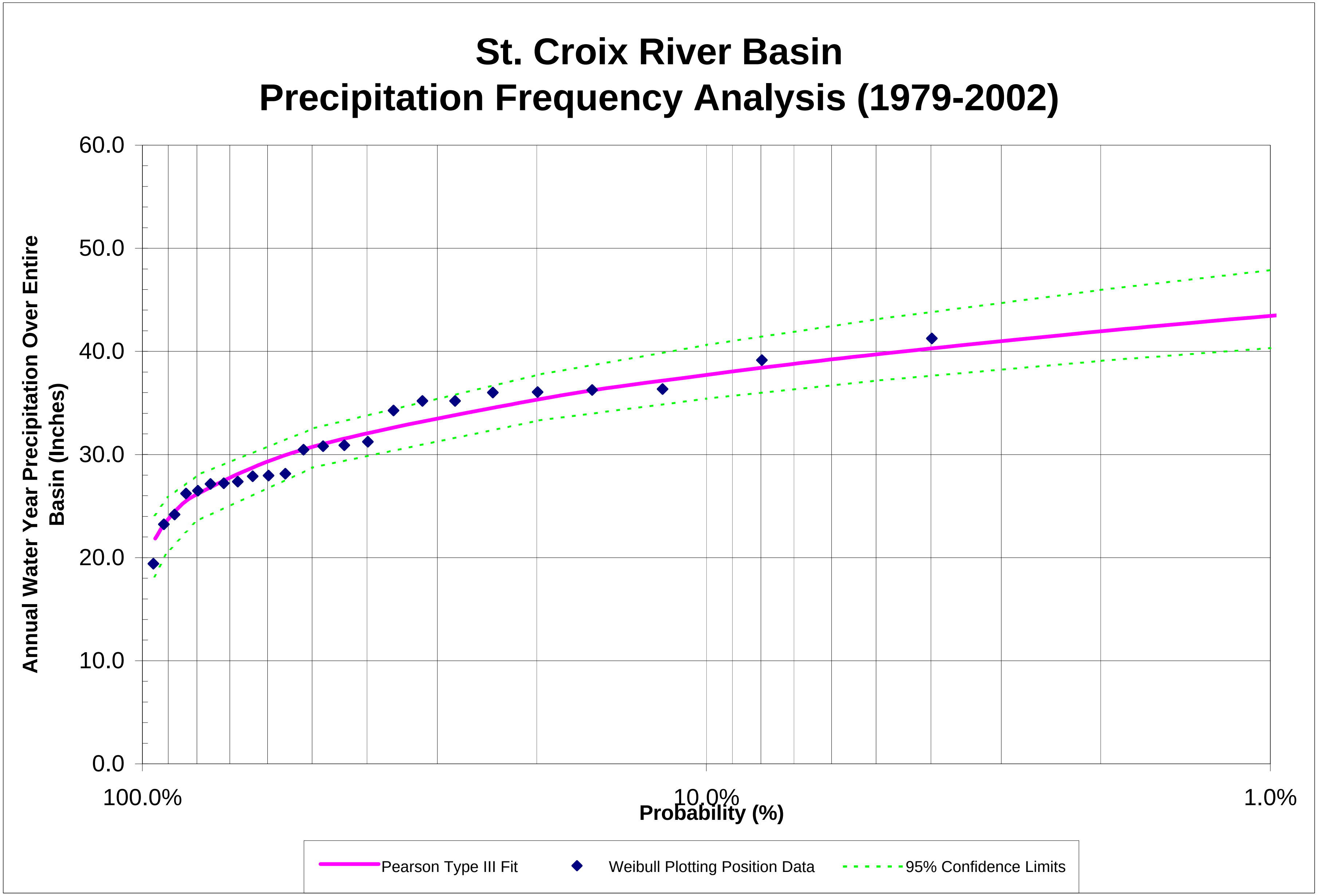
P:\23\62\853\Basin Hydrology_Mass Balance\WatershedData\USGS\DAN_Figs\Precip\RedBasin_FrequencyAnalysis



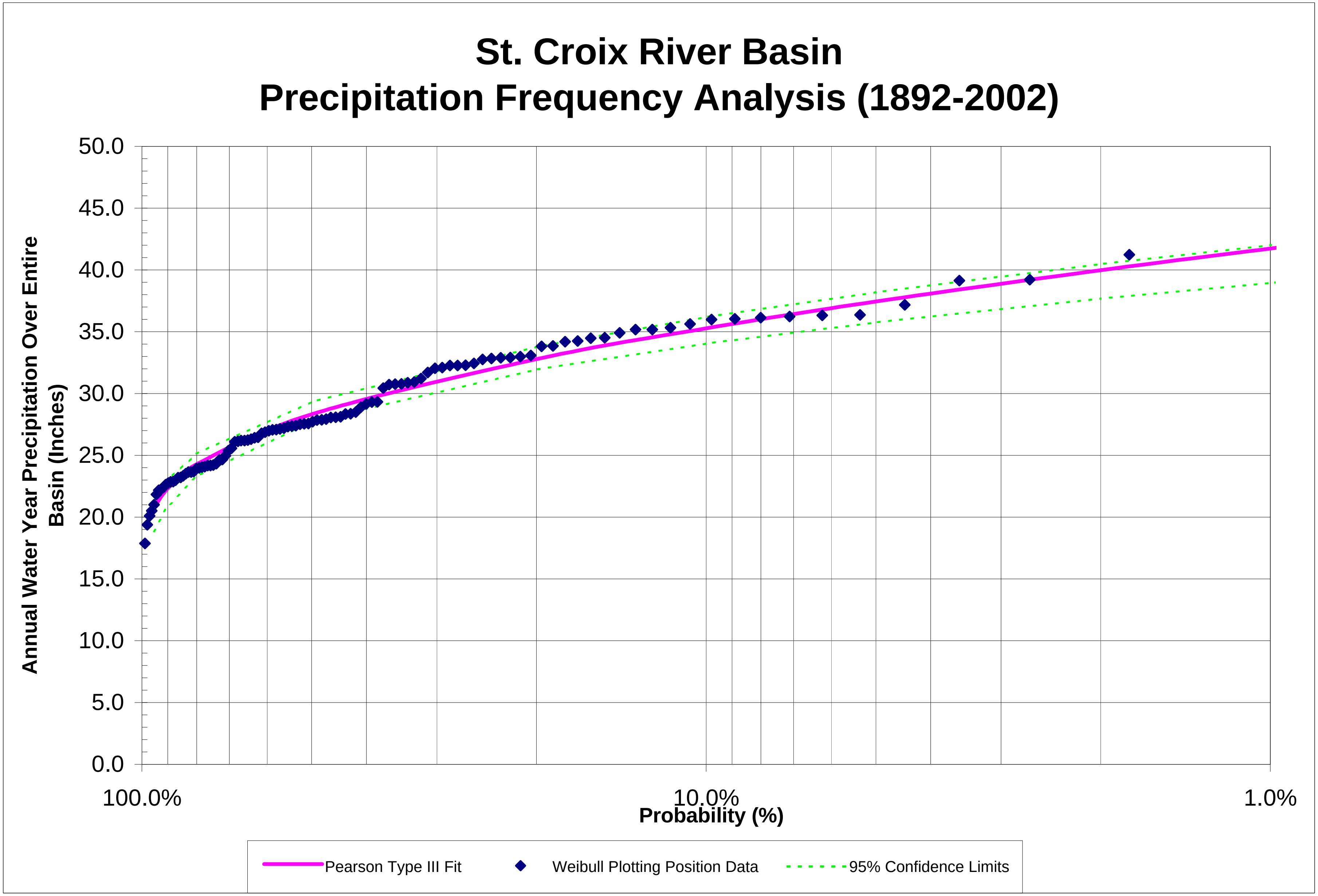
P:\23\62\853\Basin Hydrology_Mass Balance\WatershedData\USGS\DAN_Figs\Precip\RedBasin_FrequencyAnalysis

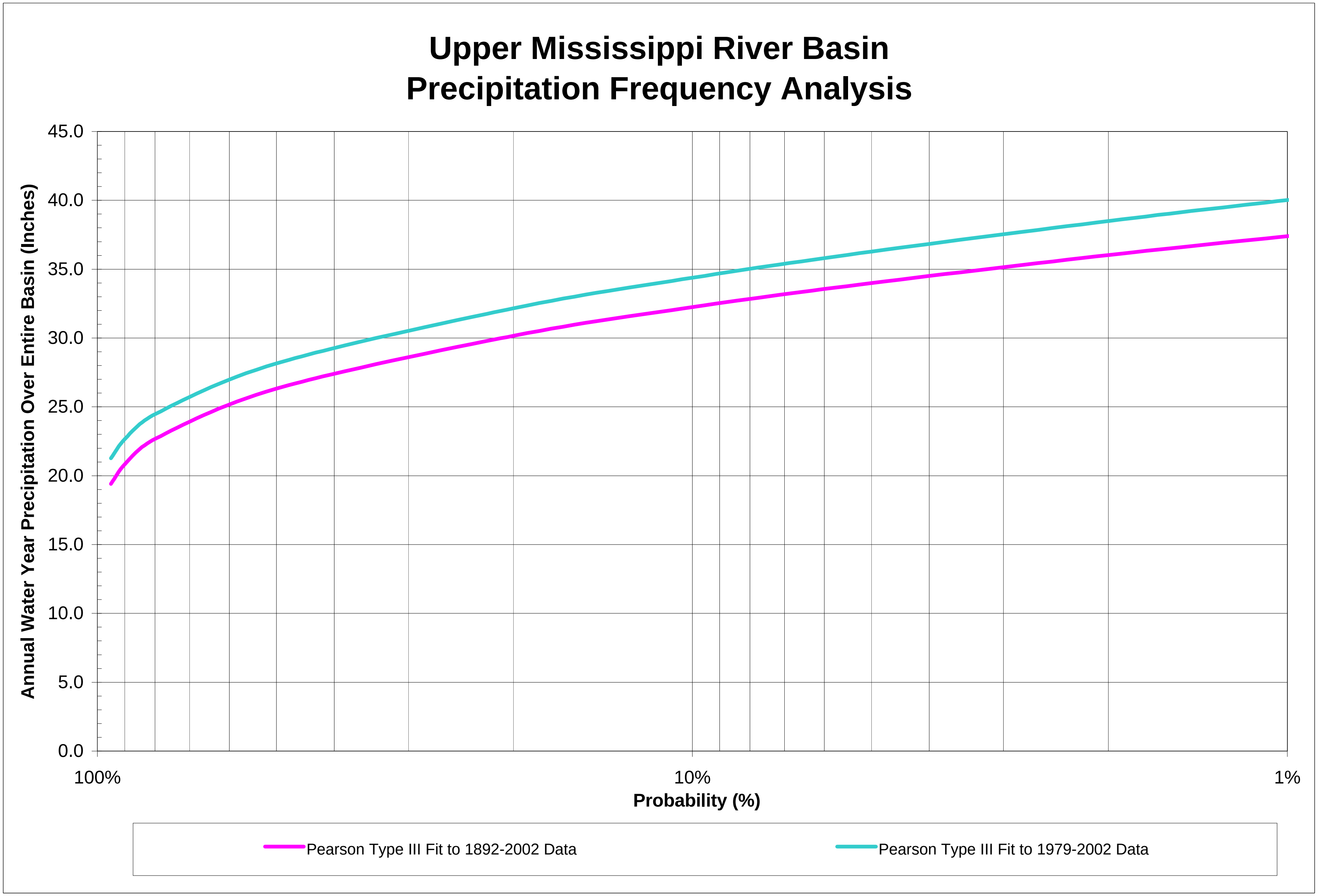


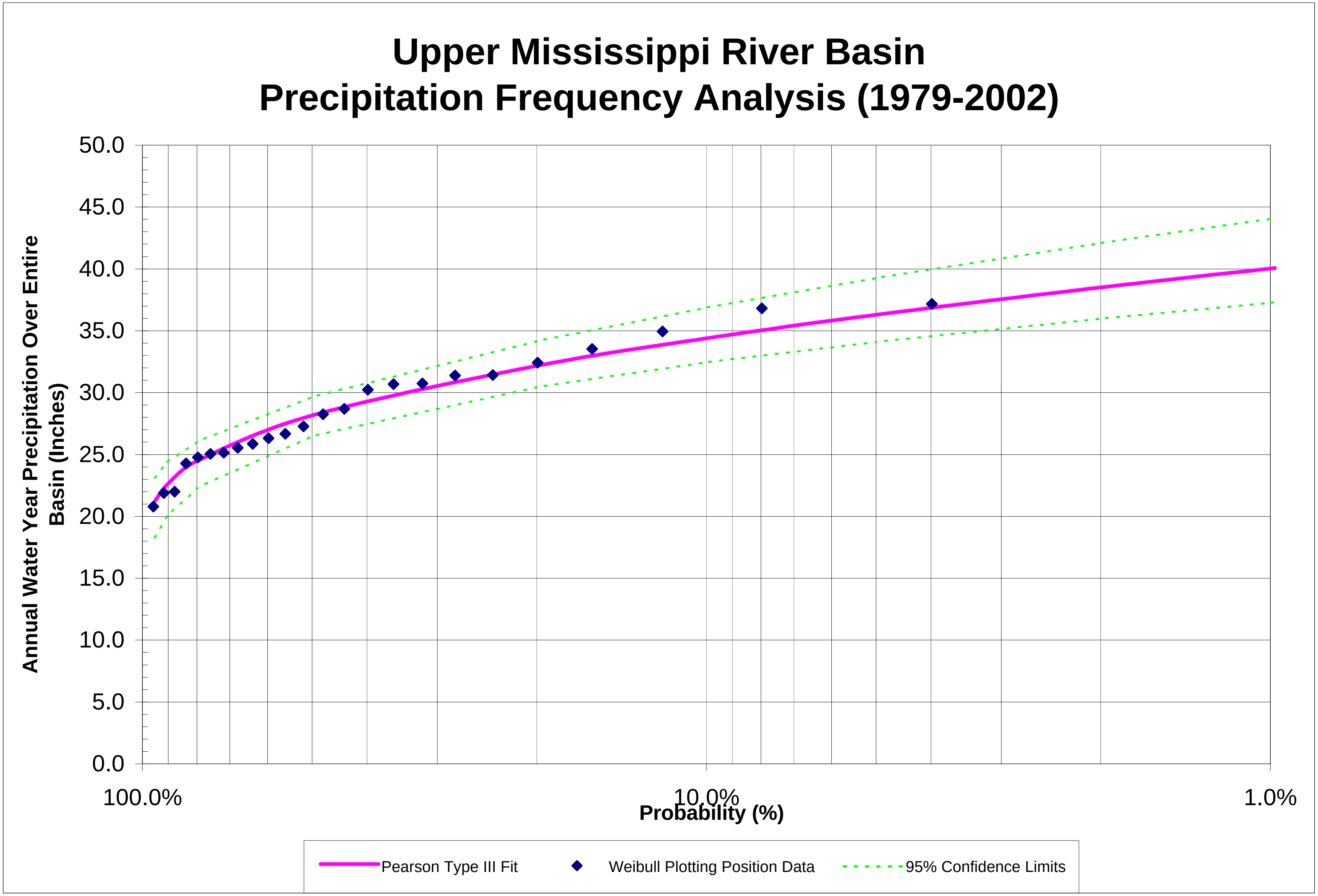
St. Croix River Basin
Precipitation Frequency Analysis
Annual Water Year Precipitation Over Entire Basin (Inches)
50.0
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
100%
10%
1%
Probability (%)
Pearson Type III Fit to 1892-2002 Data
Pearson Type III Fit to 1979-2002 Data



P:\23\62\853\Basin Hydrology_Mass Balance\WatershedData\USGS\DAN_Figs\Precip\StCroixBasin_FrequencyAnalysis


St. Croix River Basin
Precipitation Frequency Analysis (1892-2002)
Annual Water Year Precipitation Over Entire Basin (Inches)
50.0
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
100.0%
10.0%
1.0%
Probability (%)
Pearson Type III Fit
Weibull Plotting Position Data
95% Confidence Limits


Upper Mississippi River Basin
Precipitation Frequency Analysis
Annual Water Year Precipitation Over Entire Basin (Inches)
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
100%
10%
1%
Probability (%)
Pearson Type III Fit to 1892-2002 Data
Pearson Type III Fit to 1979-2002 Data



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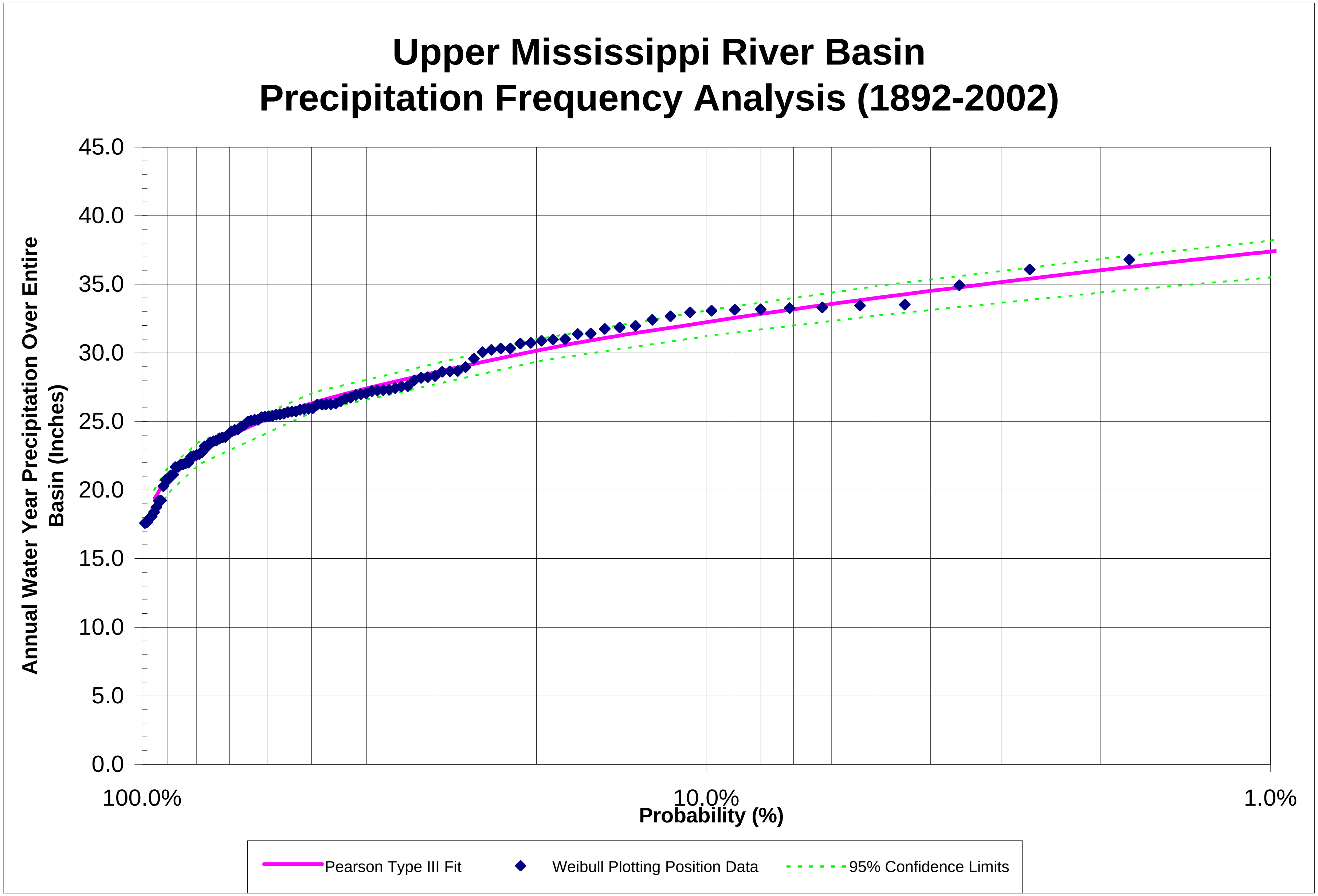

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Technical Memorandum

To: Marvin Hora, Minnesota Pollution Control Agency
Douglas Hall, Minnesota Pollution Control Agency
Mark Tomasek, Minnesota Pollution Control Agency

From: Nick Nelson, Dan Nesler, and Teresa Perry

Subject: Detailed Assessment of Phosphorus Sources to Minnesota Watersheds – Point Sources

Date: February 16, 2004

Project: 23/62-853 POTW 010

c: Greg Wilson
Henry Runke

The purpose of this memorandum is to provide a discussion regarding point sources of phosphorus to Minnesota watersheds and regarding the sources of phosphorus discharged to Minnesota publicly owned treatment works (POTWs). This discussion is based on a review of the available literature, monitoring data and the results of phosphorus loading computations done for each of Minnesota's major watershed basins as part of this study. This memorandum is intended to:

- Provide an overview and introduction to point sources as a source of phosphorus,
- Describe the results of the literature search and review of available monitoring data,
- Discuss the characteristics of each watershed basin as it pertains to point sources as a source of phosphorus,
- Describe the assumptions made and methodology used to complete the phosphorus loading computations and assessments for point sources as a source of phosphorus,
- Describe the methodology used to determine the various components of phosphorus loading,
- Discuss the results of the phosphorus loading computations and assessments,
- Discuss the uncertainty of the phosphorus loading computations and assessment,
- Provide recommendations for future refinements to phosphorus loading estimates and methods for reducing error terms, and
- Provide recommendations for lowering phosphorus export from point sources.

In addition, the results of this study and the information developed as part of this study is intended to assist the MPCA in complying with Minnesota Laws 2003, Chap. 128 Art. 1, Sec. 122

The state goal for reducing phosphorus from non-ingested sources entering municipal wastewater treatment systems is at least a 50 percent reduction based on the timeline for reduction developed by the commissioner under section 166, and a reasonable estimate of the amount of phosphorus from non-ingested sources entering municipal wastewater treatment systems in calendar year 2003.

Therefore, it is the intent of this memorandum to also:

- Estimate the current phosphorus load entering municipal wastewater treatment plants, referred to as Publicly Owned Treatment Works (POTWs) for the remainder of this memorandum
- Estimate the various sources of phosphorus entering POTWs.

Overview and Introduction to Point Source(s) of Phosphorus

Point sources of phosphorus to Minnesota watersheds typically include domestic (private and public) and industrial facilities that discharge treated wastewater to surface water through distinct discharge points and are regulated under state and federal pollution permit programs. Nonpoint sources of phosphorus, such as stormwater runoff from various land use sources, are not covered in this memorandum. Additionally, this memorandum does not address discharge of wastewater associated with individual sewage treatment system (ISTS) nor does it address wastewater that is land applied.

Wastewater is generated by a number of sources and falls into two categories: Domestic/Household wastewater and Industrial and Commercial wastewater. Wastewater from these two sources is discharged to one of three categories of wastewater treatment facilities (WWTFs); POTWs, privately owned wastewater treatment systems for domestic sources, and industrial wastewater treatment systems. Each of the three categories of point sources is discussed in further detail below.

Publicly Owned Treatment Works (POTWs)

POTWs include wastewater treatment facilities owned and operated by public entities (cities and sanitary districts) usually. These facilities treat varying proportions of domestic wastewater and industrial wastewater. For the purposes of this study, POTWs have been subdivided into the following additional categories:

1. Size (based on Average Wet Weather Design flow)
    a. Small – less than 0.2 million gallons per day (mgd)
    b. Medium – from 0.2 mgd to 1.0 mgd
    c. Large – greater than 1.0 mgd

2. Waste Treated (% by flow volume treated)
    a. POTWs that serve mainly households and residences - less than 20 % industrial or commercial contributions
    b. POTWs that have some commercial or industrial contribution – between 20% and 50% industrial or commercial contributions
    c. POTWs that are dominated by a variety of commercial and industrial contributions – greater than 50% industrial or commercial contributions

Privately Owned Wastewater Treatment Systems

Privately owned wastewater treatment systems include those designated for treatment of domestic sources and that are privately owned and operated. This category of facility is generally small and serves a limited number of residences. Mobile home parks, resorts, and small communities are examples of privately owned wastewater treatment facilities.

Industrial Wastewater Treatment Systems

Wastewater generated as a byproduct of an industrial or commercial process can either be discharged to a POTW for treatment or it can be treated (if needed) on site and discharged to a surface water under its own NPDES permit. Although, typically there is no difference in the type of wastewater generated, these two discharge arrangements are referred to separately in this memorandum for clarity. Those industries discharging to a surface water under their own NPDES permit are referred to as industrial wastewater treatment systems, while the industrial wastewater discharged to a POTW is referred to as an industrial process wastewater. Again, this nomenclature is strictly for the purposes of clarity when discussing industrial wastewater.

The industrial water treatment system category includes industries that discharge their treated wastewater to a surface water under their own National Pollutant Discharge Elimination System (NPDES) permit. In most cases, the wastewater discharged from an industrial wastewater facility is from an industrial process. In some cases, small quantities of domestic wastewater (i.e. employee wastewater) are also included in these discharges. It was assumed that the domestic portion of the wastewater discharges from an industrial facility was minor in comparison to the process wastewater discharge and no attempt was made to separate the two. This category also includes noncontact cooling water.

Sources of Phosphorus

In addition to identifying the point source loading of phosphorus to each basin from each of the three types of treatment facilities (POTWs, privately owned treatment facilities, and industrial wastewater treatment systems), the other goal of this study is to identify the sources and estimate the amount of phosphorus discharged into POTWs. Although not required by the legislation, the sources of phosphorus and an estimate of the amount discharged into privately owned treatment works was also completed. Finally, the major types of industrial discharged were also identified for the industrial wastewater treatment systems. Phosphorus loading to each was categorized into the following sources:

POTWs

The following individual and/or categorical sources of phosphorus were researched for each POTW:

- Commercial/industrial process wastewater sources (including noncontact cooling water)
- Finished water supply and water treatment chemicals (such as polyphosphate compounds or orthophosphate compounds used for corrosion control purposes)
- Industrial and institutional automatic dishwasher detergent
- Residential automatic dishwasher detergent
- Dentifrices (oral hygiene products)
- Groundwater intrusion into sanitary sewers
- Food soils and garbage disposal wastes (food soils include waste food and beverages poured down the sink, and food washed down the drain as a result of dish rinsing and washing)
- Other consumer cleaning products
- Human wastes

Privately Owned Treatment Facilities

The following individual and/or categorical sources of phosphorus were evaluated for each privately owned treatment facility:

- Finished water supply and water treatment chemicals
- Residential automatic dishwasher detergent
- Dentifrices
- Food soils and garbage disposal wastes

- Other consumer cleaning products
- Human wastes

It was assumed that the privately owned treatment systems for domestic use were small and that no industries would be discharging to them. Therefore, the commercial/industrial process wastewater sources, industrial and institutional automatic dishwasher detergent and groundwater intrusion into the sanitary sewers sources were assumed not to contribute to these facilities.

Industrial Wastewater Treatment Systems

The various types of industries discharging phosphorus in their wastewater were identified. For each industrial wastewater discharger, their North American Industry Classification System (NAICS) code number was identified. The NAICS has replaced the U.S. Standard Industrial Classification (SIC) system. This NAICS allowed the data to be sorted by industry type.

The study presents a discussion and the results of phosphorus loading to each of the ten Minnesota watershed basins and for the entire state.

Results of Literature Search and Review of Available Monitoring Data

Identification of the point sources of phosphorus and load estimates was accomplished with existing data and literature information. No direct monitoring of waste streams was undertaken for this portion of the study.

Available Data

Minnesota Pollution Control Agency (MPCA) Database

As authorized by the Clean Water Act, the National Pollutant Discharge Elimination System (NPDES) permit program controls water pollution by regulating point sources that discharge pollutants into waters of the United States (US). This includes all wastewater treatment facilities. The NPDES program requires all point source discharges to obtain a permit and follow the discharge limits and monitoring requirements outlined in the permit. The MPCA administers the NPDES program within the state of Minnesota. The MPCA maintains a database of information required by NPDES permit holders and the monitoring data required by the permit. The MPCA's database for NPDES permit information is referred to as the Delta database. Monitoring is performed by the permit holders and data are sent to the MPCA via hardcopy and entered into the MPCA Delta database by MPCA staff. Data submitted include the monthly averages, maximums and, in some cases, minimums for the required parameters.

Delta is a relatively new database and was phased in beginning in 1998. As permits came up for renewal, the permit information was transferred into the MPCA Delta database. Prior to this time, the MPCA used the Environmental Protection Agency's (EPA), Permit Compliance System (PCS) database to track its data. All NPDES permit information was being entered into Delta by January 2001. Therefore, at a minimum, data from the years 2001, 2002 and the first half of 2003 were used in the analysis report here. It was realized that using data from two and a half years rather than two full years may be a source of slight error due to the potential for seasonal patterns in phosphorus loading. However, it was decided to use two and a half years rather than two full years for several reasons:

- In many cases, the data were for more than the two and a half years (predating January 1, 2001), depending on when the permit came up for renewal,
- The error introduced by the additional half year of data was believed to be minor and would likely be industry-based only due to seasonal variations in production,
- It was believed that the two full years of data would balance out any seasonal variation due to the partial year of data,
- The data set available was limited and using two and a half years rather just the two full years expanded the data set.

The MPCA's Delta data contained data for more than 1,300 separate permits, many with multiple discharge points called stations, and all available phosphorus data contained therein was used for this study.

The specific information provided by the MPCA Delta database is described below:

- Permit number
- Name and location of treatment facility (Latitude and longitude)
- Location of discharges to surface waters from each permit
- Flow monitoring data (Monthly average, total and maximum)
- Phosphorus monitoring data (Monthly average and maximum concentrations)
- Population served by POTW facilities

Although the Delta database was our most important data source, it did not provide complete information for each permit. Phosphorus data are submitted by permittees for Delta database entry when effluent limits are included in permits. Since many permits do not include limits and/or monitoring requirements for phosphorus, there was no phosphorus data available for these permits. As a result, it was necessary to extrapolate phosphorus data from other permit information (e.g. permit application data and basin average phosphorus for similar facilities, etc.). This process and the assumptions are described in detail in subsequent sections of this memorandum. (Detailed information on the data fields for the Delta database are presented in Appendix A)

MNPRO Database

The Minnesota Department of Trade and Economic Development maintains a database (MNPRO) that contains information regarding community profiles for each city in Minnesota. The MNPRO database was used to obtain the following information (see Appendix B):

- A complete listing of Minnesota communities
- Information on the type of wastewater treatment system a community discharges to
- Population of the community
- A list of businesses and industries in each community, the NAICS code and number of employees for each business.

All population data obtained from the MNPRO database were from 2001 estimates. The other data obtained from the MNPRO database were provided by the communities and there may be some variation regarding the dates this information was reported.

Metropolitan Council Environmental Services

The Metropolitan Council Environmental Services (MCES) owns and operates the eight Twin Cities Metropolitan Area wastewater treatment facilities. MCES treatment plants process 300 million gallons of wastewater every day from 2.2 million residents in 104 communities. MCES serves 64 percent of the State's sewered population and flow from the MCES treatment facilities represents 56 percent of the flow discharged from POTWs in the state and nine percent of the total flow discharged from all permitted facilities (POTWs, privately owned treatment facilities and industrial facilities) to the waters of the state. MCES treatment plants discharge treated wastewater to four area rivers: the Minnesota, Mississippi, St. Croix and Vermillion.

The Industrial Waste & Pollution Prevention (IWPP) Section, located within MCES's Environmental Planning and Evaluation Department, regulates and monitors industrial discharges to the sewer system to ensure compliance with local and federal regulations. IWPP Section staff issue Industrial Discharge Permits to industrial users of the Metropolitan Disposal System. Currently, more than 700 permits are in effect. Each permit holder is also required to conduct self-monitoring and submit reports to the IWPP section on a routine basis. The frequency of monitoring and the parameters monitored vary significantly by permit. For each MCES industrial permit holder, MCES provided the following information (See Appendix C):

- Name and location of permit holder
- SIC code number for each permit holder (was converted to NAICS code number)
- Flow and phosphorus estimates (phosphorus data were not available for all permit holders)
- Employee counts

Minnesota Department of Health (MDH)

The Minnesota Department of Health (MDH), the agency that regulates the quality of drinking water supplies in Minnesota, provided a list of communities that supplemented their water supply with continuous phosphate additions (for corrosion control for lead and copper, and iron and manganese sequestration) from 2001 to 2003 (see Appendix D). All public water systems in the state took part in an initial round of lead and copper testing that ended in 1994. The water was tested in a number of homes within each system, to determine if they exceeded the federal “action level” of 15 parts per billion (ppb) for lead or 1,300 ppb for copper. If a system exceeded the action level for lead or copper in more than 10 percent of the locations tested, it was required to take corrective action (such as the addition of phosphate to provide corrosion control for lead and copper) and do further testing. Lead and copper in drinking water is not an environmental contamination problem in the conventional sense. Water is almost never contaminated with lead or copper at the source, or when it first enters the distribution system. However, water can absorb lead and copper from plumbing components used in individual homes. Possible sources of lead contamination include lead pipe, lead plumbing solder, and brass fixtures. Lead exposure is a potentially serious health concern, especially for young children.

The MDH list provided the water treatment facility's annual flow rate for all 360 of the systems that add phosphorus. In addition, they provided the residual phosphorus concentrations for the 120 systems that are required to add phosphorus for corrosion control. MDH staff (Dick Clark) provided an estimate of the phosphorus concentration of the water in the communities that add phosphorus for iron and manganese sequestration and are not required to monitor. He stated that he believed they added between 2 mg/L to 2.5 mg/L as phosphate (0.6 mg/L to 0.83 mg/L as phosphorus). These data were used to calculate the total phosphorus contribution to the POTWs from the municipal water supplies.

Minnesota Pollution Control Agency (MPCA)

Discussions with MPCA staff (Deborah Schumann, Personal Communications) provided a list of the water sources for most of the noncontact cooling water dischargers in the state. Information on noncontact cooling water additives was also provided by MPCA staff.

Minnesota Communities

A number of Minnesota communities were contacted to obtain data or to verify information regarding their wastewater treatment facilities (see Appendix E). The types of information provided by these communities included:

- Industrial Phosphorus Data. Fourteen out-state (non-metro) communities with industrial phosphorus monitoring programs were contacted and provided data on influent loadings from industrial and commercial dischargers to their wastewater treatment facilities.
- Population Data. Many communities were contacted to determine the population served by the wastewater treatment facility.
- Industrial Discharge Information. Many communities and industries were contacted to verify the type and volume of wastewater discharge from an industrial source.

Literature Review

A number of literature sources, including the following, were reviewed to obtain information on the sources of phosphorus to wastewater treatment facilities.

Chemical Economics Handbook – Industrial Phosphates - The Chemical Economics Handbook (CEH) is published by Stanford Research Institute (SRI), International, and provides comprehensive analysis, historical data and forecasts pertaining to the industrial phosphorus market. Detailed supply and demand data are presented for the United States, Western Europe and Japan. The handbook provides detailed information on the mass of phosphorus consumed annually in the United States for major commercial, nonagricultural phosphate chemical products. The report provided historical data for the years 1984 through 2000 and forecasted data for the year 2005 for the following major commercial products:

- Detergent builders
- Water supply chemicals
- Food and beverages
- Dentifrices (such as toothpaste, etc.)

Metcalf and Eddy, Inc., Wastewater Engineering, 1991 is a well-respected reference in the field of wastewater treatment. This text discusses the components that make up wastewater as well as the typical wastewater flow rates and characteristics.

A number of studies were conducted in the late 1970's and early 1980's that analyzed residential wastewater. These studies segregated wastewater from toilets (human wastes), garbage disposals, dishwashing water, food soils, baths and showers, laundry discharges, and automatic dishwasher detergent, and provided typical flow rates and pollutant characteristics (including phosphorus) for each of these sources. The studies noted that while bath and shower wastes contributed to the hydraulic load from residences, there was little to no phosphorus from these sources. They did provide a phosphorus concentration from laundry discharges, but this study was conducted prior to the laundry detergent phosphorus ban. It was assumed that laundry wastes no longer contribute any phosphorus to wastewater.

These studies found the following to contribute phosphorus to residential wastewater:

- Human wastes
- Garbage disposals
- Dishwashing water
- Food soils
- Laundry discharges (These studies were completed prior to the ban on phosphorus in laundry detergent)
- And automatic dishwasher detergent

The data were provided in terms of daily per capita use rates. It was assumed that no major changes had occurred in the estimates for human waste, garbage disposal waste, and food soils and these data were used to estimate source amounts discharged to wastewater treatment facilities.

Ligman, Hutzler and Boyle (1974) characterized the types of wastewater generated in a domestic household. They surveyed a total of 50 rural and urban households to determine the various sources and amounts of wastewater generated from the bathroom, the kitchen and the laundry. They also characterized the pollutants generated from each type of wastewater discharge. A statistical analysis of data from rural households as compared with urban residences indicated no significant difference in wastewater pollutant loads.

Siegrist, Witt, and Boyle (1976) characterized waste flows from individual rural households. Eleven rural homes were monitored and the wastewater flows and water quality characterized. The results of this study presented the mean wastewater contribution from various sources on a mass per capita per day basis. The wastewater sources studied included fecal toilet flush, nonfecal toilet flush, garbage disposal waste, kitchen sink waste, automatic dishwasher usage, clothes washer-wash, clothes washer-rinse and bath/shower usage. They found that on average human waste contains approximately 1.6 grams of phosphorus per person per day.

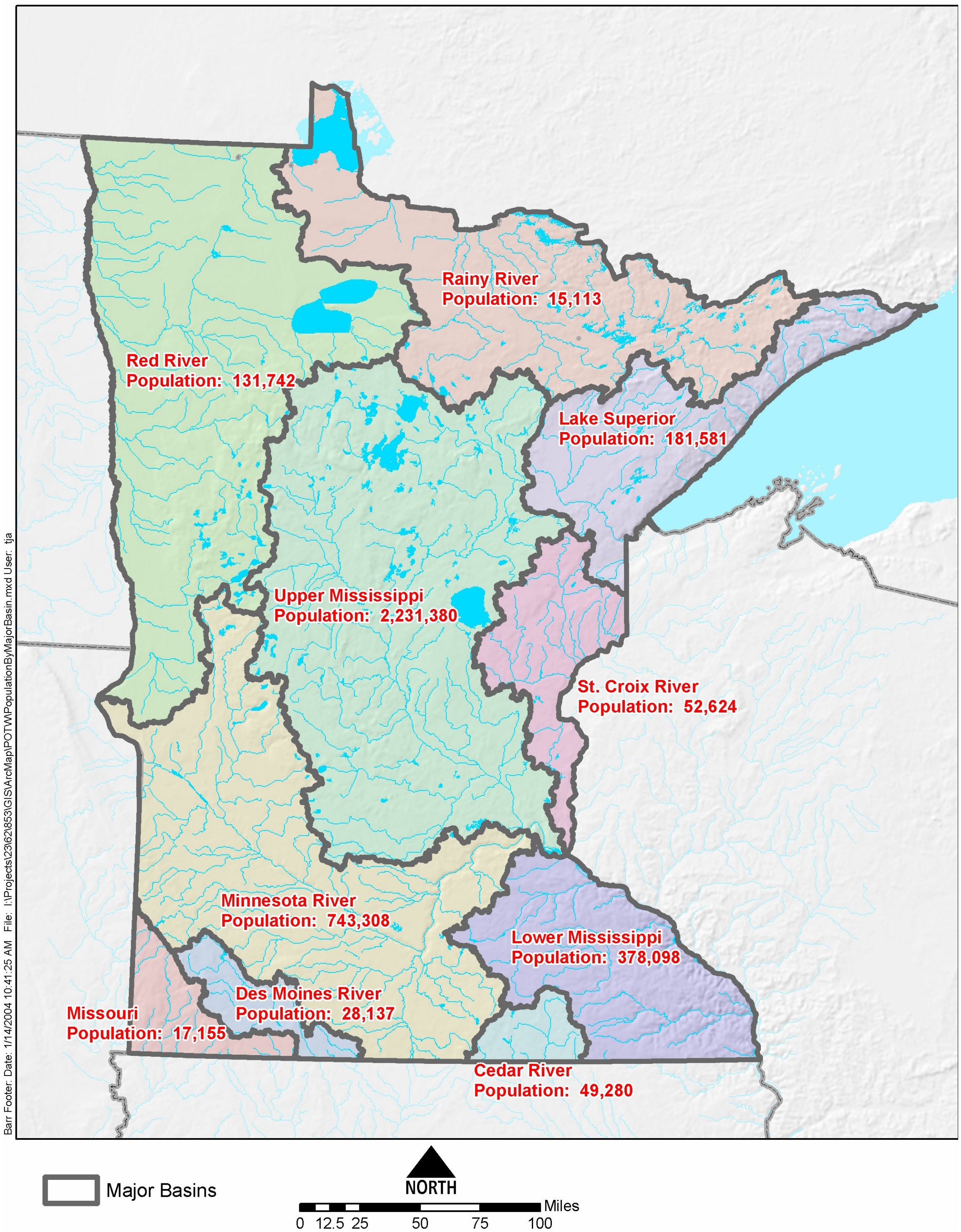
Boyle, Siegrist and Saw (1982) focused on treatment of graywater, but also provided a summary of the characterization of wastewater from households.

Strauss (2000) provided information on the nutrient concentration in human waste. He states that humans excrete in the order of 2 grams of phosphorus per day.

Watershed Basin Characteristics

Wastewater treatment plants are the main point source inputs of phosphorus to Minnesota watersheds. Therefore, it follows that inputs of point source phosphorus depends on the sewered population and number of industries in an area. Figure 1 provides a map of Minnesota showing the sewered population to POTWs and privately owned treatment facilities of the ten major watershed basins. As this map indicates, the Upper Mississippi basin has the largest sewered population, exceeding the other basins by an order of magnitude. The sources of phosphorus may also vary by watershed basin. For example, the Cedar River basin has little industry and it is expected that the majority of the phosphorus contribution in that basin would come from POTWs.

FIGURE 1
Sewered Population of Major Basins
(2000 Census)



Approach and Methodology for Phosphorus Loading Computations

The goal for determining the point source phosphorus loading for each of the watersheds consists of two parts. The first part is to quantify the point source loadings discharged to each of the watershed basins. The second is to identify the component sources of phosphorus in wastewater discharged into each of the POTWs. The process required to achieve these goals involved a multitude of steps and activities. This effort included collecting, processing and reviewing thousands of data points from a number of sources. The major data sources were discussed previously and the following paragraphs discuss the approach followed, assumptions made, and methodology used for accomplishing these goals.

The first phase of this study was to gather available data. The objectives were to:

- Obtain actual facility influent and effluent flow rates
- Obtain facility-specific phosphorus influent and effluent concentrations
- Obtain as much actual industrial discharge information as available given the schedule, both flow rate and phosphorus concentration
- Obtain actual data on phosphorus concentrations in finished water supplies
- Obtain actual data on infiltration and inflow to wastewater treatment systems, and
- Obtain literature values for the various components of the wastewater influent

After the data gathering phase, extensive data processing and quality assurance activities were performed in preparation for load calculations. These tasks are described in the paragraphs that follow.

Phosphorus Point Sources and Amounts to Waters of the State

The point source phosphorus loads to surface waters from each of the three types of treatment facilities were estimated by determining the average annual flow rate for each point source discharger and multiplying it by the average annual phosphorus concentration. Because there was limited data for some dischargers, monthly averages at best, it was decided to estimate the phosphorus load by calculating the average annual flow and multiplying it by the average annual phosphorus concentration. The phosphorus load to each basin was calculated as the sum of the loads from each point source discharger within the basin. It should be noted that sewershed boundaries do not always agree with the watershed boundaries and the assignment of point source loads to a watershed basin was based on the point of discharge to waters of the state. In some cases the phosphorus load may have been generated in other basins and sewered to a wastewater treatment plant in another basin for treatment and discharge.

Influent and Effluent Flow Data

Data on all municipal, private and industrial and commercial dischargers were obtained from the MPCA Delta database. The Delta database provided information for a total of 1,307 permitted dischargers. Because this information determined which facilities and which stations discharged to a surface water and which did not, a significant level of effort was paid to reviewing this information. As a first step, the stations for each permit were reviewed to verify that a valid discharge to a surface water was occurring for each station in each permit. As a result of this review, many stations and some entire permits were deleted from the database used for this study. The following stations were deleted for this study:

- Stations that represented a discharge to land,
- Stations that strictly represented a stormwater runoff discharge,
- Permits that had no influent and effluent flow data. It was assumed that if there was no data for either the influent or the effluent stations, that there had been no discharge from that facility.

As a result of this process the total number of stations (or outfalls) was reduced from 7,861 to 1,510 and the total number of permits was reduced from 1,307 to 910.

The NPDES discharges were separated into the following categories as part of the review process:

- Domestic vs. industrial flow was verified. In some cases, the Delta database designation was modified. For example, prisons and schools were changed from an industrial source to a domestic source
- Noncontact cooling water sources were noted, and
- Mine pit dewatering sources were noted

Next, the influent and effluent flow rates for the NPDES surface water permits and stations were reviewed. If only influent flow data were available from the Delta database, the effluent flow was assumed to be equal to the influent flow, because loss through the wastewater treatment process is minimal. Similarly, if only effluent flow rates were available from Delta, the influent flow rates were assumed to be equal to the effluent flow rates. Pond systems presented a challenge in that they discharge infrequently and, when they do, the flow rate is relatively high. For many pond systems there was no discharge information available because they had not discharged during the period of record. Conversely, in other instances the average annual effluent flow from a pond system greatly exceeded the annual average influent flow. Because is was not possible to determine the time period between discharge events and therefore the average annual effluent flow rate, it was assumed that there was no net loss of wastewater from the pond system and the average annual effluent flow rate was assumed to be equal to the measured influent flow rates for pond systems. For industrial wastewater treatment systems, only effluent flow data were required.

Next, the flow rate data were validated. All flow values were converted to million gallons per day (mgd) and then averaged for each permit and station combination. The standard deviation was calculated for each permit station. Permits with high standard deviations raised concern, and the monthly flow rate data for the individual permits were manually reviewed. By reviewing multiple years is was relatively easy to spot the general trend in discharge rates and correct obvious errors.

Once the data validation was complete, average annual influent and effluent flow rates were calculated for each facility.

Treatment Plant Influent and Effluent Phosphorus Loadings

To meet the goals of this study, it was necessary to determine both the influent phosphorus loads discharged into the POTWs and privately owned treatment facilities and the effluent phosphorus load being discharged from the POTWs and privately owned treatment facilities along with the effluent loads from the industrial wastewater treatment systems. The approach used to determine the phosphorus loading from each of the three types of facilities to the basin is very similar and is described below. Phosphorus loads were determined by multiplying the influent and effluent flow rates discussed above by the influent and effluent phosphorus concentrations, respectively. Phosphorus concentration data was obtained from the Delta database. In some cases, determining the phosphorus concentration from each discharger was complicated by the absence of phosphorus data. Delta phosphorus data are submitted by permittees for Delta entry when effluent limits or monitoring requirements are included in permits. Since many permits do not include limits and/or monitoring requirements for phosphorus, there were no effluent phosphorus data available for these permits. In addition, many facilities that have an effluent phosphorus limit monitor only the effluent phosphorus and do not monitor the influent phosphorus concentrations. 78 percent of the POTWs (which represents 88% of the flow), 52 percent of the privately owned treatment facilities (which represent 80 percent of the flow); and 22 percent of the industrial treatment facilities had effluent phosphorus data (which represents 7 percent of the flow). For these reasons, it was necessary to estimate phosphorus concentrations from other sources. Table 1 summarizes the availability of phosphorus data from the Delta database.

Table 1
Summary of Phosphorus Data

Treatment Facility Category	Total No. of Permits	Percent of Permits with Influent Phosphorus Data	Percent of Flow with Influent Phosphorus Data	Percent of Permits with Effluent Phosphorus Data	Percent of Flow with Effluent Phosphorus Data
POTW	534	71%	87%	78%	88%
Privately Owned Treatment Facility	42	31%	59%	22%	80%
Industrial Wastewater Treatment Facilty	315	NA	NA	69%	7%
Total	891	44%	87%	57%	20%

NA: Not Applicable

Effluent phosphorus data was available for approximately 505 POTWs, privately owned treatment works and industrial point source dischargers. Influent phosphorus data was available for 393 POTWs and privately owned treatment facilities. The annual influent and effluent phosphorus loads for each wastewater treatment facility and the effluent phosphorus loads for the industrial sources for which data were available were estimated as the products of the average phosphorus concentrations and flow rates extrapolated over the monitoring period.

Missing POTW and privately owned treatment facility effluent phosphorus concentrations were estimated by assuming the calculated basin average phosphorus (as described in the previous paragraph) for similar facility types. In a limited number of cases calls were made to the permittee to verify the phosphorus effluent concentrations. Missing influent phosphorus data were also estimated from basin average influent data for similar facilities.

Effluent phosphorus concentrations for industrial wastewater treatment systems that did not have monitoring data were estimated from phosphorus data for industries with like NAICS codes. This process is described in detail in subsequent paragraphs.

Noncontact Cooling Water

Certain commercial and industrial users discharge noncontact cooling water directly to surface waters. Noncontact cooling water dischargers were identified through review of the NPDES permit data. When available, the amount of phosphorus in these discharges was calculated from data contained in the Delta database. In most cases, however, no phosphorus data were available. For each noncontact cooling water discharge, the source of the water was identified as were additions of phosphorus-based corrosion control chemicals. In calculating the phosphorus loads associated with noncontact cooling water, reported data on discharge volumes and phosphorus concentration were used whenever they were available. However, when the phosphorus concentration of noncontact cooling water was not specified in the permit data, the source of the cooling water was determined and any information on phosphorus additives was investigated. Most of this information was available from MPCA staff (D. Schumann, Personal Communication) familiar with the industries discharging cooling water. This provided a basis to estimate the phosphorus concentration. For example, if the source of the cooling water was the municipal water supply and no phosphorus was added, it was assumed that the phosphorus concentration discharged was equivalent to the municipal water supply value. If the source of the cooling water was an on-site well, the phosphorus concentration was assumed to be equal to the groundwater phosphorus concentration. Finally, if the source of the cooling water was the same body of water that received the effluent and no phosphorus was added for water treatment, it was assumed that there was no additional phosphorus load to the surface water.

Phosphorus Sources and Amounts to POTWs and Privately Owned Treatment Facilities

Although the 50 percent reduction goal required by Minnesota Laws 2003, Chap. 128 Art. 1, Sec. 122 applies only to the influent to POTWs and does not apply to the influent to privately owned treatment facilities, information on the phosphorus sources to both POTWs and privately owned treatment facilities is presented for comparison and completeness. The various sources of influent wastewater entering POTWs and privately owned treatment facilities were estimated separately by the techniques described below.

Population Data

Because much of the information gathered during the literature search for the various components of the influent wastewater was based on per capita values, it was necessary to accurately determine the population served for each of the POTWs and privately owned wastewater treatment facilities. The population served for each facility was not readily available for all of the permitted facilities. Therefore, the following stepwise approach was taken:

1. MPCA Delta Database. When available, the population served by a treatment facility as listed in the Delta database was used. Approximately 230 of the permits had population data listed in the Delta database. However, through phone calls to individual wastewater treatment plant operators, some of these numbers were modified based on their comments.

2. MNPRO Database. If population data were not available from the Delta database, the population of the community corresponding to the permit was assumed to equal the population served by the WWTF. This information was obtained from the MNPRO database.

3. ISTS Information. Information obtained on ISTS and unsewered communities was obtained from MPCA as described in the Individual Sewage Treatment Systems/Unsewered Communities Technical Memorandum. These communities and the populations served by ISTS systems were compared to the communities having an NPDES permit as listed in the Delta database. If a community had both a NPDES permit to discharge to a surface water and was also listed has being served by an ISTS, the difference of the City's population and the ISTS population was used as the population served by the treatment facility. If no information could be located, the permit holder was contacted to verify the population served by each system.

4. MNPRO Database. The complete listing of communities within the state of Minnesota as contained in the MNPRO database was compared to both the NPDES list and the unsewered communities list to verify that all communities within the state were accounted for. Any community with a population greater than 1,000 that was unaccounted for was contacted by

telephone and the final disposition of their wastewater was determined. In many cases these communities transferred their wastewater to another community's treatment facility.

5. Communities with a population of less than 1,000 persons that did not have either an NPDES permit, were not listed in the ISTS database or were not listed as an unsewered community were assumed to be served by an ISTS system.

No information was available regarding septage hauled to the POTWs and therefore no estimate of this source was made.

Commercial and Industrial Process Wastewater

A wide variety of commercial and industrial operations discharge wastewater into the waters of the state. Some have direct discharges under their own NPDES permits as discussed in previous paragraphs while others discharge into POTWs under terms of city-issued wastewater discharge permits. Industrial process discharge monitoring data from MCES were collected for the eight MCES facilities. In addition to the MCES data, commercial and industrial process monitoring data were collected from the cities of Luverne, Melrose, Moorhead, St. Cloud, Winona, Faribault, Glencoe, New Ulm, Owatonna, Plainview-Elgin, Rochester, Zumbrota, Mankato and Marshall. In addition to the industrial monitoring data, the NAICS code number and number of employees were also obtained. Using this information, the estimated phosphorus load per employee was calculated for the various NAICS code numbers.

This information was used to estimate the industrial/commercial process wastewater component of the POTW phosphorus loads. The quantities of phosphorus discharged to the sewer system by commercial and industrial operations for which data were obtained was estimated by extrapolating discharge data to an annual total.

The data collected were categorized by NAICS code numbers for the commercial or industrial operation monitored, and included flow volumes and total phosphorus concentrations. NAICS code numbers are six digit numbers that organize similar industries into groups for statistical reporting purposes. Industries with the same six digit codes are virtually the same, in terms of the product(s) they produce or the service(s) they provide, although operational differences may result in wastewater discharges of varying quality. Industries having NAICS codes with the same first five and four digits are in the same general industry group, but produce slightly different products or offer slightly different services. These records were used to estimate the Industrial and Commercial wastewater components of the POTW phosphorus loads where no data were available. This monitoring data collected as described above provided a database of industrial and commercial phosphorus loading by NAICS code and by employee count. For some industries there was good agreement in data, and in others there was significant variation. The industrial data set for each NAICS code number was reviewed. If there was significant variation in data, such as a single outlier when numerous other data points were in agreement, the outlier was not used in the industrial database. An average phosphorus load per employee was then calculated for each NAICS code number. Employee count was used as the method of adjusting the phosphorus load for the variation of industry sizes within a NAICS code number. The MCES industrial information received had employee count available for most of the facilities permitted. In addition, MNPRO listed the employee count for all the industries in their database. Appendices B, C and E present the industrial information collected as part of this study.

The industries in communities that did not have monitoring data were identified from the MNPRO database. The employee counts and NAICS code numbers were also obtained. The following process was used to estimate phosphorus discharges from industries for which no data were available:

- First, exact six digit matches to database were identified and these per employee phosphorus discharge rates were applied,
- Then five digit matches were identified for the remaining permits,
- Then four digit matches,
- Finally, if no match was found at the four-digit level, then no estimate of the phosphorus contribution was made.

There were a number of industries that did not have a match from the industrial database developed from the industrial process MCES and out-state information. The industrial process wastewater phosphorus loads to each POTW was reviewed and verified by completing a check on the influent sources. A per capita estimate for the human waste contribution to POTWs was used and the sum of the phosphorus load from all the sources was compared to the influent phosphorus value. These numbers were in agreement for each basin on a whole. There was some variation when reviewed on an individual treatment plant basis.

Water Supply Treatment Chemicals

Phosphorus-based chemicals, primarily polyphosphate compounds or zinc orthophosphate, are sometimes used for corrosion control and metal sequestration purposes in water supply systems as well as industrial process water. It was assumed that the phosphorus load from the industrial process water would be accounted for in the industrial wastewater component and this section accounts only for the phosphorus added to municipal water supplies. The phosphorus-based chemicals add phosphorus to the water supply, either on a continuous or episodic basis. Discussions with staff of the Minnesota Department of Health (L. Rezania, Personal Communication), the agency that regulates the quality of drinking water supplies in Minnesota, provided a list of community water supplies that are supplemented with continuous phosphate additions for the years 2001 through mid-year 2003 (see Appendix D). The MDH found 360 systems that use a phosphate based chemical in their drinking water treatment process. Approximately 120 of these systems are required to add phosphorus under the corrosion control program. The MDH provided the average residual phosphorus concentration in the water supply for the systems that are required to add phosphorus and monitor and monitor their residual. The average residual phosphorus concentration was about 0.75 mg/L as phosphorus for the communities that monitored for phosphorus. This agreed with the estimate of 0.66mg/L to 0.85 mg/L provided by MDH staff. This average value was used for each of the communities that were known to add phosphorus, but for which there was no concentration data available.

Literature values (Metcalf and Eddy, 1991) indicate that, on average, 70 percent of the water supplied from a water treatment facility is discharged back into a wastewater treatment facility. This information was used to calculate the finished water phosphorus contribution to each facility. The phosphorus contribution from municipal water supplies to a POTW was calculated by estimating the annual phosphorus mass used in treatment of the water supply from the MDH data and assuming 70 percent of it is discharged to the POTW.

Residential Automatic Dishwasher Detergents (ADWD).

Automatic home dishwashing detergents may contain up to 11 percent phosphorus, by weight, according to Minnesota Rule Chapter 7100.0210. However, they typically average between 6 and 8 percent phosphorus, by weight, based on an informal store-shelf survey conducted as part of this project. According to the SRI report, although the demand for ADWD products has increased, the overall consumption of phosphorus in ADWD products has declined slightly. The major reason for the decline was the loss of the market for chlorinated trisodium phosphate (TSP-chlor) as more nonphosphate dishwashing formulations are being developed as well as a trend toward the use of tablets and liquids with a slightly lower phosphate content. Powder dishwashing products have historically contained about 9 percent phosphorus (as phosphorus) while liquid automatic dishwashing detergents contain only 5.7 percent phosphorus (as phosphorus). The SRI report states that although nonphosphate automatic dishwashing formulations are being developed, marketable products are not presently considered to be a serious threat because the alternatives are abrasive and costly. Total phosphorus consumption in home dishwashing detergents has declined by about 7 percent between 1993 and 2000, and values for 2002 are expected to be just below those obtained for 2000.

To estimate the residential ADWD component of the WWTF phosphorus loads, we referred to the Stanford Research Institute (SRI), an organization that tabulates raw material utilization and finished product generation for a wide variety of industries, world-wide. Using 2000 data on annual phosphate utilization for ADWD formulation in the United States (26,400 short tons, as phosphorus) from the SRI publication Chemical Economics Handbook - Industrial Phosphates, and the estimated U.S. population for 2000 (ca. 281,421,906), the estimated per capita ADWD usage was 0.085 kilograms per capita per year (kg/p·yr). This use rate was applied to the population served by each of the POTWs and privately owned treatment facilities to estimate the ADWD components of the phosphorus loads.

Commercial and Institutional Automatic Dishwasher (ADWD) Detergents

Minnesota Rules 7100.0210 B. requires both residential and commercial ADWD to be less than 11 percent by weight. Commercial and institutional ADWD are used in restaurants, cafeterias, hotels, hospitals and other institutions, etc. These facilities are not considered as part the commercial and industrial process wastewater phosphorus contribution discussed in previous paragraphs and were accounted for separately from the other commercial and industrial cleaners. To estimate the commercial and institutional ADWD component of the influent POTW phosphorus loads, information from the SRI report was again used. Using 2000 data on annual phosphate utilization for commercial and institutional ADWD formulation (12,300 short tons, as phosphorus) from the SRI publication Chemical Economics Handbook - Industrial Phosphates, and the estimated U.S. population for 2000 (ca. 281,421,906), the estimated per capita commercial and institutional ADWD usage was 0.04 kg/p·yr. This per capita use rate was applied to the population served by each of the POTWs to estimate the commercial and industrial ADWD components of the phosphorus loads. To provide an accurate account, the per capita use rate was also applied to the population served by each privately owned treatment facility. Because it is unlikely that any commercial or industrial ADWD is discharged to a privately owned treatment facility for domestic use, this phosphorus load was then assigned to the POTWs.

Other Consumer Products

The SRI report provides information regarding the phosphorus used in the production of other consumer products such as scouring cleaners (Comet® and Ajax®) and home cleaners (Spic & Span® and Lime Away®) and reports that approximately 3,600 kg/yr are consumed in the United States for the production of these cleaners. However, the Minnesota ban on phosphorus limits the phosphorus content of all household cleaners to 0.5 percent, by weight, according to Minnesota Rule Chapter 7100.0210. An informal store-shelf survey verified that these cleaning products state that they contain no phosphorus. A call was also made to the manufactures of these products and they verified that phosphorus is longer used in the production of these products. Therefore, it was assumed that there was no phosphorus contribution from these products and no further discussion of this source is provided in this memorandum.

Food Soils/Garbage Disposal Waste

Several sources were reviewed to determine the phosphorus loading to WWTFs from garbage disposals and from food soils (*Siegrist, 1976 and Boyle et al, 1982*). For the purposes of this report, food soils are defined as waste beverages and food washed down the sink and food washed down the sink through dish rinsing and dish washing. Although most of the research conducted on phosphorus loadings from these sources was conducted in the late 1970's and 1980's, it was assumed that the phosphorus loading from this source has not changed substantially on a per capita basis over time. The most recent value of 0.1895 kg/p·yr was used as the rate applied to the populations served by each of the WWTFs to determine the phosphorus loading from this source. Approximately

25 percent of the phosphorus from this source can be attributed to garbage disposal wastes and the other 75 percent is from food soils washed down the sink during dish rinsing and dish washing.

Dentifrices

Dentifrices are substances such as toothpaste and denture cleaners. Data on annual phosphate utilization in dentifrices was available from the SRI publication Chemical Economics Handbook - Industrial Phosphates. Using 2000 data on phosphate consumed in dentifrices in the U.S. (3,560 short tons as phosphorus) and the estimated U.S. population for 2000 (ca. 281,421,906), the estimated per capita phosphorus contribution from dentifrices was 0.0115 kg/p·yr.

Industrial and Institutional Cleaners

Minnesota rules on cleaning agent phosphates limits the phosphorus content of household cleaning agents to 0.5 percent phosphorus, by weight. However, commercial and institutional cleaners are not covered by this rule, and may use phosphate-based cleaners. These institutional and industrial cleaners are used in dairies, meat processing plants, breweries and so forth. They are also used in scouring agents in commercial laundries and in metal and tile cleaners and in sanitizers. Finally, cleaning compositions for the exterior of vehicles, particularly trucks and buses, commonly use phosphate builders. Data on annual phosphate utilization for industrial and institutional cleaners was available from the SRI publication Chemical Economics Handbook - Industrial Phosphates. However, further evaluation of this source indicated that most of the facilities discharging industrial and commercial cleaners would be accounted for in the industrial and commercial process wastewater component. To avoid double counting, this source was not categorized separately.

Car Washes

An attempt was made to determine the phosphorus loading from car and truck washes. Unfortunately, there were no data available to determine either the amount of flow or the number of car washes discharging to Minnesota POTWs. In addition, it is becoming common for car washes to recycle or reuse wash water. Therefore, no phosphorus load estimate for this source was made in this report.

Inflow and Infiltration

Measurable effects from inflow and infiltration (I & I) can be seen at WWTFs. The amount of I & I entering the sewer system and eventually making its way to the WWTF depends on the age of the sewer system piping, the total length of the sewer system piping and the joint construction of the sewer pipes. It was not within the scope of this study to determine the specific I & I loading for each WWTF, instead an average infiltration rate was obtained from data provided by MCES. They provided average annual I & I flow estimates for their eight wastewater treatment facilities. These facilities vary in size and age and were considered to be representative of the systems throughout the state. The average I & I rate was approximately 10 percent of the total influent annually for the eight Twin Cities Metropolitan Area wastewater treatment facilities operated by MCES.

The phosphorus concentration in the I & I was estimated from data provided by the MPCA. The MPCA provided information on phosphorus concentrations for each of the aquifers underlying the state. An average phosphorus concentration of 0.035 mg/L was assumed to be representative of the shallow groundwater throughout the state.

Human Waste

Human waste-derived phosphorus was separated from the total phosphorus load to each of the POTWs and privately owned treatment systems by difference, subtracting all other estimated phosphorus contributions from the total phosphorus inflows. This value was converted to a per capita value and was validated by comparing it to literature values for blackwater (ingested human waste). Literature values ranged from 1.2 grams of phosphorus per capita per day (g/p·d) (*Boyle et al.*, 1982) to 2 g/p·d (*Strauss*, 2000).

Results of Phosphorus Loading Computations and Assessments

This section is divided into two parts. The first part discusses the sources and amounts of phosphorus being discharged to the influent to POTWs and privately owned treatment facilities and the second part of this section discusses the results of the effluent phosphorus loading to waters of the state from POTWs, privately owned treatment facilities and industrial treatment facilities.

Phosphorus Sources and Amounts to POTWs and Privately Owned Treatment Facilities

The sources of phosphorus to POTWs and to privately owned treatment facilities were identified and quantified by the methods described in the Approach and Methodology section. The total phosphorus load discharged to POTWs is presented by basin in Table 2. The total phosphorus discharged into POTWs in Minnesota is estimated to be 4,468,000 kg/yr.

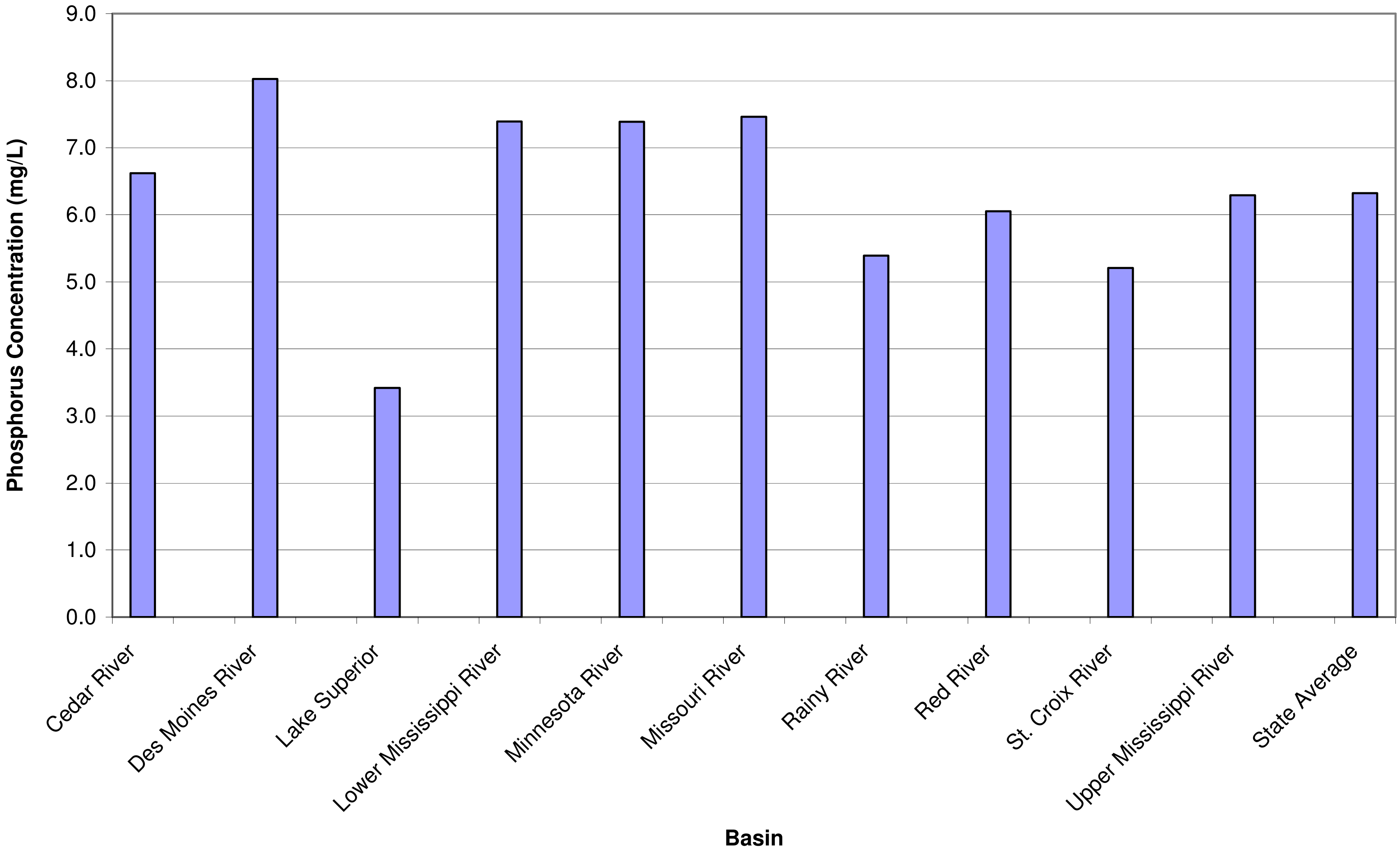
Although flow to the treatment facilities varied seasonally, the phosphorus load to the POTWs and privately owned treatment facilities remained fairly constant through the year. Therefore, the phosphorus contribution to and from the various treatment facilities was assumed to be constant throughout the year and at low flow, mean flow, and high flow levels for rivers and streams.

Table 2
Total Phosphorus Load Discharged to POTWs

	Total (kg/yr)
Basin	
Cedar River	105,200
Des Moines River	46,200
Lake Superior	227,000
Lower Mississippi River	501,900
Minnesota River	952,200
Missouri River	26,400
Rainy River	20,100
Red River	150,600
St. Croix River	53,500
Upper Mississippi River	2,384,900
Total	4,468,000

Figure 2 illustrates the flow weighted mean influent phosphorus concentration discharged into POTWs and privately owned treatment facilities for the ten Minnesota watershed basins and the state. The flow weighted mean concentration for the state was estimated to be 6.2 mg/L. Metcalf and Eddy (1991) have classified wastewater phosphorus concentrations of 4, 8 and 15 mg/L as being “weak”, “medium” and “strong”, respectively. Based on this information, it would appear that the average influent phosphorus concentration to wastewater treatment facilities in Minnesota is relatively weak based on this number.

Figure 2
Flow Weighted Mean Influent Phosphorus Concentration to POTWs and Privately Owned Treatment Facilities



As part of this study, the influent phosphorus discharged into POTWs and publicly owned treatment facilities was separated into its major constituent sources. The following individual and/or categorical sources of phosphorus were evaluated:

- Residential Automatic Dishwashing Detergents
- Food Soils and Garbage Disposal Wastes
- Dentifrices
- Human Wastes
- Commercial and Industrial Wastewater
- Commercial Automatic Dishwashing Detergents
- Water Treatment Supply Chemicals
- Inflow and Infiltration

The domestic wastewater influent sources of phosphorus were also categorized for privately owned wastewater treatment facilities. These sources included:

- Residential Automatic Dishwashing Detergents
- Food Soils and Garbage Disposal Wastes
- Dentifrices
- Human Wastes
- Water Treatment Supply Chemicals

As discussed previously, phosphorus in other consumer cleaning products was also investigated, but it was determined that these products no longer contain phosphorus and no further discussion is provided in this memorandum.

The results of this portion of the study are presented in several different ways to provide as much information as possible. Note that when the results of the influent sources discharged into the POTWs and privately owned treatment facilities are being presented, they are expressed in terms of the influent concentration and the fraction of the influent phosphorus load to the POTW or privately owned treatment facility. Figures 3A and 3B illustrates the contributions of various phosphorus sources to the influent phosphorus loads for the POTWs and privately owned treatment facilities. For clarity purposes, the scales on the two figures differ.

Figure 3A
Influent Phosphorus Loading To POTWs & Privately Owned Treatment Facilities By Basin

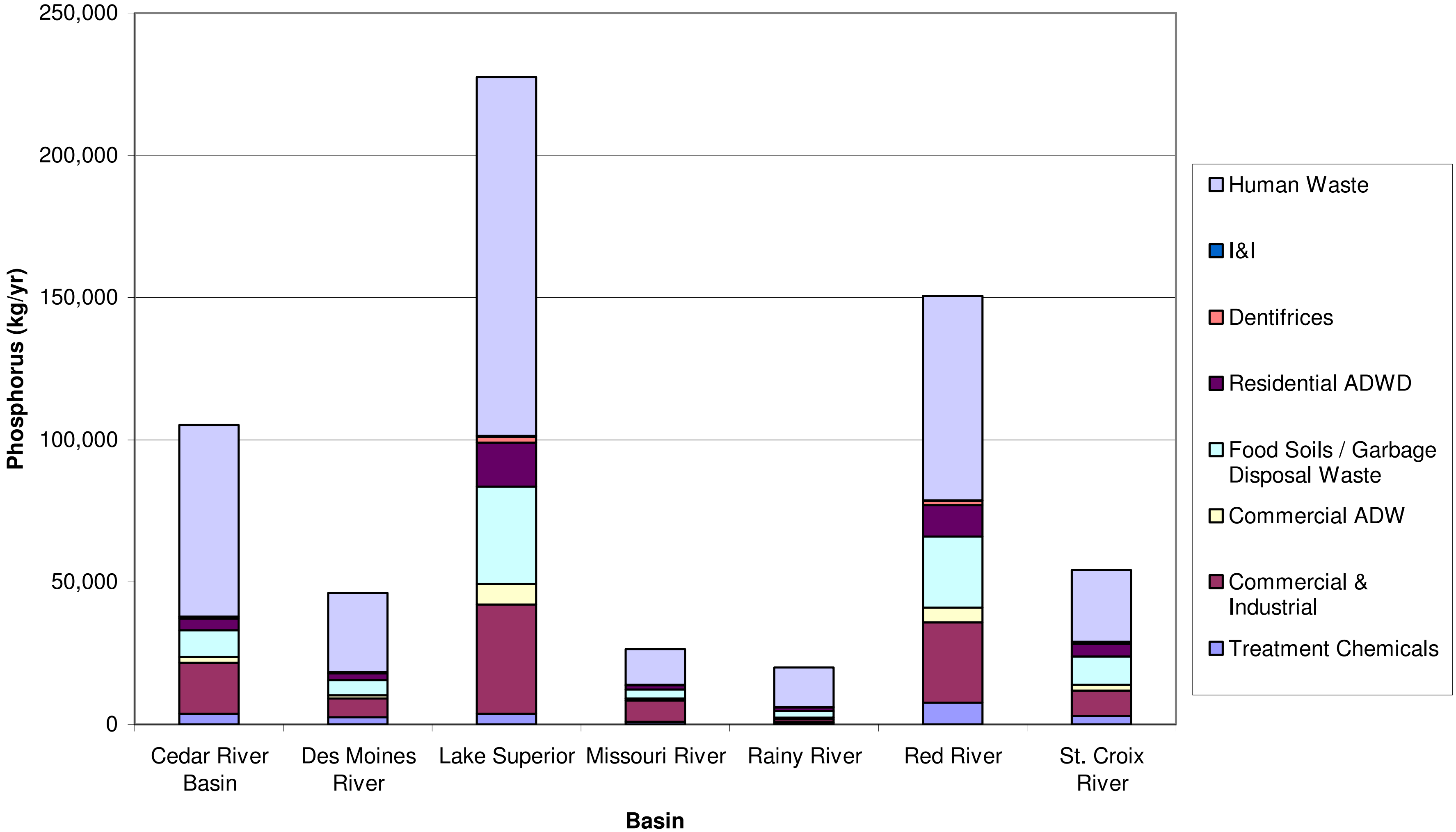
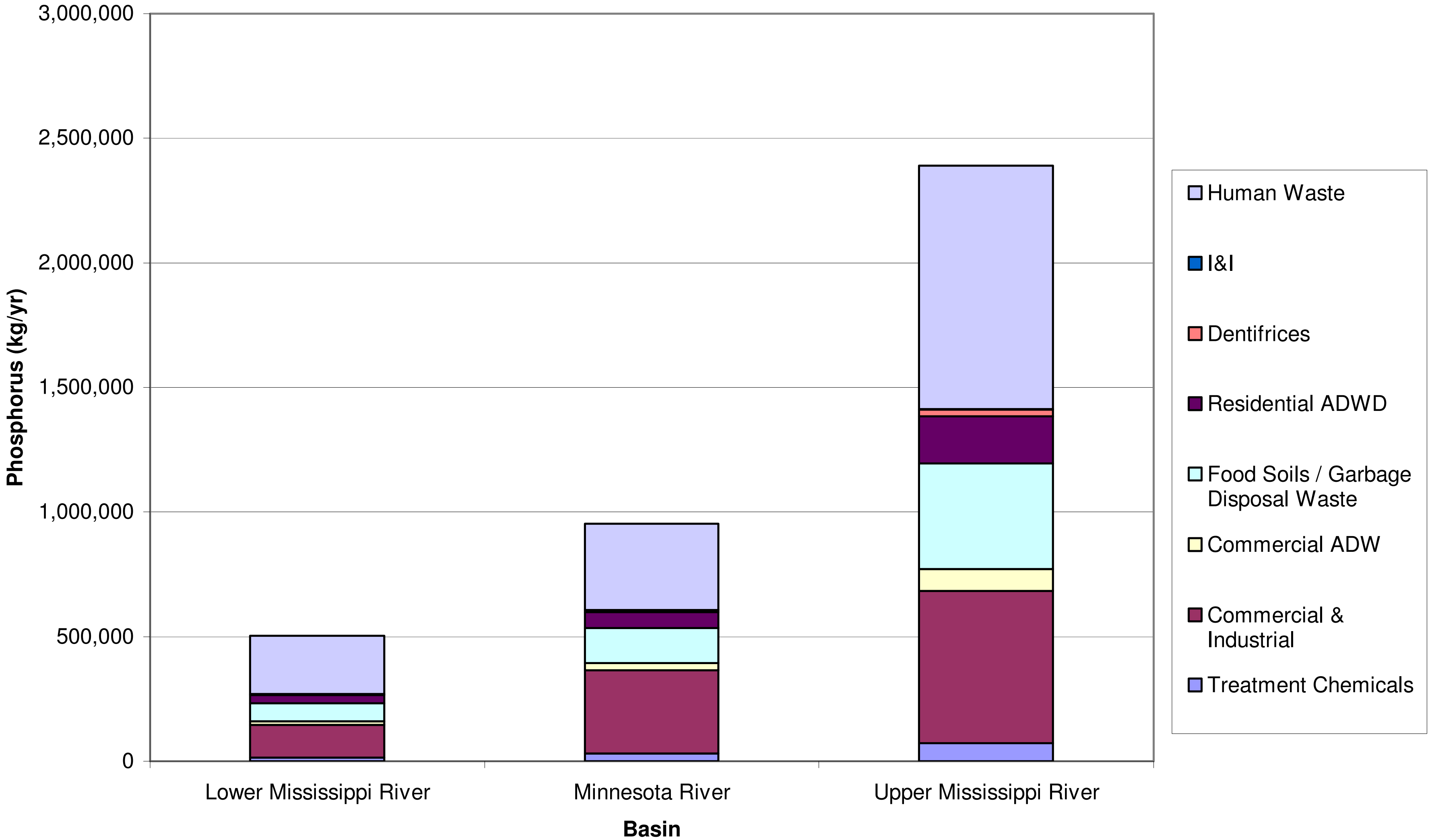


Figure 3B
Influent Phosphorus Loading To POTWs & Privately Owned Treatment Facilities By Basin



The influent phosphorus load discharged to POTWs and privately owned treatment facilities for each basin and the state are presented alphabetically, by basin, interspersed in both tabular (Tables 3 through 24) and graphical (Figures 4 through 14) formats. These tables and figures present each component of the influent phosphorus load to the POTWs and the privately owned treatment facilities as a mass load in kg/yr and as a percent of the total influent phosphorus load to the treatment facilities in each basin.

Subtracting the human waste component from the total POTW phosphorus influent yields the estimated total non-ingested phosphorus load discharged to POTWs. Table 25 presents the non-ingested phosphorus load to POTWs for each basin and the state. The total non-ingested phosphorus load to POTWs is approximately 2,573,000 kg/yr. Commercial and industrial process wastewater represents the largest percentage, approximately 46 percent of that load.

The influent components of the POTW's and privately owned treatment facility's phosphorus loads are discussed in detail in the following paragraphs.

Table 3
Estimated POTW Point Source Phosphorus Load - Cedar River Basin

		Phosphorus Load (kg/yr)		% of Total
INFLUENT				
Domestic Wastewater		81,413		77.4%
Residential Automatic Dishwasher Detergents	4,176		4.0%	
Food Soils / Garbage Disposal Waste	9,310		8.8%	
Dentifrices	565		0.5%	
Human Waste	67,362		64.0%	
Commercial & Industrial Process Wastewater		17,982		17.1%
Commercial & Institutional Automatic Dishwasher Detergent		1,951		1.9%
Water Treatment Chemicals		3,827		3.6%
Inflow & Infiltration		67		0.1%
Total		105,241		100.0%
EFFLUENT				
Total		56,424		100.0%

Table 4
Estimated Private WWTP Point Source Phosphorus Load - Cedar River Basin

		Phosphorus Load (kg/yr)		% of Total
INFLUENT				
Domestic Wastewater		0		0.0%
Residential Automatic Dishwasher Detergents	0		0.0%	
Food Soils / Garbage Disposal Waste	0		0.0%	
Dentifrices	0		0.0%	
Human Waste	0		0.0%	
Water Treatment Chemicals		0		0.0%
Total		0		0.0%
EFFLUENT				
Total		0		0.0%

Table 5
Estimated POTW Point Source Phosphorus Load - Des Moines River Basin

		Phosphorus Load (kg/yr)		% of Total
INFLUENT				
Domestic Wastewater		35,856		77.6%
Automatic Dishwasher Detergents	2,392		5.2%	
Food Soils / Garbage Disposal Waste	5,332		11.5%	
Dentifrices	324		0.7%	
Human Waste	27,809		60.2%	
Commercial & Industrial Process Wastewater		6,607		14.3%
Commercial & Institutional Automatic Dishwasher Detergent		1,117		2.4%
Water Treatment Chemicals		2,595		5.6%
Inflow & Infiltration		28		0.1%
Total		46,203		100.0%
EFFLUENT				
Total		15,142		100.0%

Table 6
Estimated Private WWTP Point Source Phosphorus Load - Des Moines River Basin

			Phosphorus Load (kg/yr)	% of Total
INFLUENT				
Domestic Wastewater			0	0.0%
Residential Automatic Dishwasher Detergents	0	0.0%		
Food Soils / Garbage Disposal Waste	0	0.0%		
Dentifrices	0	0.0%		
Human Waste	0	0.0%		
Water Treatment Chemicals			0	0.0%
Total			0	0.0%
EFFLUENT				
Total			0	0.0%

Table 7
Estimated POTW Point Source Phosphorus Load - Lake Superior Basin

		Phosphorus Load (kg/yr)		% of Total
INFLUENT				
Domestic Wastewater		177,353		78.1%
Residential Automatic Dishwasher Detergents	15,365		6.8%	
Food Soils / Garbage Disposal Waste	34,256		15.1%	
Dentifrices	2,079		0.9%	
Human Waste	125,653		55.4%	
Commercial & Industrial Process Wastewater		38,215		16.8%
Commercial & Institutional Automatic Dishwasher Detergent		7,190		3.2%
Water Treatment Chemicals		3,914		1.7%
Inflow & Infiltration		313		0.1%
Total		226,986		100.0%
EFFLUENT				
Total		31,774		100.0%

Table 8
Estimated Private WWTP Point Source Phosphorus Load - Lake Superior Basin

		Phosphorus Load (kg/yr)		% of Total
INFLUENT				
Domestic Wastewater		542		100.0%
Residential Automatic Dishwasher Detergents	31		5.7%	
Food Soils / Garbage Disposal Waste	69		12.7%	
Dentifrices	4		0.8%	
Human Waste	438		80.8%	
Water Treatment Chemicals		0		0.0%
Total		542		100.0%
EFFLUENT				
Total		39		100.0%

Table 9
Estimated POTW Point Source Phosphorus Load - Lower Mississippi River Basin

		Phosphorus Load (kg/yr)		% of Total
INFLUENT				
Domestic Wastewater		339,782		67.7%
Residential Automatic Dishwasher Detergents	32,050		6.4%	
Food Soils / Garbage Disposal Waste	71,452		14.2%	
Dentifrices	4,336		0.9%	
Human Waste	231,943		46.2%	
Commercial & Industrial Process Wastewater		132,867		26.5%
Commercial & Institutional Automatic Dishwasher Detergent		14,993		3.0%
Water Treatment Chemicals		13,940		2.8%
Inflow & Infiltration		321		0.1%
Total		501,903		100.0%
EFFLUENT				
Total		183,974		100.0%

Table 10
Estimated Private WWTP Point Source Phosphorus Load - Lower Mississippi River Basin

		Phosphorus Load (kg/yr)		% of Total
INFLUENT				
Domestic Wastewater		779		99.2%
Residential Automatic Dishwasher Detergents	85		10.8%	
Food Soils / Garbage Disposal Waste	197		25.1%	
Dentifrices	12		1.5%	
Human Waste	485		61.8%	
Water Treatment Chemicals		6		0.8%
Total		785		100.0%
EFFLUENT				
Total		269		100.0%

Table 11
Estimated POTW Point Source Phosphorus Load - Minnesota River Basin

		Phosphorus Load (kg/yr)		% of Total
INFLUENT				
Domestic Wastewater		557,358		58.5%
Residential Automatic Dishwasher Detergents	63,090		6.6%	
Food Soils / Garbage Disposal Waste	140,653		14.8%	
Dentifrices	8,536		0.9%	
Human Waste	345,080		36.2%	
Commercial & Industrial Process Wastewater		333,212		35.0%
Commercial & Institutional Automatic Dishwasher Detergent		29,498		3.1%
Water Treatment Chemicals		31,481		3.3%
Inflow & Infiltration		612		0.1%
Total		952,161		100.0%
EFFLUENT				
Total		237,842		100.0%

Table 12
Estimated Private WWTP Point Source Phosphorus Load - Minnesota River Basin

			Phosphorus Load (kg/yr)	% of Total
INFLUENT				
Domestic Wastewater			1,469	98.9%
Residential Automatic Dishwasher Detergents	65	4.4%		
Food Soils / Garbage Disposal Waste	115	7.7%		
Dentifrices	9	0.6%		
Human Waste	1,280	86.2%		
Water Treatment Chemicals			16	1.1%
Total			1,485	100.0%
EFFLUENT				
Total			840	100.0%

Table 13
Estimated POTW Point Source Phosphorus Load - Missouri River Basin

		Phosphorus Load (kg/yr)		% of Total
INFLUENT				
Domestic Wastewater		17,272		65.3%
Residential Automatic Dishwasher Detergents	1,447		5.5%	
Food Soils / Garbage Disposal Waste	3,211		12.1%	
Dentifrices	196		0.7%	
Human Waste	12,419		47.0%	
Commercial & Industrial Process Wastewater		7,475		28.3%
Commercial & Institutional Automatic Dishwasher Detergent		679		2.6%
Water Treatment Chemicals		1,003		3.8%
Inflow & Infiltration		17		0.1%
Total		26,445		100.0%
EFFLUENT				
Total		12,359		100.0%

Table 14
Estimated Private WWTP Point Source Phosphorus Load - Missouri River Basin

			Phosphorus Load (kg/yr)	% of Total
INFLUENT				
Domestic Wastewater			74	100.0%
Residential Automatic Dishwasher Detergents	6	8.0%		
Food Soils / Garbage Disposal Waste	13	17.8%		
Dentifrices	1	1.1%		
Human Waste	54	73.1%		
Water Treatment Chemicals			0	0.0%
Total			74	100.0%
EFFLUENT				
Total			17	100.0%

Table 15
Estimated POTW Point Source Phosphorus Load - Rainy River Basin

		Phosphorus Load (kg/yr)		% of Total
INFLUENT				
Domestic Wastewater		17,677		88.1%
Residential Automatic Dishwasher Detergents	1,257		6.3%	
Food Soils / Garbage Disposal Waste	2,480		12.4%	
Dentifrices	170		0.8%	
Human Waste	13,770		68.7%	
Commercial & Industrial Process Wastewater		1,043		5.2%
Commercial & Institutional Automatic Dishwasher Detergent		587		2.9%
Water Treatment Chemicals		729		3.6%
Inflow & Infiltration		18		0.1%
Total		20,054		100.0%
EFFLUENT				
Total		4,073		100.0%

Table 16
Estimated Private WWTP Point Source Phosphorus Load - Rainy River Basin

			Phosphorus Load (kg/yr)	% of Total
INFLUENT				
Domestic Wastewater			29	100.0%
Residential Automatic Dishwasher Detergents	0	0.0%		
Food Soils / Garbage Disposal Waste	0	0.0%		
Dentifrices	0	0.0%		
Human Waste	29	100.0%		
Water Treatment Chemicals			0	0.0%
Total			29	100.0%
EFFLUENT				
Total			6	100.0%

Table 17
Estimated POTW Point Source Phosphorus Load - Red River Basin

		Phosphorus Load (kg/yr)		% of Total
INFLUENT				
Domestic Wastewater		109,433		72.7%
Residential Automatic Dishwasher Detergents	11,181		7.4%	
Food Soils / Garbage Disposal Waste	24,928		16.6%	
Dentifrices	1,513		1.0%	
Human Waste	71,810		47.7%	
Commercial & Industrial Process Wastewater		28,026		18.6%
Commercial & Institutional Automatic Dishwasher Detergent		5,222		3.5%
Water Treatment Chemicals		7,801		5.2%
Inflow & Infiltration		116		0.1%
Total		150,597		100.0%
EFFLUENT				
Total		64,309		100.0%

Table 18
Estimated Private WWTP Point Source Phosphorus Load - Red River Basin

		Phosphorus Load (kg/yr)		% of Total
INFLUENT				
Domestic Wastewater		33		100.0%
Residential Automatic Dishwasher Detergents	0		0.0%	
Food Soils / Garbage Disposal Waste	26		79.4%	
Dentifrices	2		4.8%	
Human Waste	5		15.7%	
Water Treatment Chemicals		0		0.0%
Total		33		100.0%
EFFLUENT				
Total		33		100.0%

Table 19
Estimated POTW Point Source Phosphorus Load - St. Croix River Basin

		Phosphorus Load (kg/yr)		% of Total
INFLUENT				
Domestic Wastewater		39,494		73.8%
Residential Automatic Dishwasher Detergents	4,292		8.0%	
Food Soils / Garbage Disposal Waste	9,570		17.9%	
Dentifrices	581		1.1%	
Human Waste	25,051		46.8%	
Commercial & Industrial Process Wastewater		8,834		16.5%
Commercial & Institutional Automatic Dishwasher Detergent		2,008		3.8%
Water Treatment Chemicals		3,115		5.8%
Inflow & Infiltration		47		0.1%
Total		53,498		100.0%
EFFLUENT				
Total		20,438		100.0%

Table 20
Estimated Private WWTP Point Source Phosphorus Load - St. Croix River Basin

		Phosphorus Load (kg/yr)		% of Total
INFLUENT				
Domestic Wastewater		793		100.0%
Residential Automatic Dishwasher Detergents	181		22.8%	
Food Soils / Garbage Disposal Waste	403		50.8%	
Dentifrices	24		3.1%	
Human Waste	185		23.3%	
Water Treatment Chemicals		0		0.0%
Total		793		100.0%
EFFLUENT				
Total		297		100.0%

Table 21
Estimated POTW Point Source Phosphorus Load - Upper Mississippi River Basin

		Phosphorus Load (kg/yr)		% of Total
INFLUENT				
Domestic Wastewater		1,610,756		67.5%
Residential Automatic Dishwasher Detergents	189,181		7.9%	
Food Soils / Garbage Disposal Waste	421,682		17.7%	
Dentifrices	25,595		1.1%	
Human Waste	974,298		40.9%	
Commercial & Industrial Process Wastewater		611,967		25.7%
Commercial & Institutional Automatic Dishwasher Detergent		88,571		3.7%
Water Treatment Chemicals		71,783		3.0%
Inflow & Infiltration		1,794		0.1%
Total		2,384,871		100.0%
EFFLUENT				
Total		1,109,534		100.0%

Table 22
Estimated Private WWTP Point Source Phosphorus Load - Upper Mississippi River Basin

		Phosphorus Load (kg/yr)		% of Total
INFLUENT				
Domestic Wastewater		4,086		96.0%
Residential Automatic Dishwasher Detergents	487		11.4%	
Food Soils / Garbage Disposal Waste	1,196		28.1%	
Dentifrices	66		1.5%	
Human Waste	2,338		54.9%	
Water Treatment Chemicals		171		4.0%
Total		4,257		100.0%
EFFLUENT				
Total		1,955		100.0%

Table 23
Estimated POTW Point Source Phosphorus Load - State of Minnesota

		Phosphorus Load (kg/yr)		% of Total
INFLUENT				
Domestic Wastewater		2,986,392		66.8%
Residential Automatic Dishwasher Detergents	324,431		7.3%	
Food Soils / Garbage Disposal Waste	722,873		16.2%	
Dentifrices	43,894		1.0%	
Human Waste	1,895,195		42.4%	
Commercial & Industrial Process Wastewater		1,186,229		26.5%
Commercial & Institutional Automatic Dishwasher Detergent		151,815		3.4%
Water Treatment Chemicals		140,188		3.1%
Inflow & Infiltration		3,333		0.1%
Total		4,467,958		100.0%
EFFLUENT				
Total		1,735,869		100.0%

Table 24
Estimated Private WWTP Point Source Phosphorus Load - State of Minnesota

		Phosphorus Load (kg/yr)		% of Total
INFLUENT				
Domestic Wastewater		7,804		97.6%
Residential Automatic Dishwasher Detergents	855		10.7%	
Food Soils / Garbage Disposal Waste	2,019		25.2%	
Dentifrices	118		1.5%	
Human Waste	4,813		60.2%	
Water Treatment Chemicals		193		2.4%
Total		7,997		100.0%
EFFLUENT				
Total		3,456		100.0%

Table 25
Non-ingested Phosphorus Sources to POTWs

	Residential ADWD (kg/yr)	Food Soils / Garbage Disposal Waste (kg/yr)	Dentifrices (kg/yr)	Commercial and Industrial Process Wastewater (kg/yr)	Commercial and Institutional ADWD (kg/yr)	Water Treatment Chemicals (kg/yr)	Inflow and Infiltration (kg/yr)	Total (kg/yr)
Basin								
Cedar River	4,200	9,300	600	18,000	2,000	3,800	70	38,000
Des Moines River	2,400	5,300	300	6,600	1,100	2,600	30	18,300
Lake Superior	15,400	34,300	2,100	38,200	7,200	3,900	310	101,400
Lower Mississippi River	32,000	71,452	4,300	132,900	15,000	13,900	320	269,900
Minnesota River	63,100	140,700	8,500	333,200	29,500	31,500	610	607,100
Missouri River	1,400	3,200	200	7,500	700	1,000	20	14,000
Rainy River	1,300	2,500	200	1,000	600	700	20	6,300
Red River	11,200	24,900	1,500	28,000	5,200	7,800	120	78,700
St. Croix River	4,300	9,600	600	8,800	2,000	3,100	50	28,500
Upper Mississippi River	189,200	421,700	25,600	612,000	88,600	71,800	1,790	1,410,700
Total	324,500	723,000	43,900	1,186,200	151,900	140,100	3,300	2,572,900
Percent of Non-Ingested Phosphorus Load to POTWs	12.6%	28.1%	1.7%	46.1%	5.9%	5.4%	0.1%	

Figure 4
Cedar River Basin POTW Estimated Influent Phosphorus Load

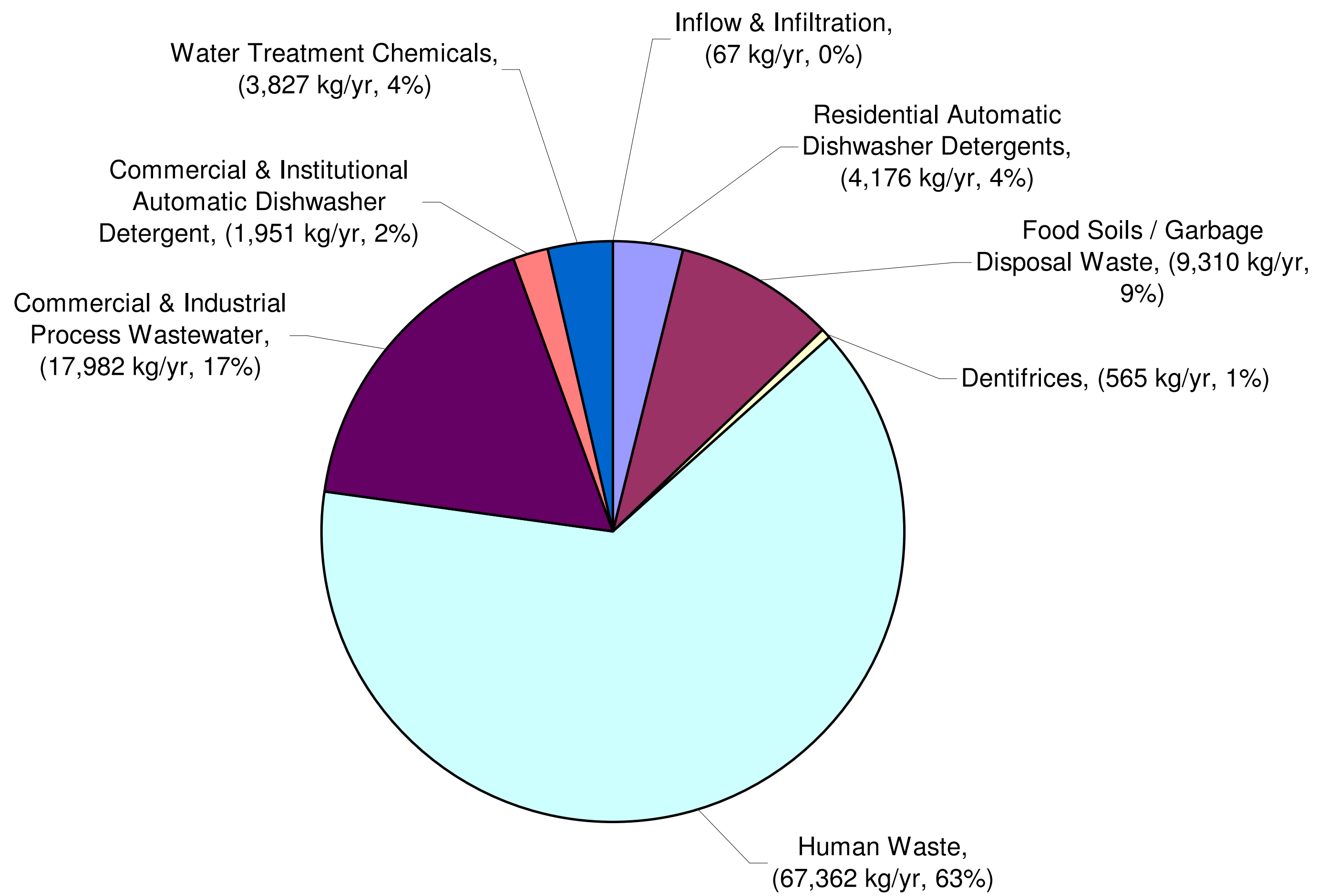


Figure 5
Des Moines River Basin POTW Estimated Influent Phosphorus Load

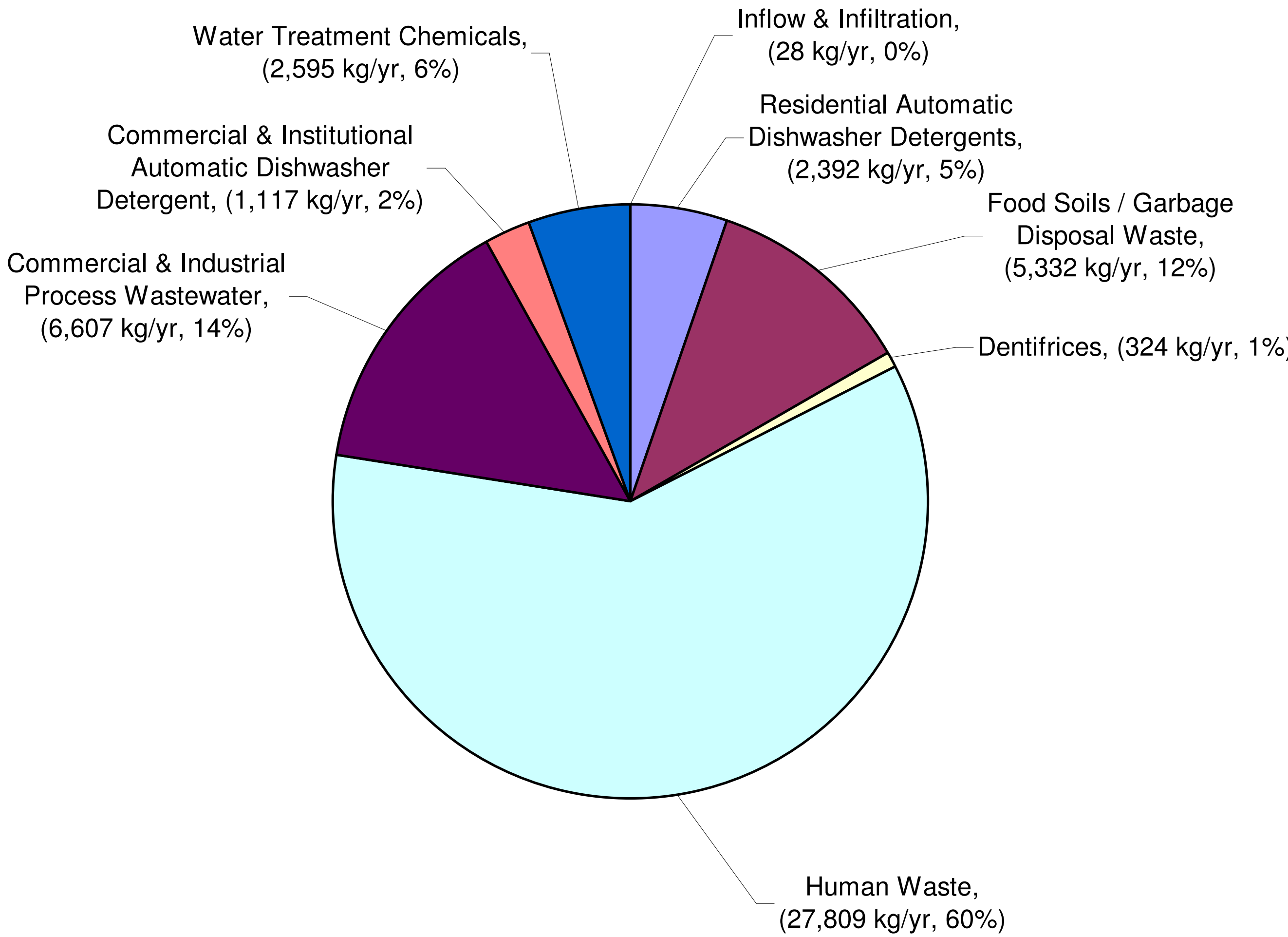


Figure 6
Lake Superior Basin POTW Estimated Influent Phosphorus Load

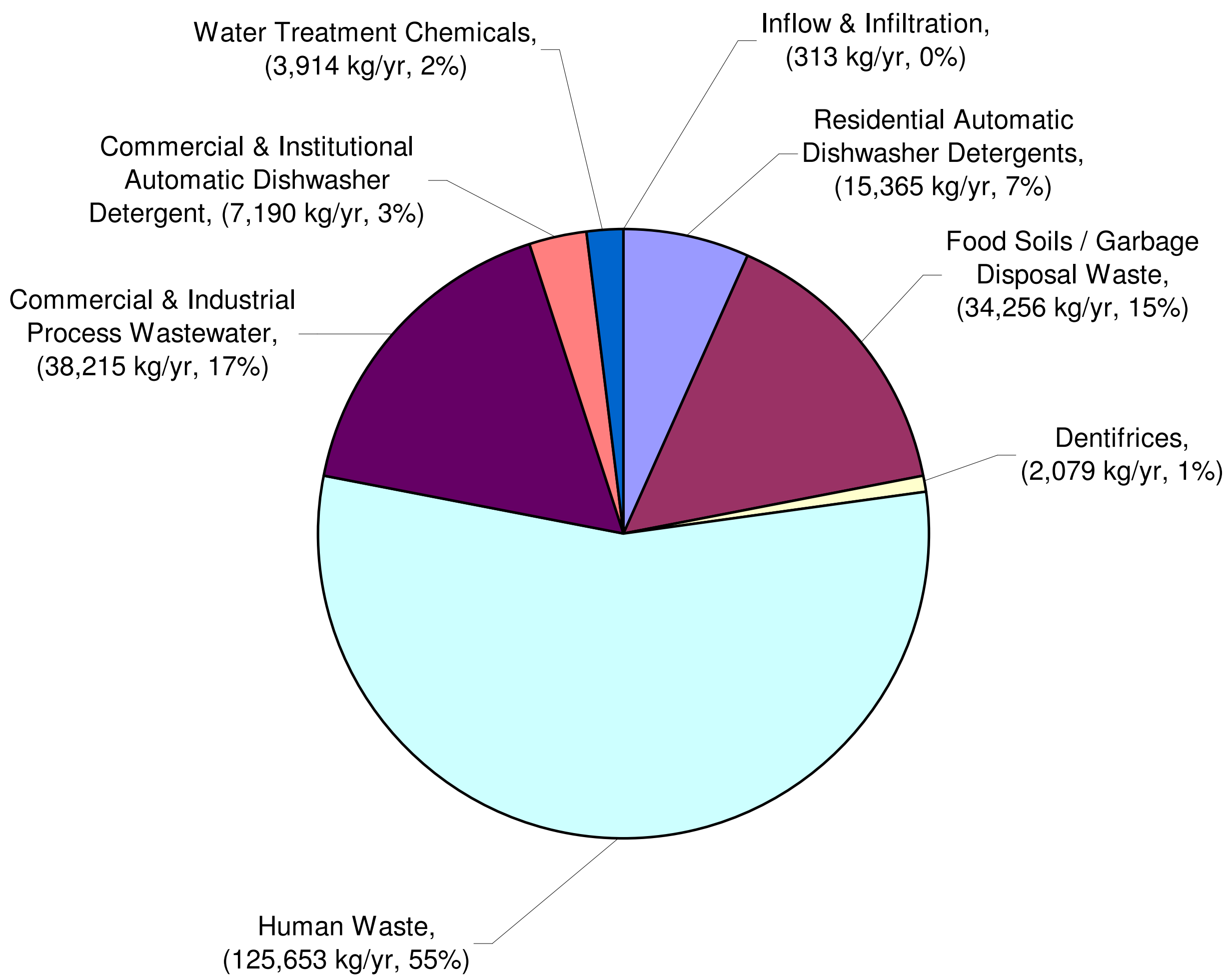


Figure 7
Lower Mississippi River Basin POTW Estimated Influent Phosphorus Load

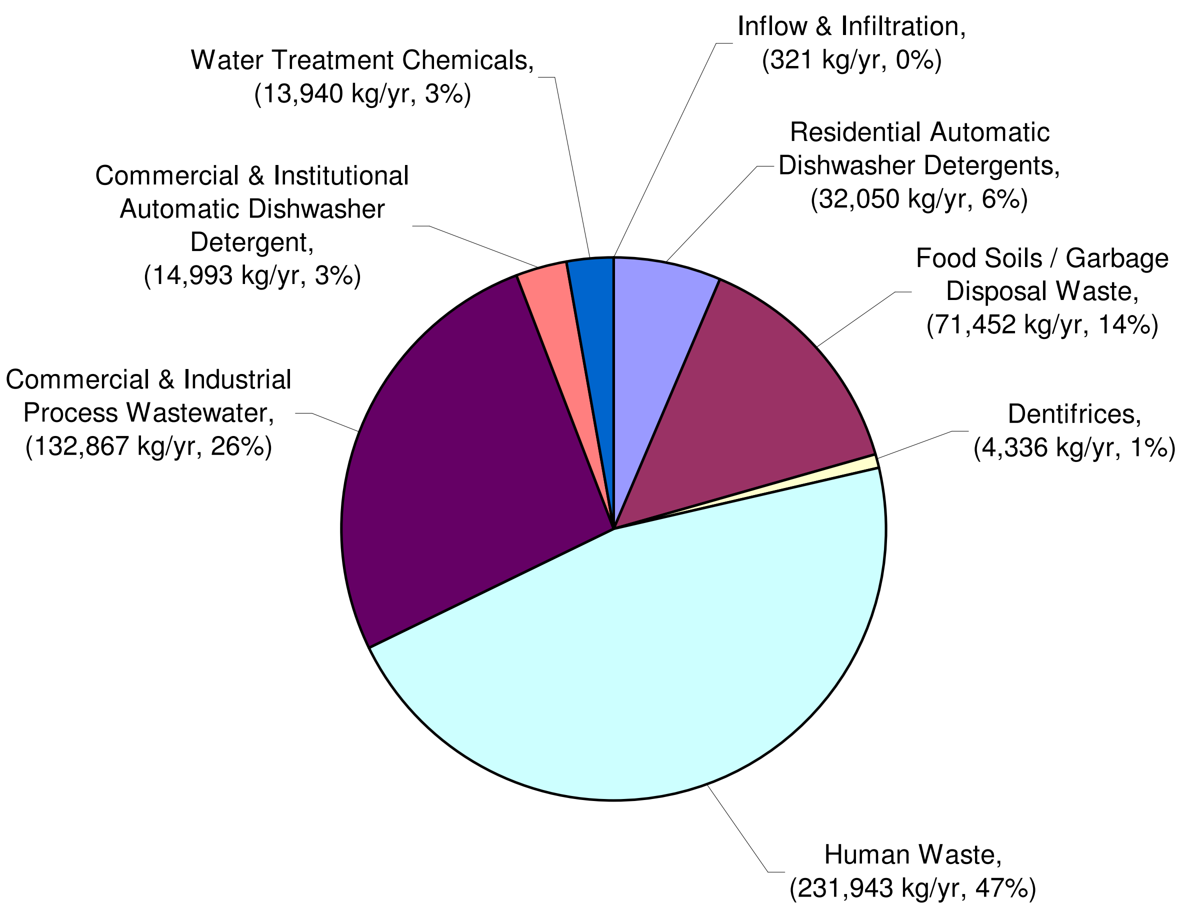


Figure 8
Minnesota River Basin POTW Estimated Influent Phosphorus Load

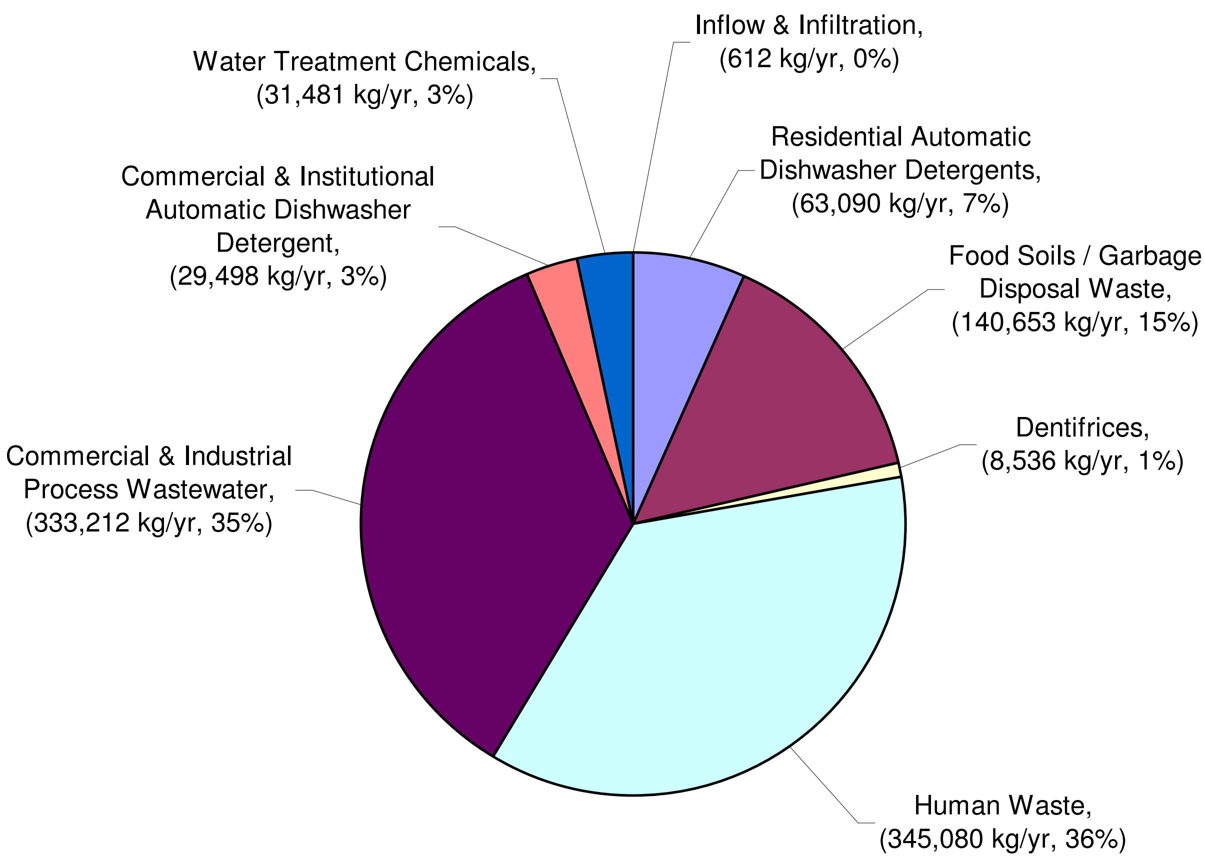


Figure 9
Missouri River Basin POTW Estimated Influent Phosphorus Load

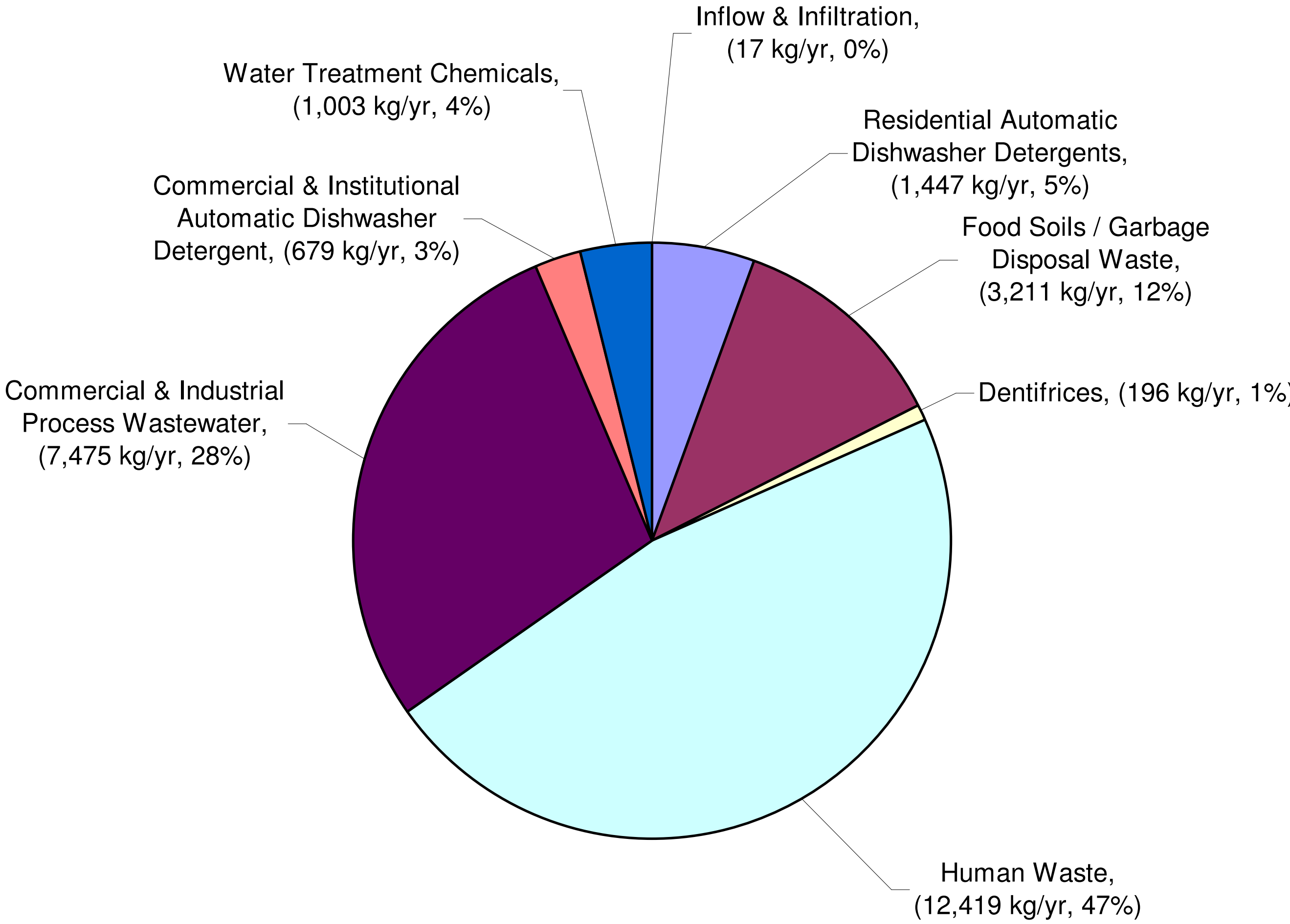


Figure 10
Rainy River Basin POTW Estimated Influent Phosphorus Load

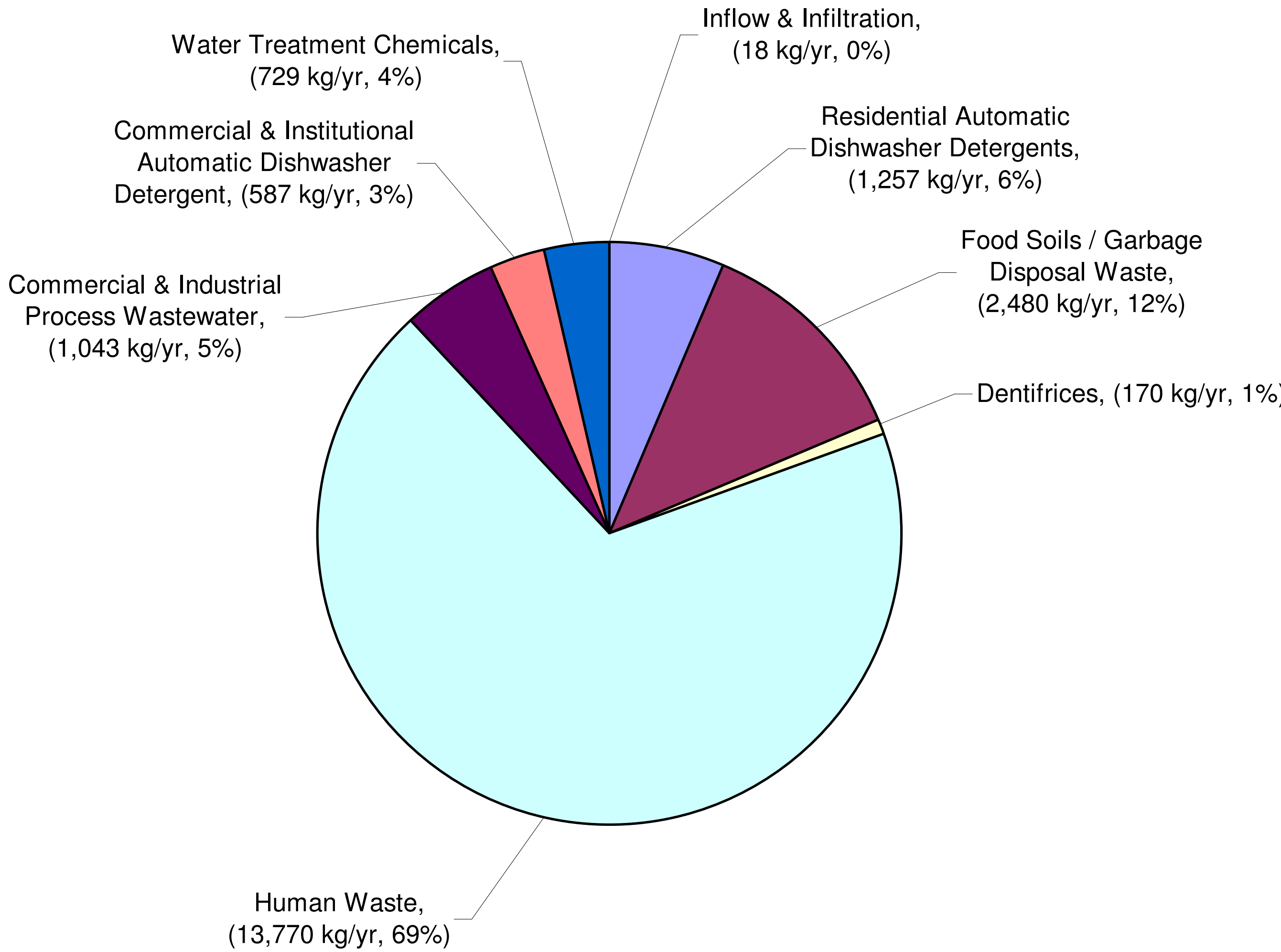


Figure 11
Red River Basin POTW Estimated Influent Phosphorus Load

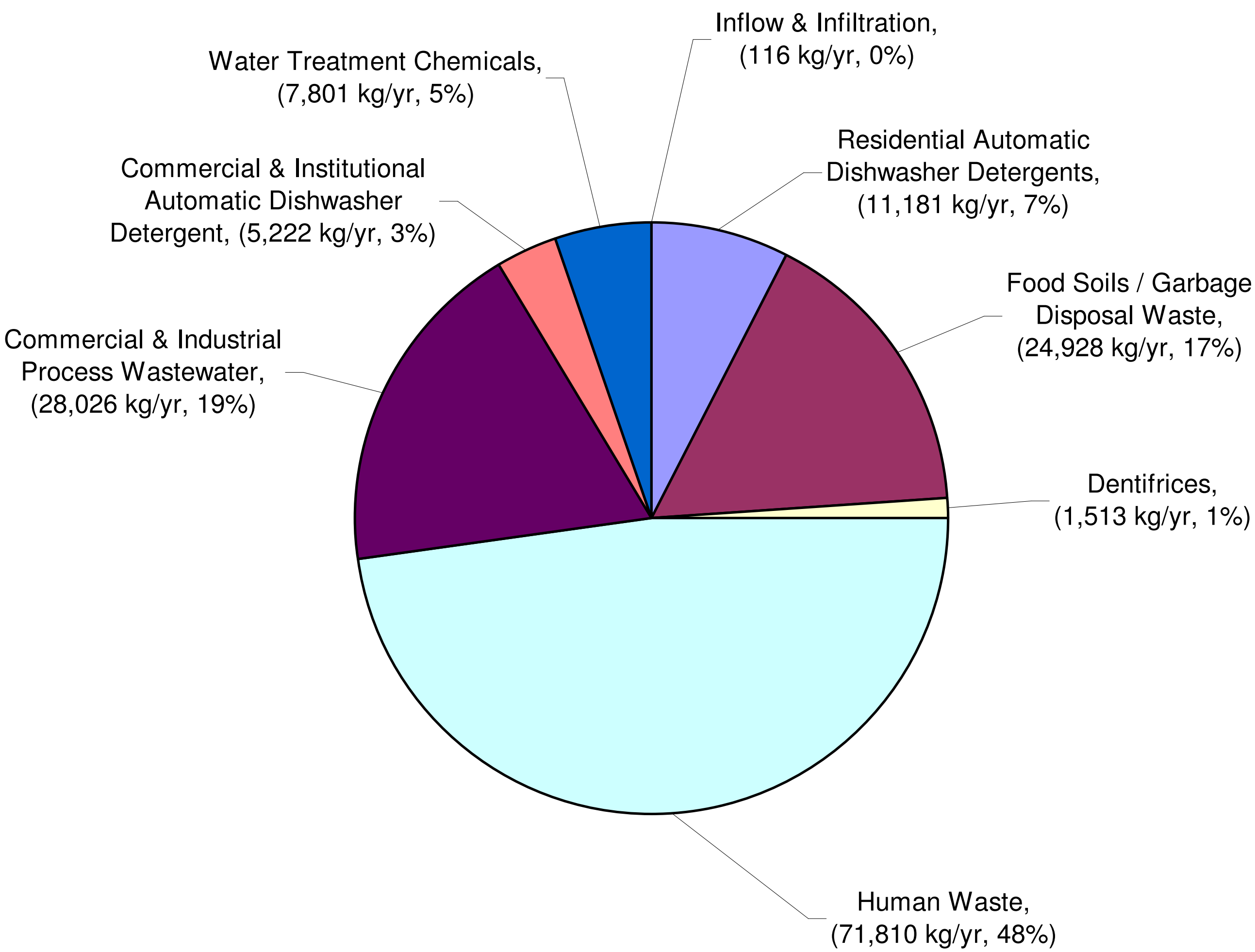


Figure 12
St. Croix Basin POTW Estimated Influent Phosphorus Load

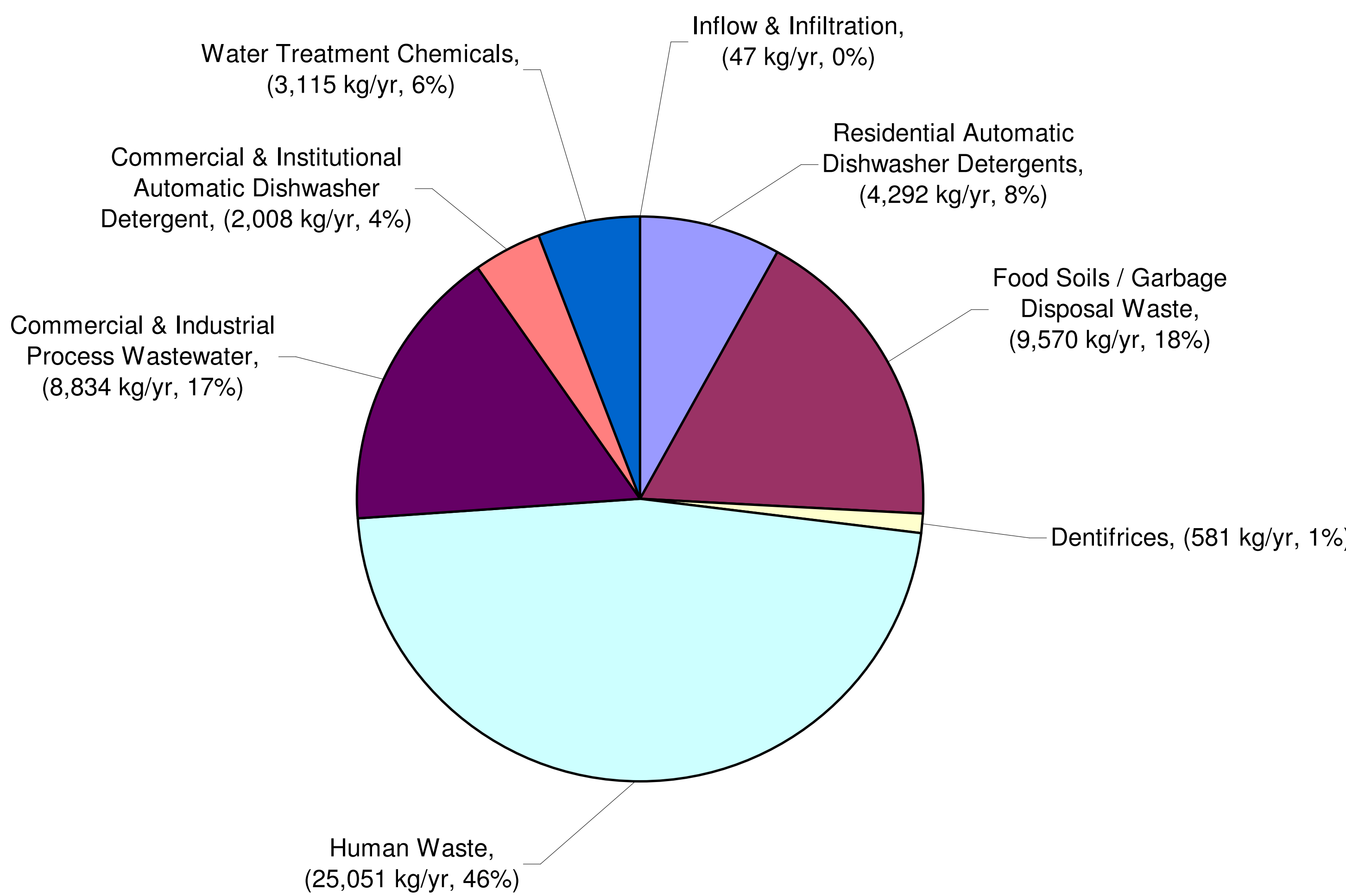


Figure 13
Upper Mississippi River Basin POTW Estimated Influent Phosphorus Load

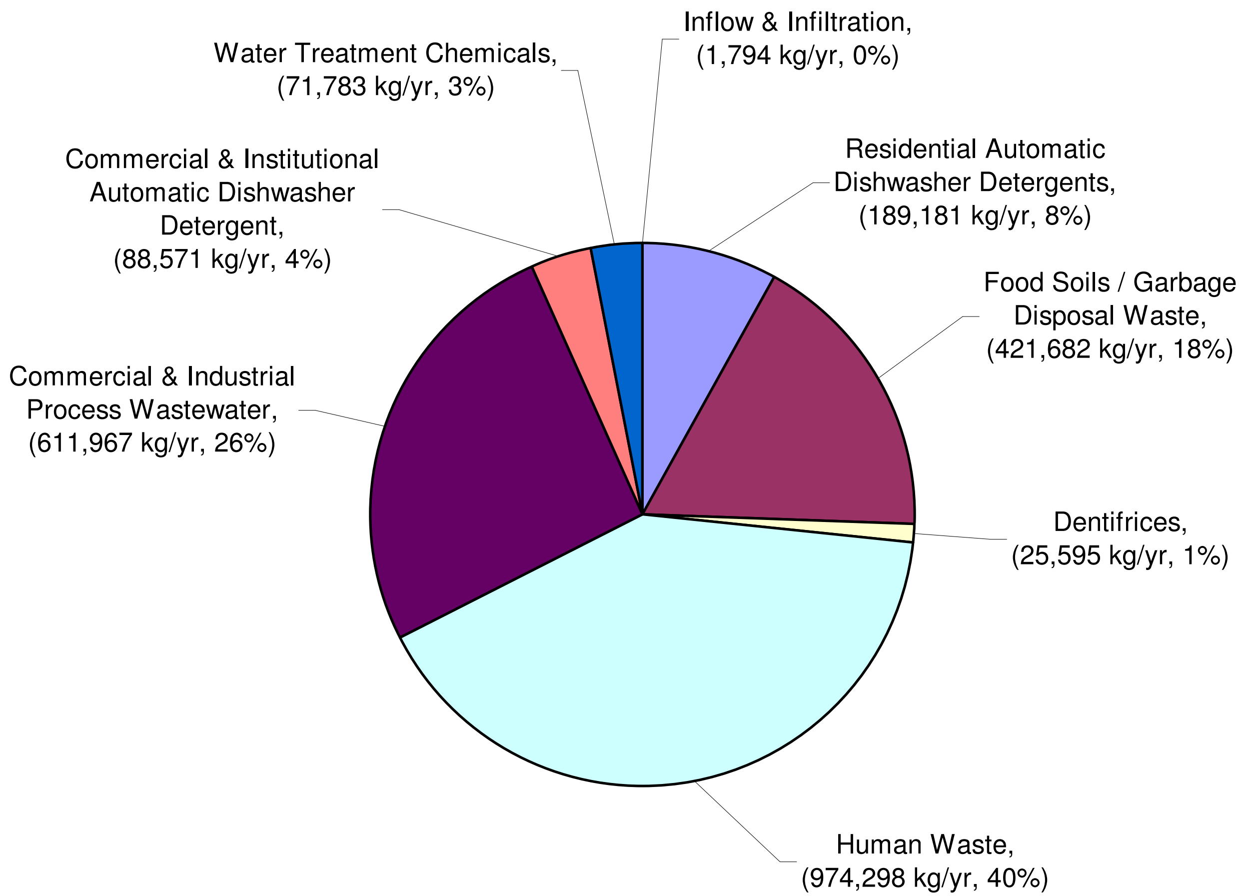
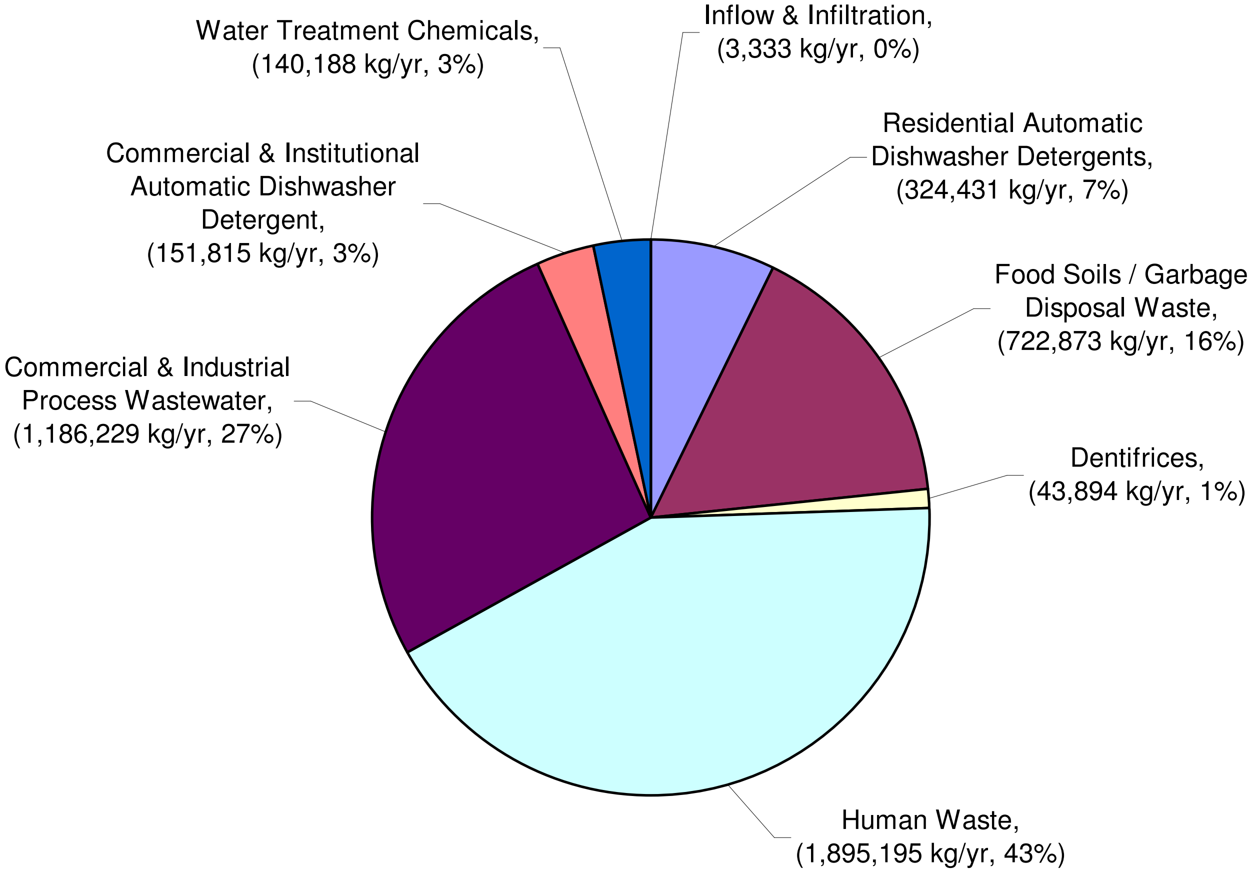


Figure 14
State of Minnesota POTW Estimated Influent Phosphorus Load



Residential Automatic Dishwasher Detergents (ADWD)

The per capita use information suggests that the residential use of ADWD contributes a moderate amount of phosphorus discharged to wastewater for treatment. For the Minnesota watershed basins, these amounts range from 4.0 percent to 8.2 percent and averaged 7.3 percent statewide of influent phosphorus totals (see Table 26), discharging into POTWs and privately owned treatment facilities.

Table 26
Estimated Influent Phosphorus Load from Residential Automatic Dishwasher Detergents to POTWs and Privately Owned Treatment Works by Basin

Basin	**Influent Phosphorus Load (kg/yr)**	**Influent Phosphorus Load (% of Total)**
Cedar River	4,200	4.0%
Des Moines River	2,400	5.2%
Lake Superior	15,400	6.8%
Lower Mississippi River	32,100	6.4%
Minnesota River	63,200	6.6%
Missouri River	1,500	5.5%
Rainy River	1,300	6.3%
Red River	11,200	7.4%
St. Croix River	4,500	8.2%
Upper Mississippi River	189,700	7.9%
State Total	325,500	7.3%

The use of phosphates in the residential ADWD market declined about seven percent between 1993 and 2000 (SRI, 2002). Nonphosphate ADWD formulations are being developed and this market segment is projected to continue to decline marginally. The trend toward the use of tablets, with a slightly lower phosphate content, is also a factor in the decline.

Food Soils/Garbage Disposal Waste

The information obtained regarding food soils and garbage disposal wastes suggests that this source contributes a moderate amount of phosphorus to untreated wastewater. For the ten Minnesota watershed basins, these amounts range from 8.8 percent to 18.4 percent and averages approximately16 percent statewide of influent phosphorus totals (see Table 27). The total phosphorus load to POTWs and privately owned treatment facilities from food soils and garbage disposal wastes was estimated to be approximately 725,000 kg/yr.

Table 27
Estimated Influent Phosphorus Load from Food Soils and Garbage Disposal Wastes to POTWs and Privately Owned Treatment Works by Basin

Basin	Influent Phosphorus Load (kg/yr)	Influent Phosphorus Load (% of Total)
Cedar River	9,300	8.8%
Des Moines River	5,300	11.5%
Lake Superior	34,300	15.1%
Lower Mississippi River	71,600	14.3%
Minnesota River	140,800	14.8%
Missouri River	3,200	12.2%
Rainy River	2,500	12.3%
Red River	25,000	16.6%
St. Croix River	10,000	18.4%
Upper Mississippi River	422,900	17.7%
State Total	724,900	16.2%

<u>Dentifrices</u>

Dentifrices contribute a relatively small amount of phosphorus to the influent wastewater stream to wastewater treatment plants for each of the watershed basins. These amounts range from 0.5 percent to 1.1 percent (1.0 percent statewide average) of the total influent phosphorus discharged into

POTWs and privately owned treatment facilities (see Table 28). This is a relatively minor source of phosphorus to POTWs.

Table 28
Estimated Influent Phosphorus Load from Dentifrices to POTWs and Privately Owned Treatment Works by Basin

Basin	Influent Phosphorus Load (kg/yr)	Influent Phosphorus Load (% of Total)
Cedar River	600	0.5%
Des Moines River	300	0.7%
Lake Superior	2,100	0.9%
Lower Mississippi River	4,300	0.9%
Minnesota River	8,500	0.9%
Missouri River	200	0.7%
Rainy River	200	0.8%
Red River	1,500	1.0%
St. Croix River	600	1.1%
Upper Mississippi River	25,700	1.1%
State Total	44,000	1.0%

Human Wastes

The human waste component of the influent phosphorus loading to POTWs and privately owned treatment facilities is the single largest influent source in all ten watershed basins. Only in the Minnesota River basin does the phosphorus contribution from the commercial/industrial process wastewater component approach that of the human waste component. The human waste component comprises between approximately 36 percent and 69 percent on a basin basis and averages approximately 42 percent statewide of the total influent phosphorus loading (see Table 29). The one market segment of phosphorus use that has reported an increase is the food and beverage market. The increase is due to an increased use of phosphorus in food manufacturing and preparation (SRI, 2002). One of the increases has been in the meat, poultry and seafood segment, followed by baking products. Sodium tripolyphosphate (STPP) is the main phosphate product in this market. Its use has expanded significantly because of increased deli-type packaged poultry and meat sales as well as a significant growth in marinated and rotisserie chicken. Another increase in the consumption of phosphorus is due to the increased consumption of colas. Colas contain phosphoric acid that is used to give them a tart taste and as a preservative.

Table 29
Estimated Influent Phosphorus Load from Human Waste to POTWs and Privately Owned Treatment Works by Basin

Basin	Influent Phosphorus Load (kg/yr)	Influent Phosphorus Load (% of Total)	Average Human Waste Phosphorus Content (g/p·d)
Cedar River	67,400	64.0%	3.98
Des Moines River	27,800	60.2%	1.45
Lake Superior	126,100	55.4%	2.19
Lower Mississippi River	232,400	46.2%	1.75
Minnesota River	346,400	36.3%	1.45
Missouri River	12,500	47.0%	2.21
Rainy River	13,800	68.7%	2.61
Red River	71,800	47.7%	1.71
St. Croix River	25,200	46.5%	1.52
Upper Mississippi River	976,600	40.9%	1.29
State Total	1,900,000	42.4%	1.53

Commercial and Industrial Process Wastewater

Next to human wastes, a variety of industrial and commercial dischargers contribute the most phosphorus to POTW influent wastewater. These commercial and industrial dischargers comprised between approximately 5 percent and 35 percent on a basin basis and approximately 27 percent statewide of the total phosphorus loads entering the POTWs (see Table 30). The POTWs in the Minnesota River basin receive an average of 35 percent of the influent phosphorus load from commercial and industrial process wastewater sources. This is the only basin in which the commercial and industrial process wastewater contribution approaches the human waste contribution. This basin appears to be receiving effluent from several communities that have a significant commercial and industrial base. The majority of the commercial and industrial phosphorus sources in this basin are from food processing facilities.

Table 30
Estimated Influent Phosphorus Load from Commercial and Industrial Dischargers to POTWs by Basin

Basin	Influent Phosphorus Load (kg/yr)	Influent Phosphorus Load (% of Total)
Cedar River	18,000	17.1%
Des Moines River	6,600	14.3%
Lake Superior	38,200	16.8%
Lower Mississippi River	132,900	26.4%
Minnesota River	333,200	34.9%
Missouri River	7,500	28.2%
Rainy River	1,000	5.2%
Red River	28,000	18.6%
St. Croix River	8,800	16.3%
Upper Mississippi River	612,000	25.6%
State Total	1,186,200	26.5%

Although it was not in the scope of this study to provide a detailed breakdown or discussion of the various industries that discharge phosphorus to POTWs, the major industrial/commercial process wastewater phosphorus contributors were identified. The commercial and industrial process wastewater dischargers were grouped by four digit NAICS code and presented graphically (see Figures 15 through 25) for each of the watershed basins. These figures present each industry (grouped by four digit NAICS code number) whose phosphorus contribution exceeded one percent of the total industrial/commercial process wastewater phosphorus load discharged to POTWs. See Appendices B, C and E for a listing of the various industries listed under each NAICS code number. The industries that contributed less than one percent of the industrial/commercial process wastewater phosphorus load were grouped together and presented as "Other". This information suggests that food product processing is the largest contributor of phosphorus to untreated wastewater discharged to POTWs. Animal slaughtering and processing (NAICS #3116) was the largest phosphorus contributor, estimated to discharge168,000 kg/yr. Fruit and vegetable preserving and specialty food manufacturing (NAICS #3114) contributed 132,000 kg/yr, followed by grain and oilseed manufacturing (NAICS #3112) and dairy product manufacturing (NAICS # 3115) at 127,000 kg/L and 45,000 kg/L respectively.

Figure 15
Estimated Phosphorus Load to POTWs from Industrial & Commercial Process Wastewater to Cedar River Basin (by 4 Digit NAICS Code)

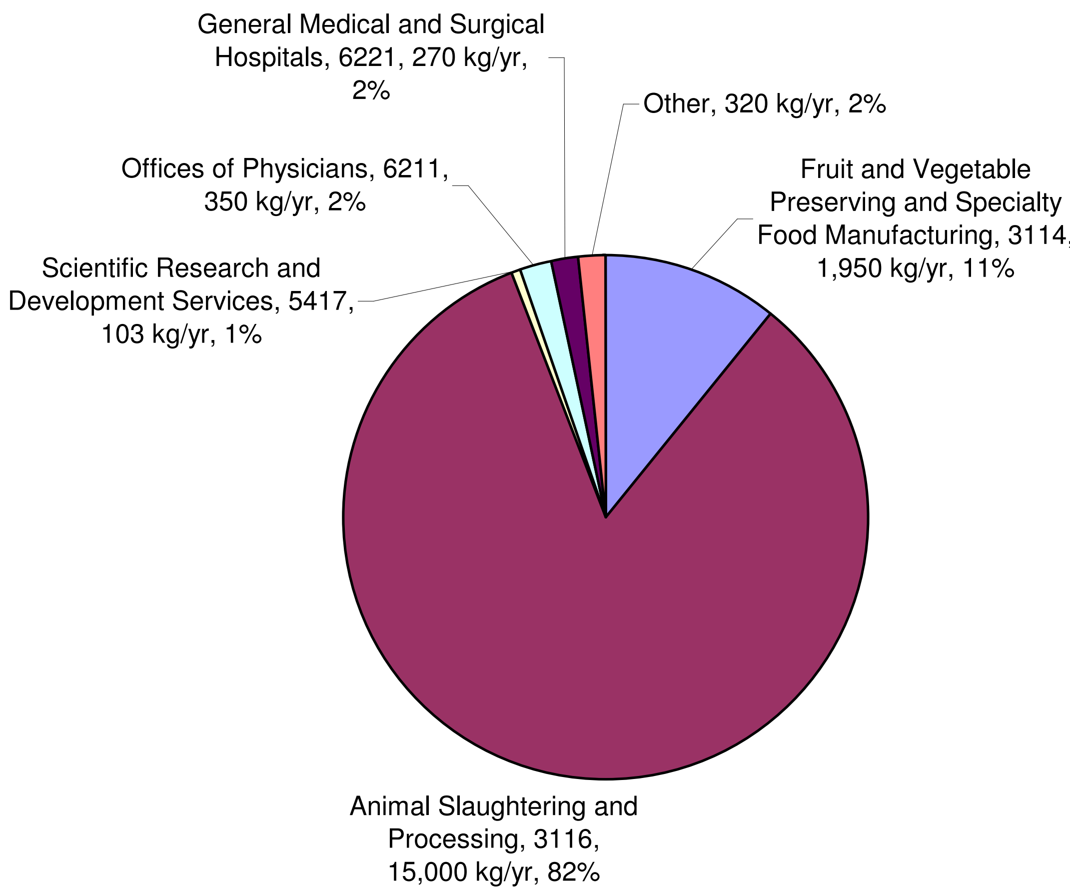


Figure 16
Estimated Phosphorus Load to POTWs from Industrial & Commercial Process Wastewater to Des Moines River Basin (by 4 Digit NAICS Code)

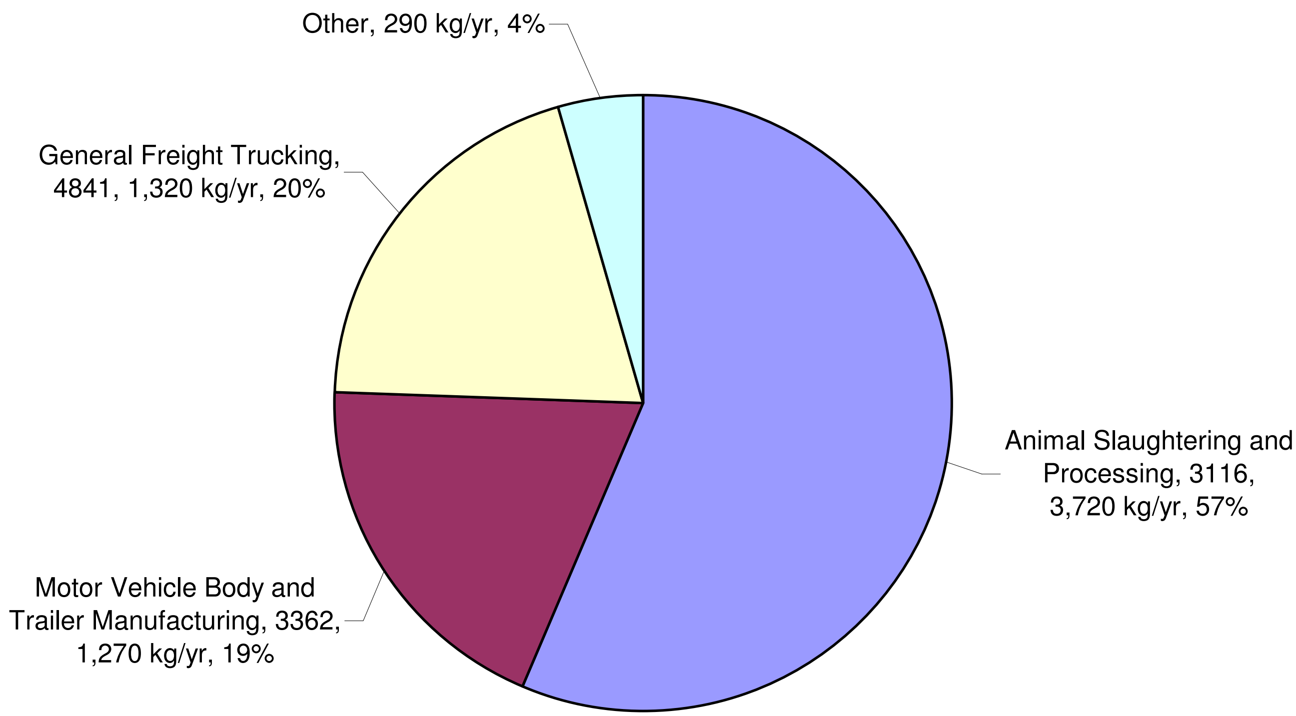


Figure 17
Estimated Phosphorus Load to POTWs from Industrial & Commercial to Lake Superior River Basin (by 4 Digit NAICS Code)

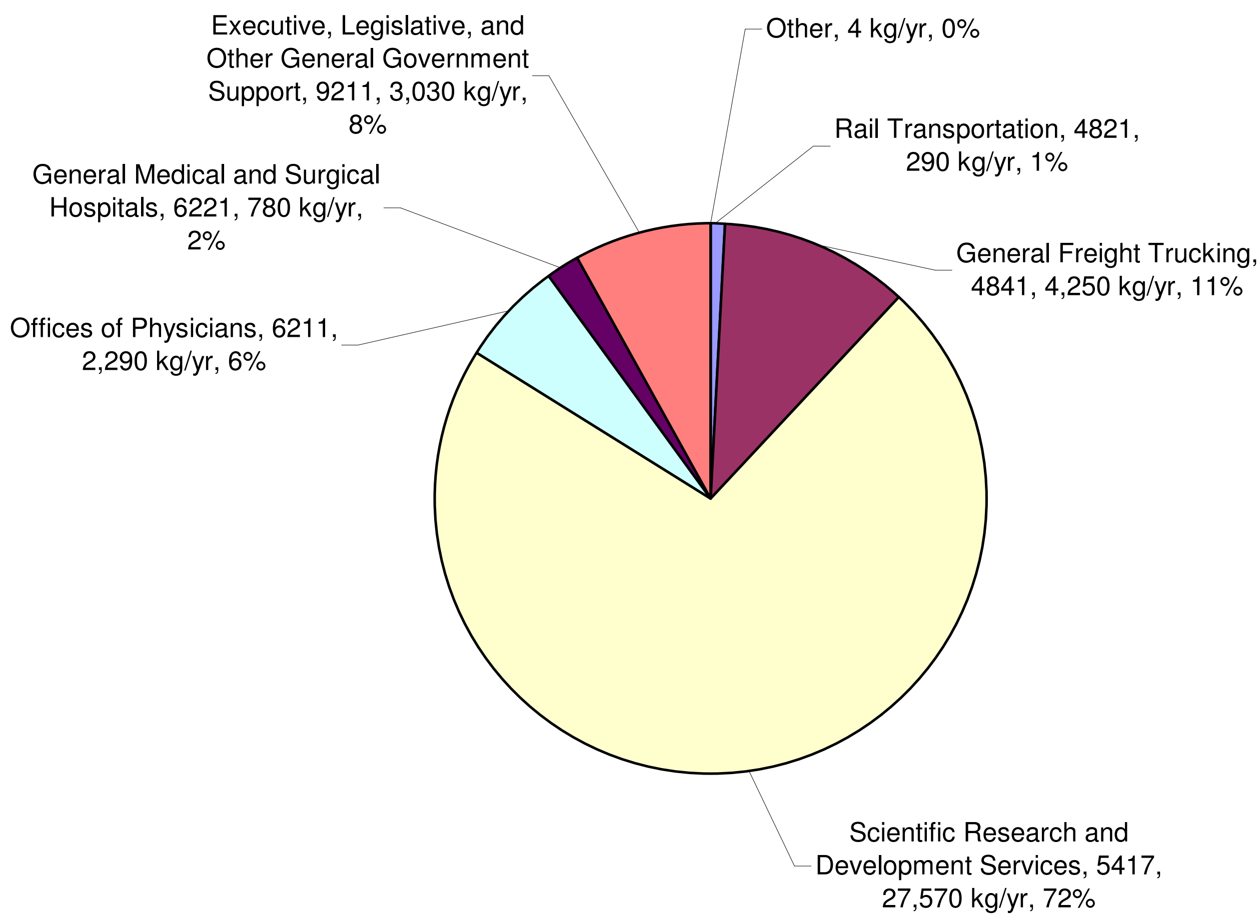


Figure 18
Estimated Phosphorus Load to POTWs from Industrial & Commercial Process Wastewater to Lower Mississippi River Basin (by 4 Digit NAICS Code)

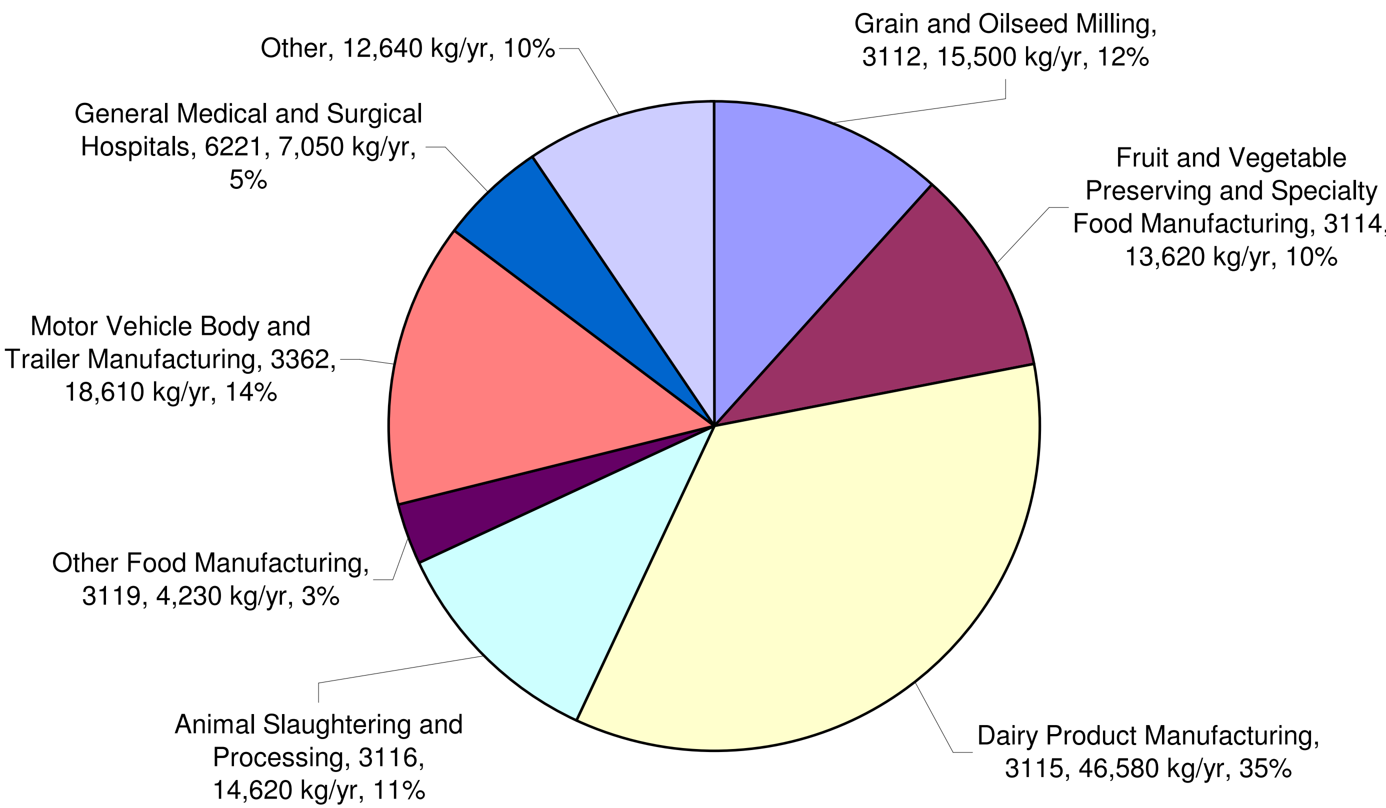


Figure 19
Estimated Phosphorus Load to POTWs from Industrial & Commercial Process Wastewater to Minnesota River Basin (by 4 Digit NAICS Code)

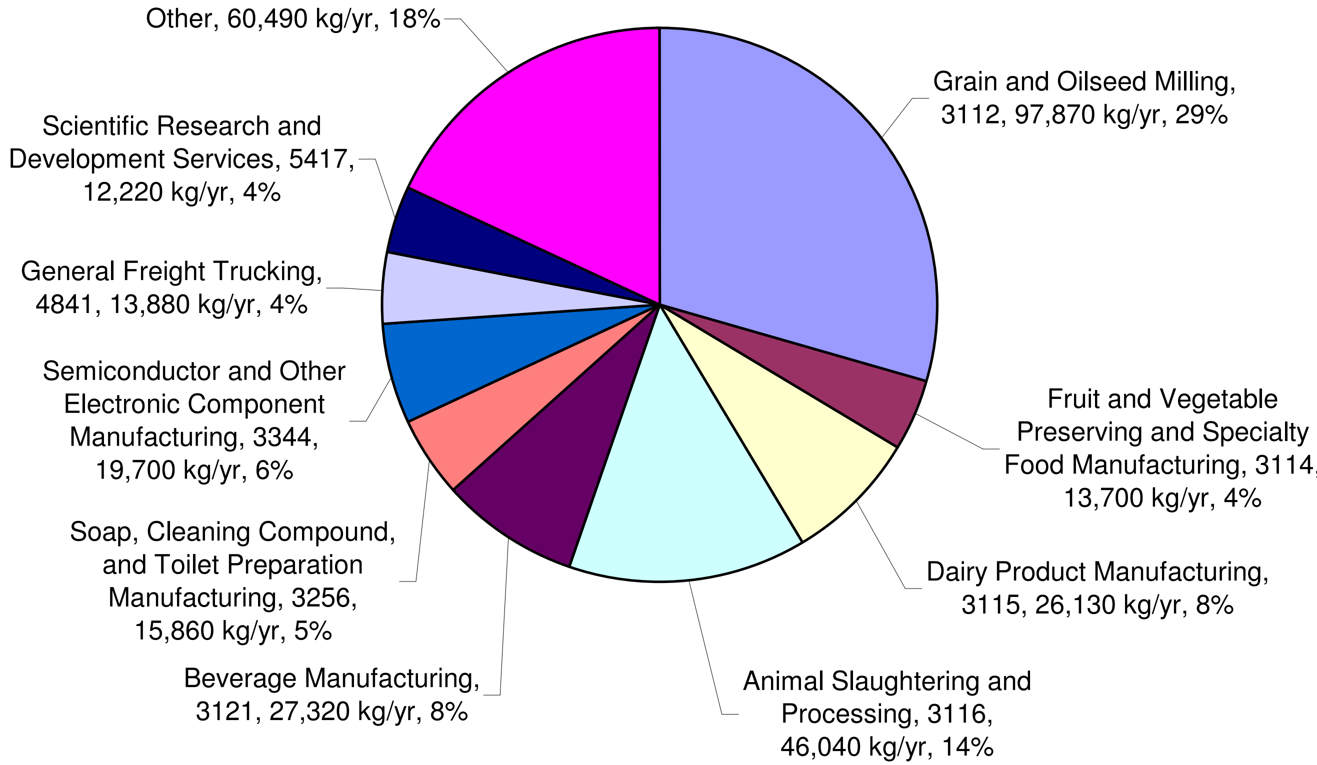


Figure 20
Estimated Phosphorus Load to POTWs from Industrial & Commercial Process Wastewater to Missouri River Basin (by 4 Digit NAICS Code)

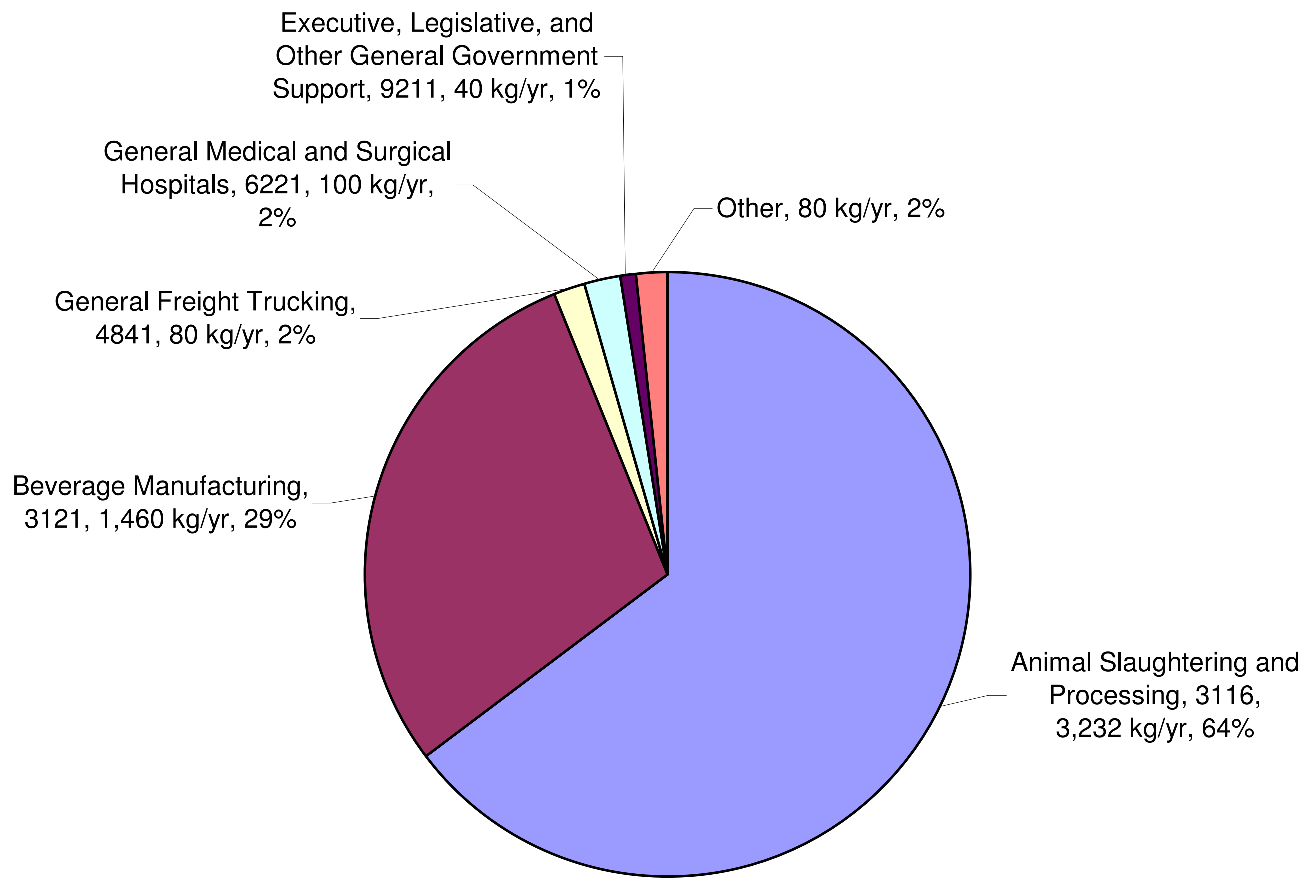


Figure 21
Estimated Phosphorus Load to POTWs from Industrial & Commercial Process Wastewater to Rainy River Basin (by 4 Digit NAICS Code)

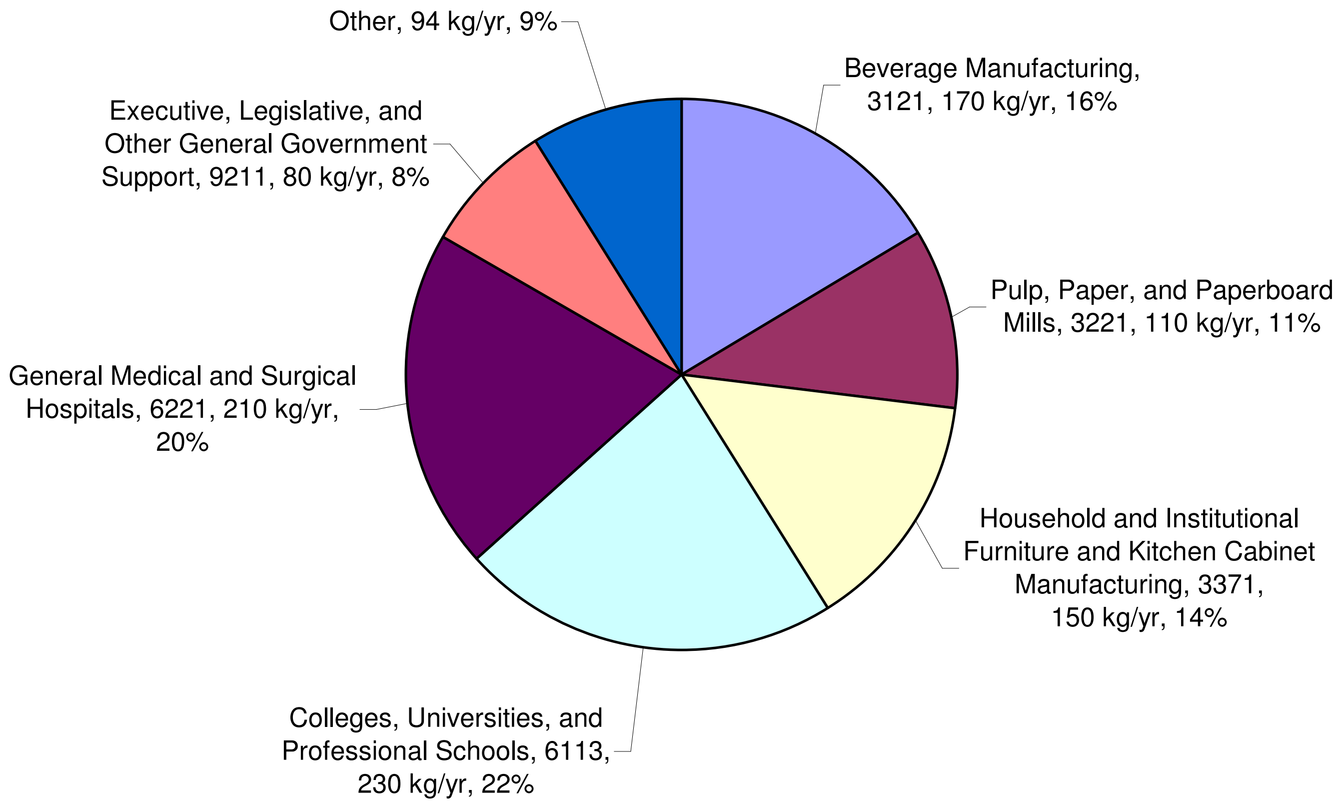


Figure 22
Estimated Phosphorus Load to POTWs from Industrial & Commercial Process Wastewater to Red River Basin (by 4 Digit NAICS Code)

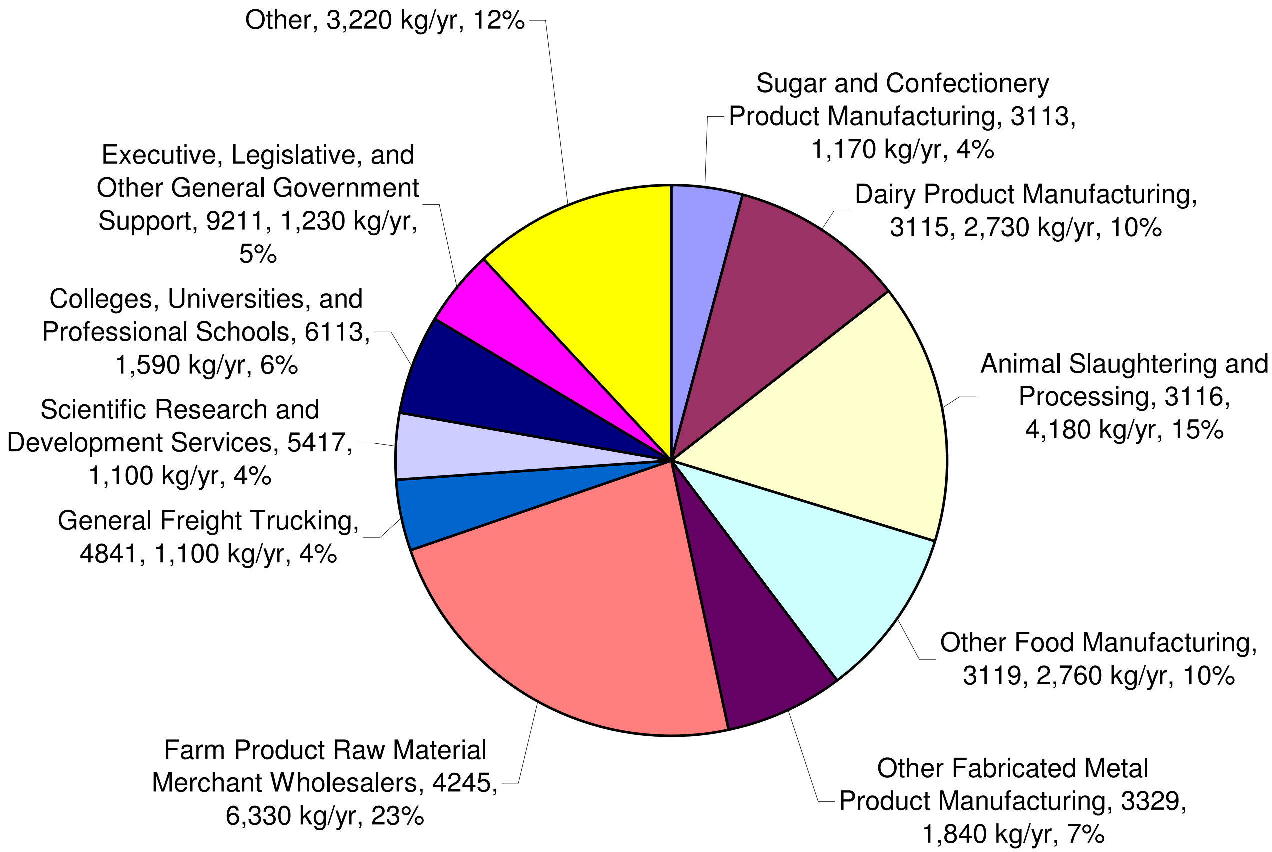


Figure 23
Estimated Phosphorus Load to POTWs from Industrial & Commercial Process Wastewater to St. Croix River Basin (by 4 Digit NAICS Code)

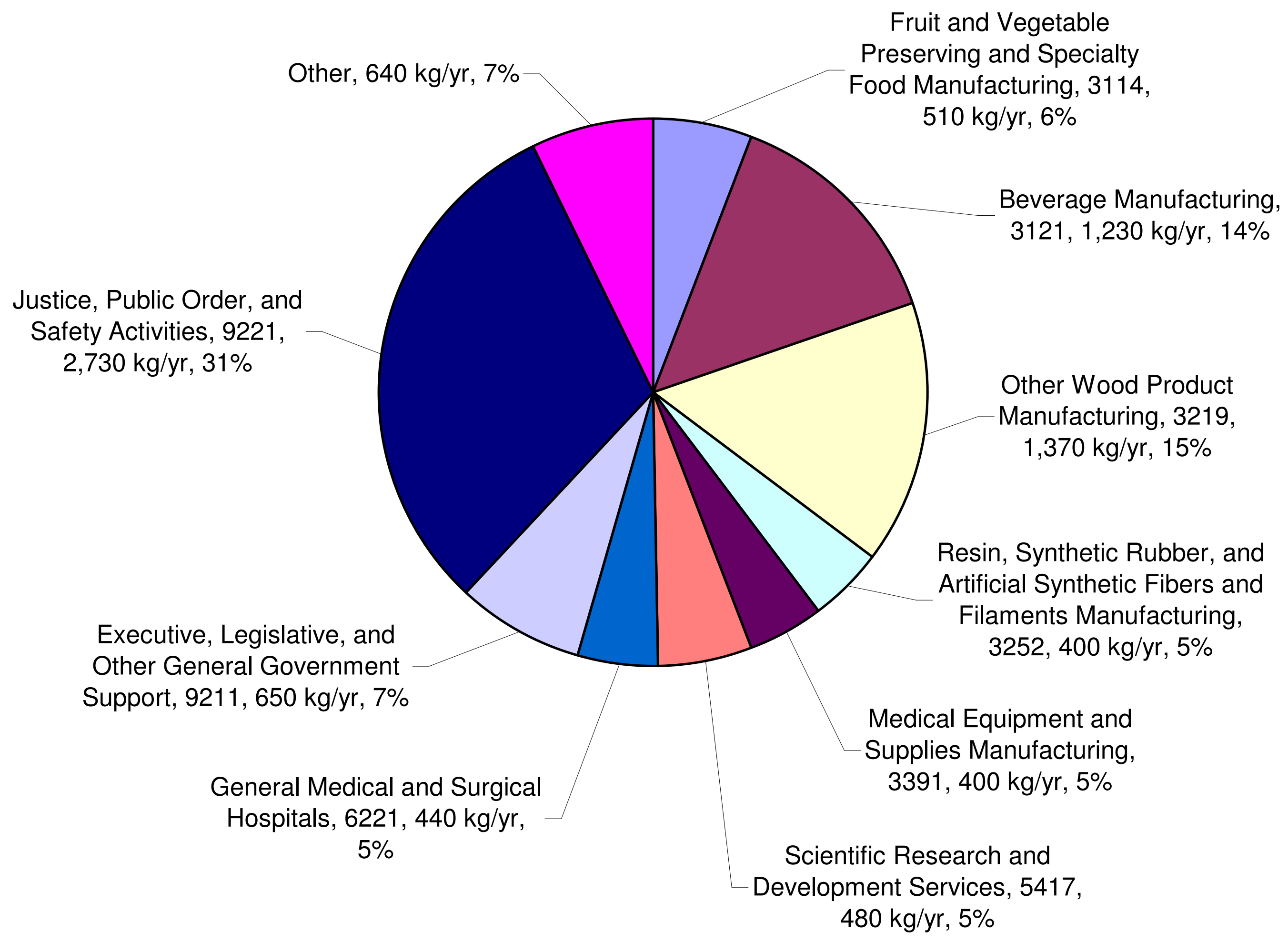


Figure 24
Estimated Phosphorus Load to POTWs from Industrial & Commercial Process Wastewater to Upper Mississippi River Basin (by 4 Digit NAICS Code)

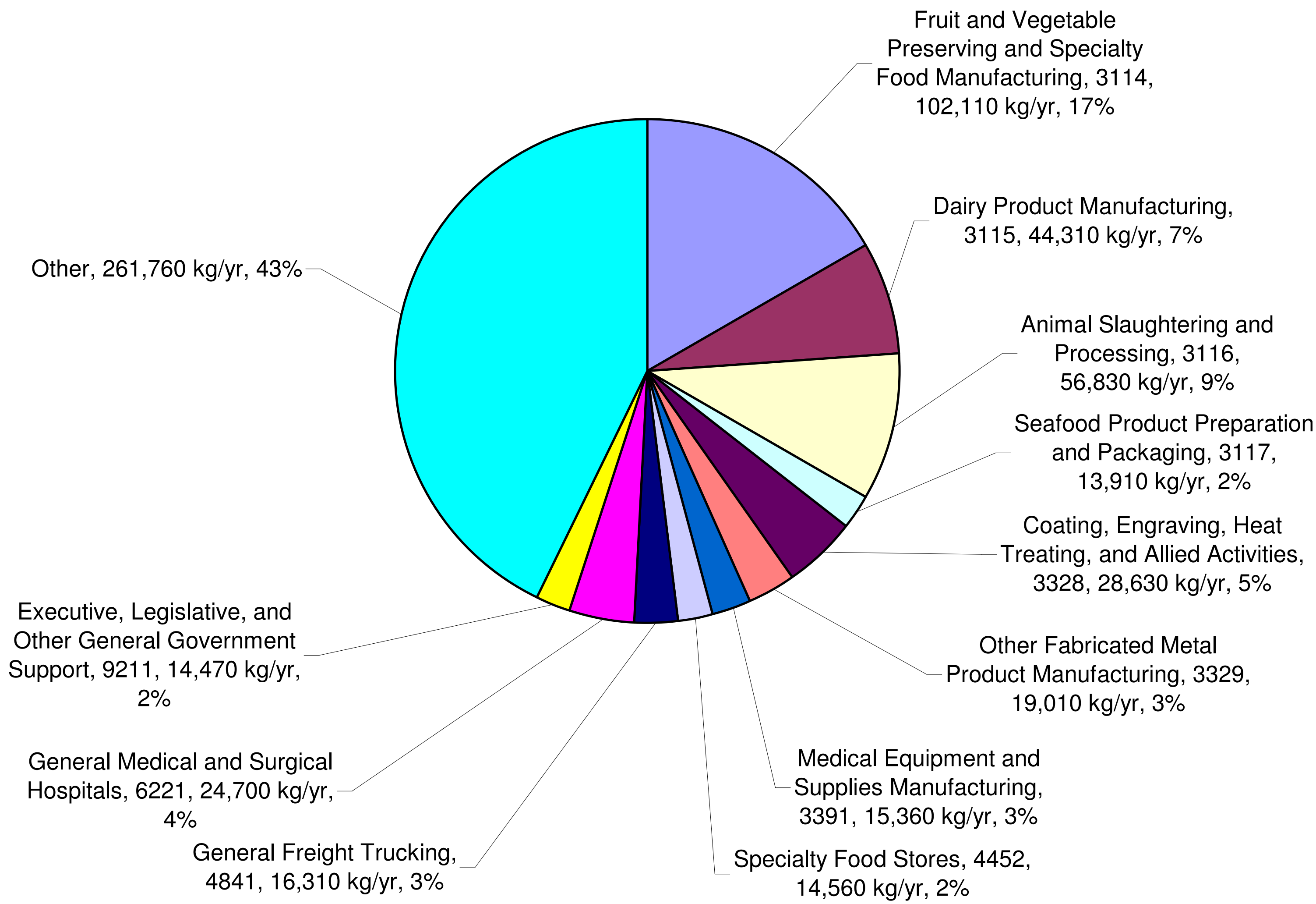
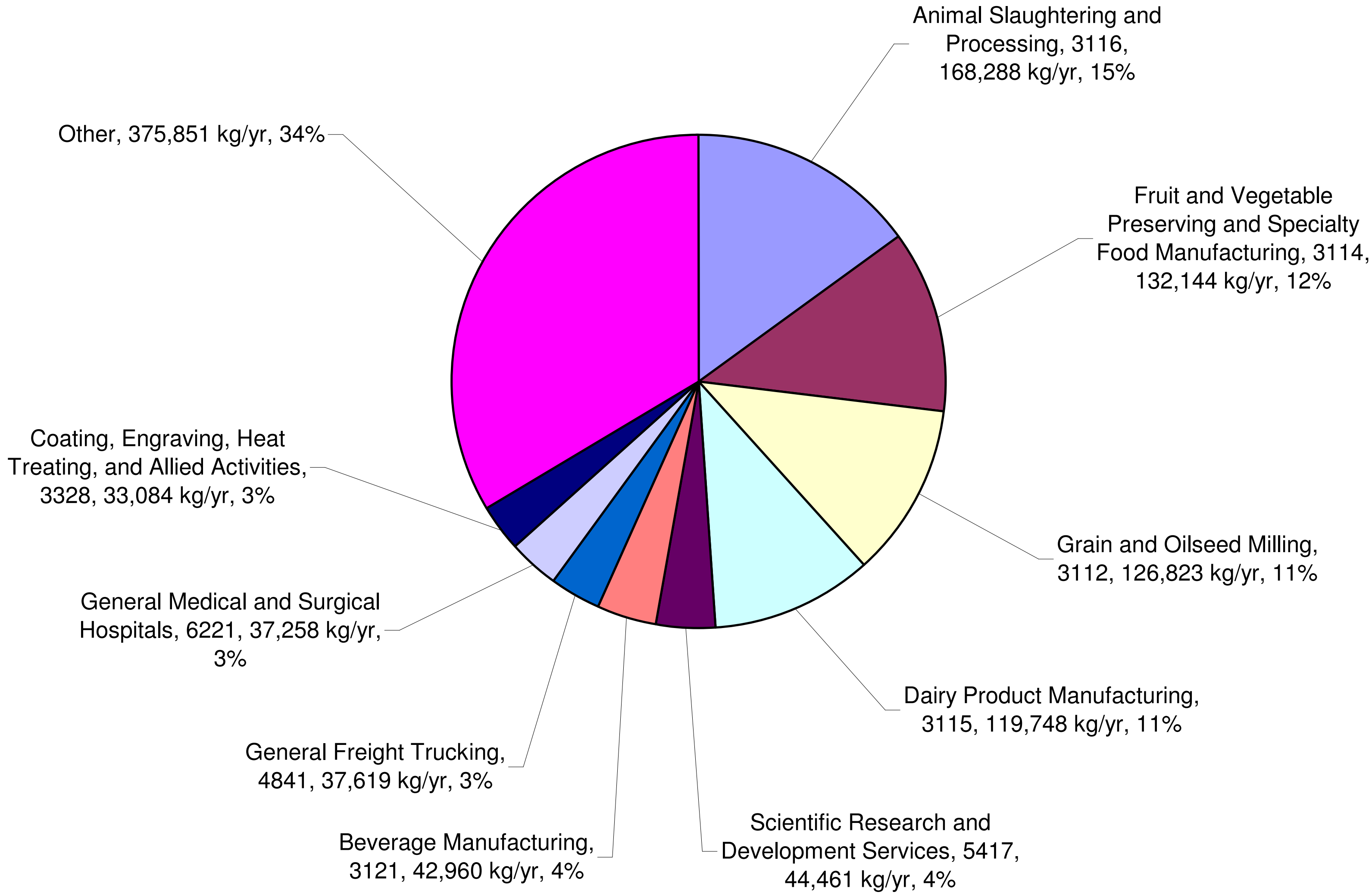


Figure 25
Estimated Phosphorus Load to POTWs from Industrial & Commercial Process Wastewater to State of Minnesota (by 4 Digit NAICS Code)



Commercial and Institutional Automatic Dishwasher Detergents (ADWD)

The per capita use information indicates that the commercial and institutional use of ADWD contributes a relatively small amount of phosphorus to untreated wastewater. For the ten Minnesota watershed basins, these amounts ranged from 1.9 percent to 3.7 percent on a basin basis and 3.4 percent statewide of the total influent phosphorus (see Table 31).

Table 31
Estimated Influent Phosphorus Load from Commercial & Institutional Automatic Dishwasher Detergent to POTWs by Basin

Basin	Influent Phosphorus Load (kg/yr)	Influent Phosphorus Load (% of Total)
Cedar River	2,000	1.9%
Des Moines River	1,100	2.4%
Lake Superior	7,200	3.2%
Lower Mississippi River	15,000	3.0%
Minnesota River	29,500	3.1%
Missouri River	700	2.6%
Rainy River	600	2.9%
Red River	5,200	3.5%
St. Croix River	2,000	3.7%
Upper Mississippi River	88,600	3.7%
State Total	151,900	3.4%

No specific information regarding trends in the commercial and institutional use of ADWD was available from the literature reviewed. However, the general industrial and institution cleaner market of which commercial and institutional ADWD is a part, has declined moderately and a marginal rate of decline is projected during the forecast period to 2005. (SRI, 2002)

Water Supply Treatment Chemicals

A variety of phosphorus-based chemicals are applied to municipal water supplies to inhibit and control scale and corrosion, soften water and control pH. For the years 2001 through mid-year 2003, the MDH provided data on the annual flow volume for each of the communities adding phosphorus and average residual phosphorus concentration in the water supply for a number of the communities adding phosphorus. The municipal water treatment chemicals phosphorus contribution to POTWs ranged from 1.7 percent to 5.7 percent in each of the basins and 3.1 percent statewide of the total influent phosphorus (see Table 32). The phosphorus contribution from water treatment chemicals was based on actual numbers from MDH and an estimated average and was also compared to per capita values. Using the MDH data on phosphorus used in municipal water supply treatment in Minnesota (140,000 kg/yr) and the estimated Minnesota population for 2000 (ca. 4,919,479), the estimated per capita phosphorus used for municipal water treatment was 0.029 kg/p·yr.

Table 32
Estimated Influent Phosphorus Load from Water Treatment Chemicals to POTWs and Privately Owned Treatment Works by Basin

Basin	Influent Phosphorus Load (kg/yr)	Influent Phosphorus Load (% of Total)
Cedar River	3,800	3.6%
Des Moines River	2,600	5.6%
Lake Superior	3,900	1.7%
Lower Mississippi River	13,900	2.8%
Minnesota River	31,500	3.3%
Missouri River	1,000	3.8%
Rainy River	700	3.6%
Red River	7,800	5.2%
St. Croix River	3,100	5.7%
Upper Mississippi River	72,000	3.0%
State Total	140,300	3.1%

Using 2000 data on annual U.S. phosphate consumption for water treatment chemicals (13,700 short tons, as phosphorus) from the SRI publication Chemical Economics Handbook - Industrial Phosphates, and the estimated U.S. population for 2000 (ca. 281,421,906), the estimated per capita phosphorus usage in water treatment chemicals was 0.044 kg/p·yr. However, because the water treatment chemical phosphorus estimate completed for this study includes only municipal water treatment and not industrial water treatment chemical usage, the 0.029 kg/p·yr may be an accurate number.

The use of phosphates nationally in the municipal water treatment market increased slightly between 1993 and 2000 (SRI, 2002), a trend that is expected to continue with the increased regulatory requirements for drinking water suppliers.

Inflow and Infiltration

The results of this study indicate that inflow and infiltration contribute a negligible amount of phosphorus to POTW influent. The inflow and infiltration contribution was approximately 0.1 percent of the total influent phosphorus load discharged into POTWs (see Table 33).

Table 33
Estimated Influent Phosphorus Load from Inflow & Infiltration to POTWs by Basin

Basin	Influent Phosphorus Load (kg/yr)	Influent Phosphorus Load (% of Total)
Cedar River	70	0.1%
Des Moines River	30	0.1%
Lake Superior	310	0.1%
Lower Mississippi River	320	0.1%
Minnesota River	610	0.1%
Missouri River	20	0.1%
Rainy River	20	0.1%
Red River	120	0.1%
St. Croix River	50	0.1%
Upper Mississippi River	1,790	0.1%
State Total	3,340	0.1%

Phosphorus Point Sources and Amounts to Waters of the State

The point source effluent phosphorus loads to each of the ten Minnesota basins and the state were computed using the methods described in the Approach and Methodology section. The estimated annual phosphorus load to waters of the state is 2,124,000 kg/yr with a flow weighted mean effluent concentration of 0.6 mg/L. The following tabulation (see Table 34) summarizes the estimated point source phosphorus loads to each of the ten Minnesota watershed basins by average annual load. The effluent phosphorus load is presented in both kg/yr and in flow weighted mean concentration. The subsequent table (Table 35) and figures (Figures 26 through 36) summarize the estimated point source phosphorus loads for the three categories of treatment facilities; POTWs, privately owned wastewater treatment systems for domestic sources, and industrial wastewater treatment systems for each basin and the state. Table 35 also summarizes the estimated flow weighted mean effluent concentration for the three categories of treatment facilities.

Table 34
Point Source Phosphorus Loads by Basin

Basin	Point Source Effluent Phosphorus Load (kg/yr)	Flow Weighted Mean Effluent Phosphorus Concentration (mg/L)
Cedar River	56,800	2.5
Des Moines River	55,500	5.4
Lake Superior	34,800	0.04
Lower Mississippi River	267,400	0.5
Minnesota River	371,700	0.6
Missouri River	13,200	3.3
Rainy River	44,300	0.6
Red River	78,100	0.8
St. Croix River	22,100	1.3
Upper Mississippi River*	1,180,100	0.9
State Total	2,124,000	0.6

*Expected Load reduction of (578,600 kg/yr) associated with 1 mg/L effluent discharge limit at the MCES Metro WWTF (Effective 12/31/05)

Table 35
Point Source Phosphorus Loads by Basin and Facility Type

Basin	Publicly Owned Treatment Works (kg/yr)	POTW Flow Weighted Mean Effluent Phosphorus Concentration (mg/L)	Private WWT Systems for Domestic Use (kg/yr)	Private WWT Systems Flow Weighted Mean Effluent Phosphorus Concentration (mg/L)	Commercial and Industrial WWT Systems (kg/yr)	Commercial and Industrial Flow Weighted Mean Effluent Phosphorus Concentration (mg/L)
Cedar River	56,400	3.95	0	NA	390	0.25
Des Moines River	15,100	2.04	0	NA	40,440	10.61
Lake Superior	31,800	0.48	40	0.41	2,970	0.004
Lower Mississippi River	184,000	2.71	270	2.50	83,120	0.34
Minnesota River	237,800	1.84	840	3.73	133,060	0.30
Missouri River	12,400	3.49	20	1.18	750	2.03
Rainy River	4,100	1.06	10	1.06	40,160	0.57
Red River	64,300	2.62	30	3.00	13,810	0.37
St. Croix River	20,400	2.04	300	1.95	1,360	0.21
Upper Mississippi River	1,109,500	2.94	1,960	3.50	68,650	0.35
State Total	1,735,800	2.47	3,470	2.96	384,710	0.29

NA - Not Applicable

Figure 26
Point Source Phosphorus Loads Discharged to the Cedar River Basin by Treatment Facility

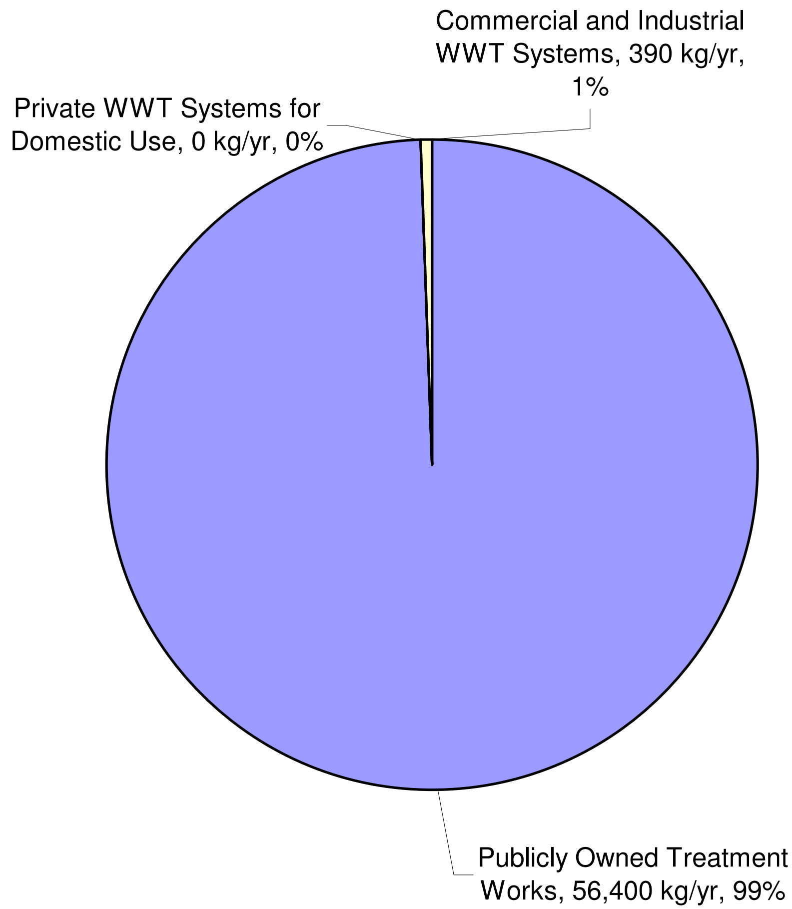


Figure 27
Point Source Phosphorus Loads Discharged to the Des Moines River Basin by Treatment Facility

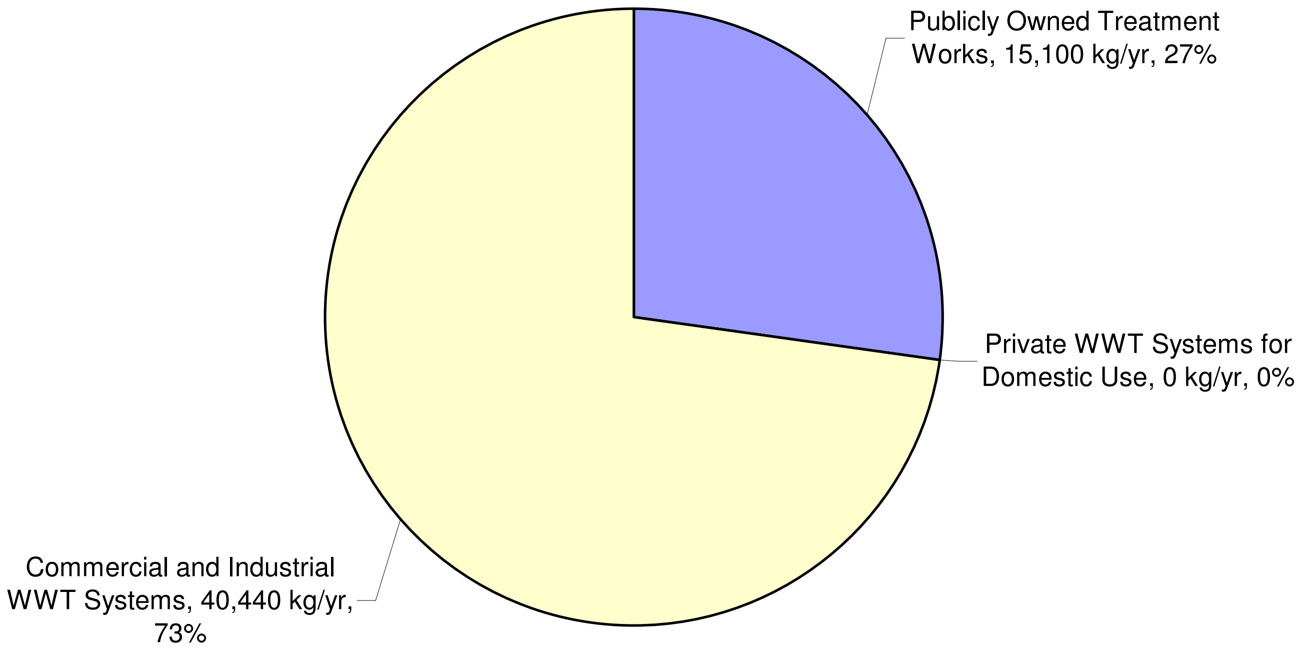


Figure 28
Point Source Phosphorus Loads Discharged to the Lake Superior Basin by Treatment Facility

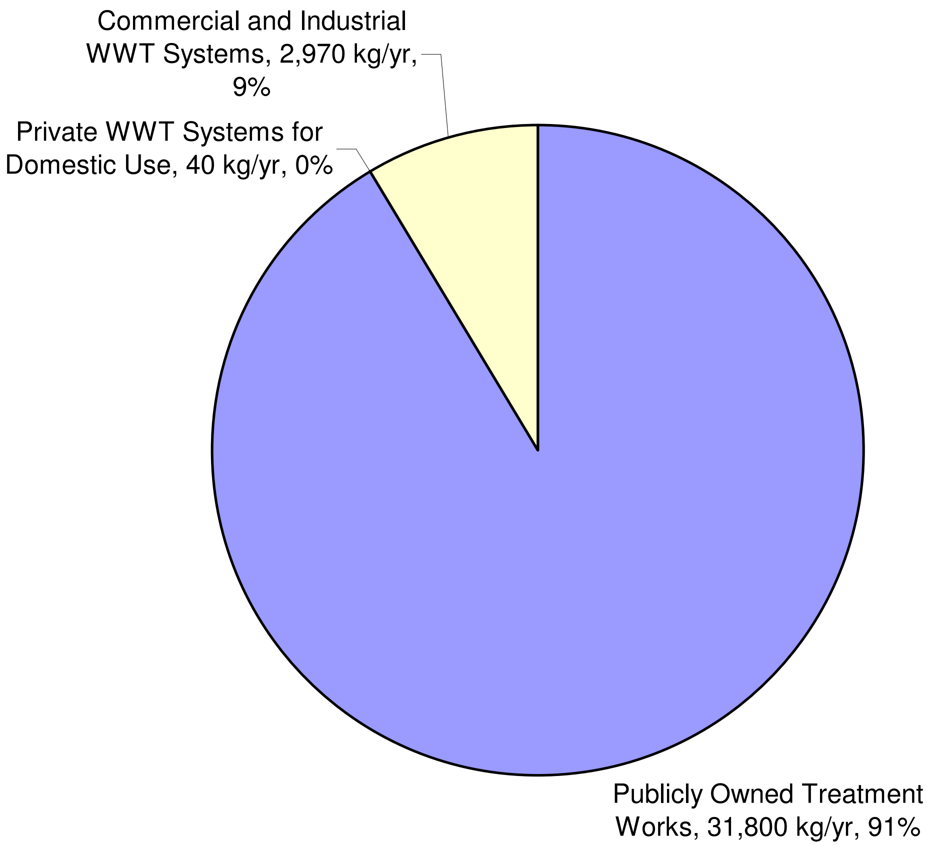


Figure 29
Point Source Phosphorus Loads Discharged to the Lower Mississippi River Basin by Treatment Facility

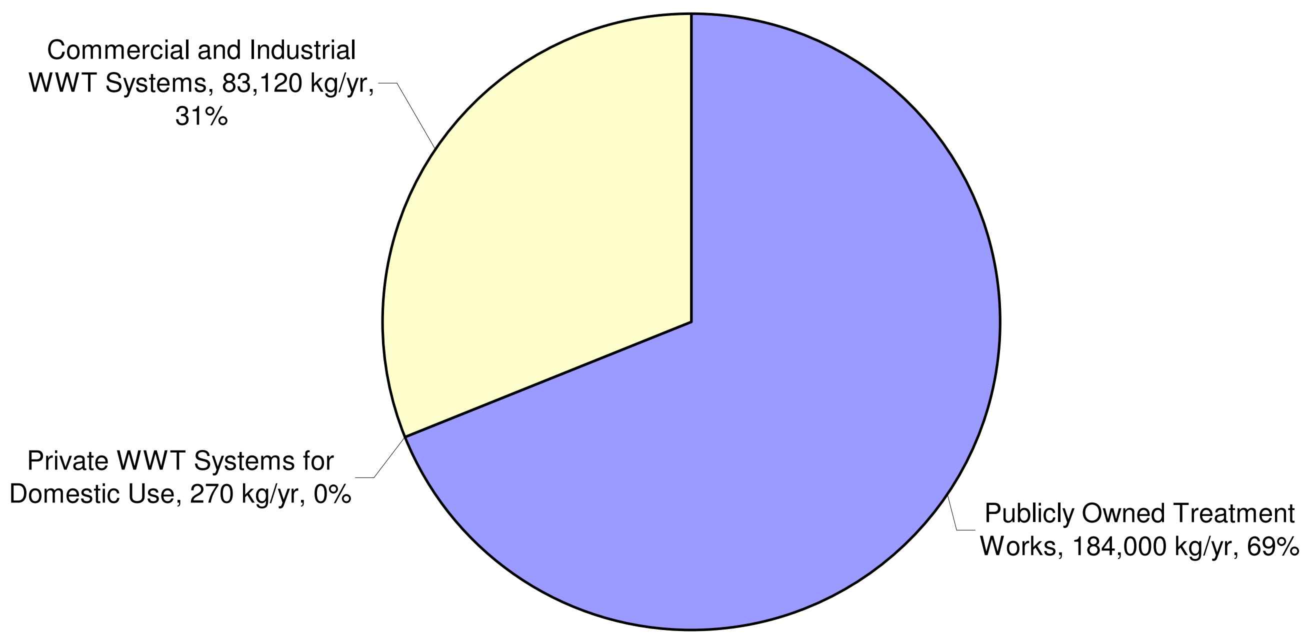


Figure 30
Point Source Phosphorus Loads Discharged to the Minnesota River Basin by Treatment Facility

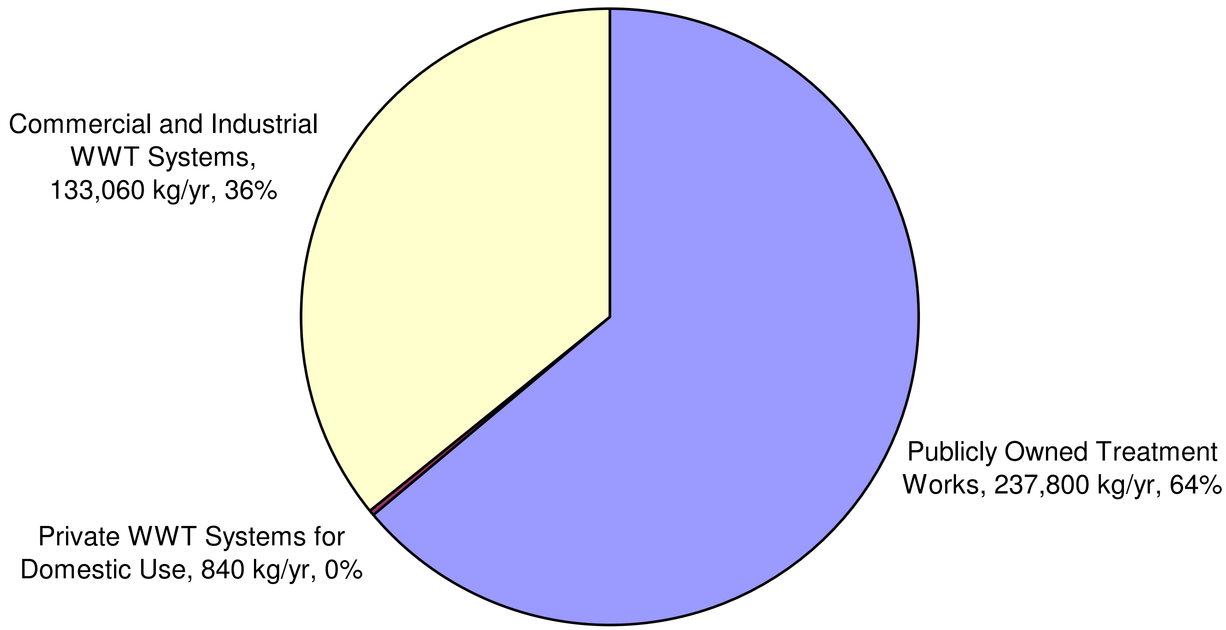


Figure 31
Point Source Phosphorus Loads Discharged to the Missouri River Basin by Treatment Facility

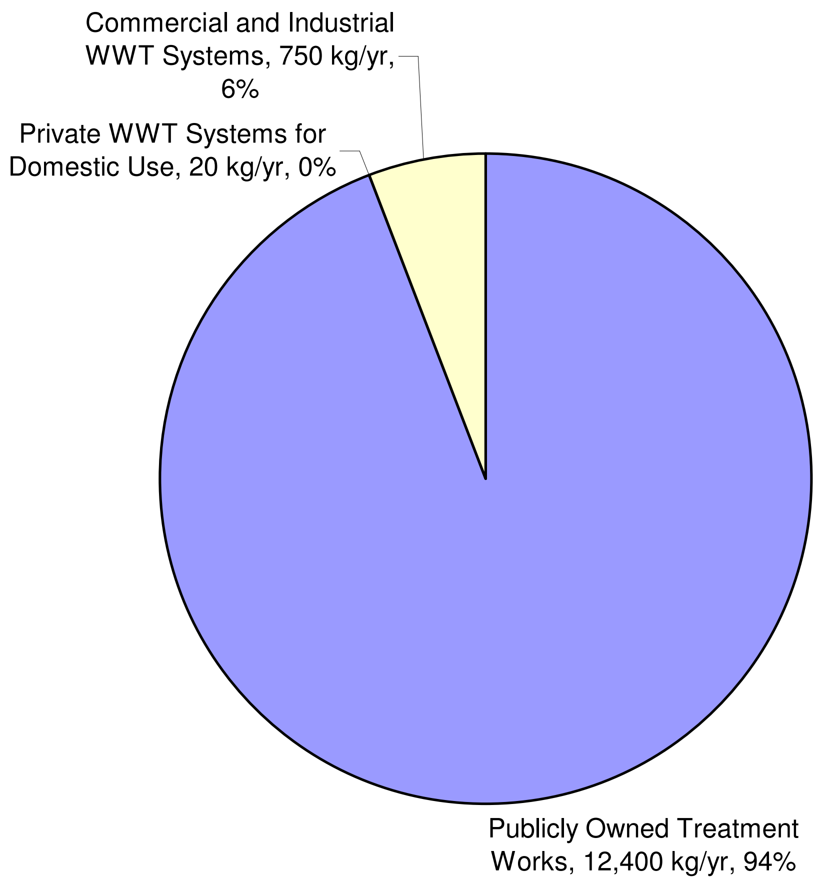


Figure 32
Point Source Phosphorus Loads Discharged to the Rainy River Basin by Treatment Facility

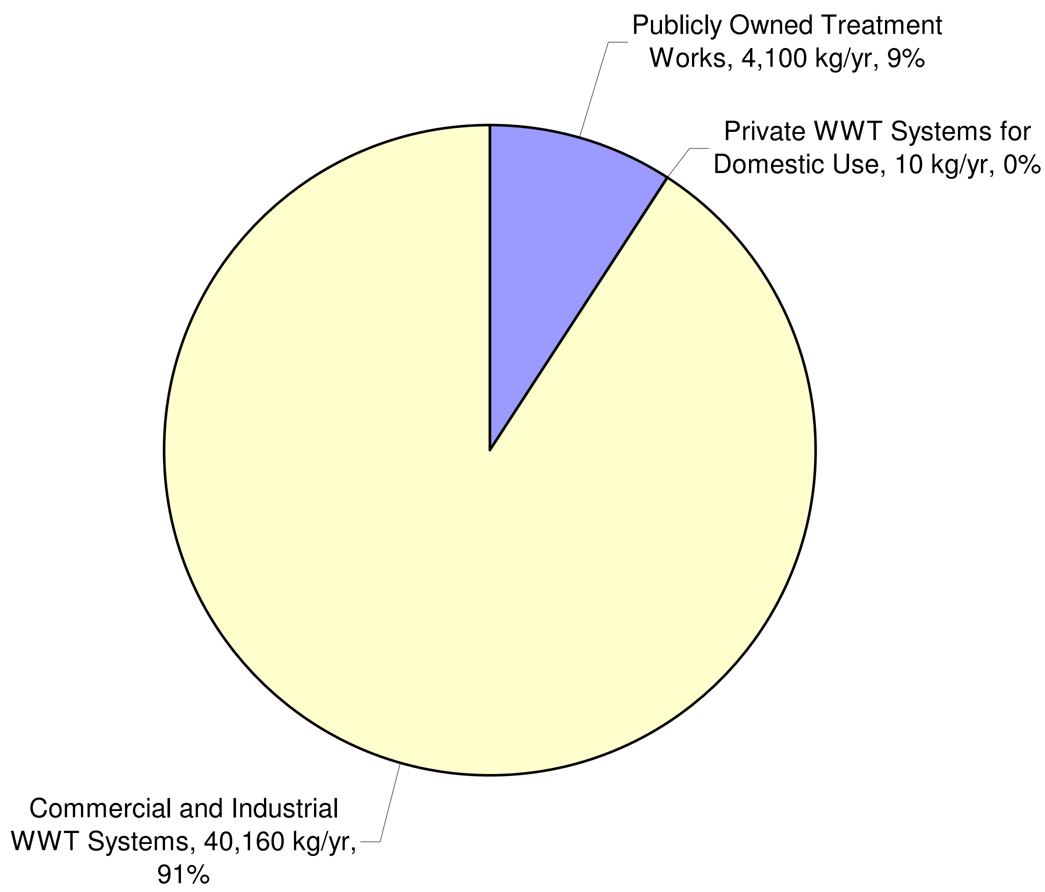


Figure 33
Point Source Phosphorus Loads Discharged to the Red River Basin by Treatment Facility

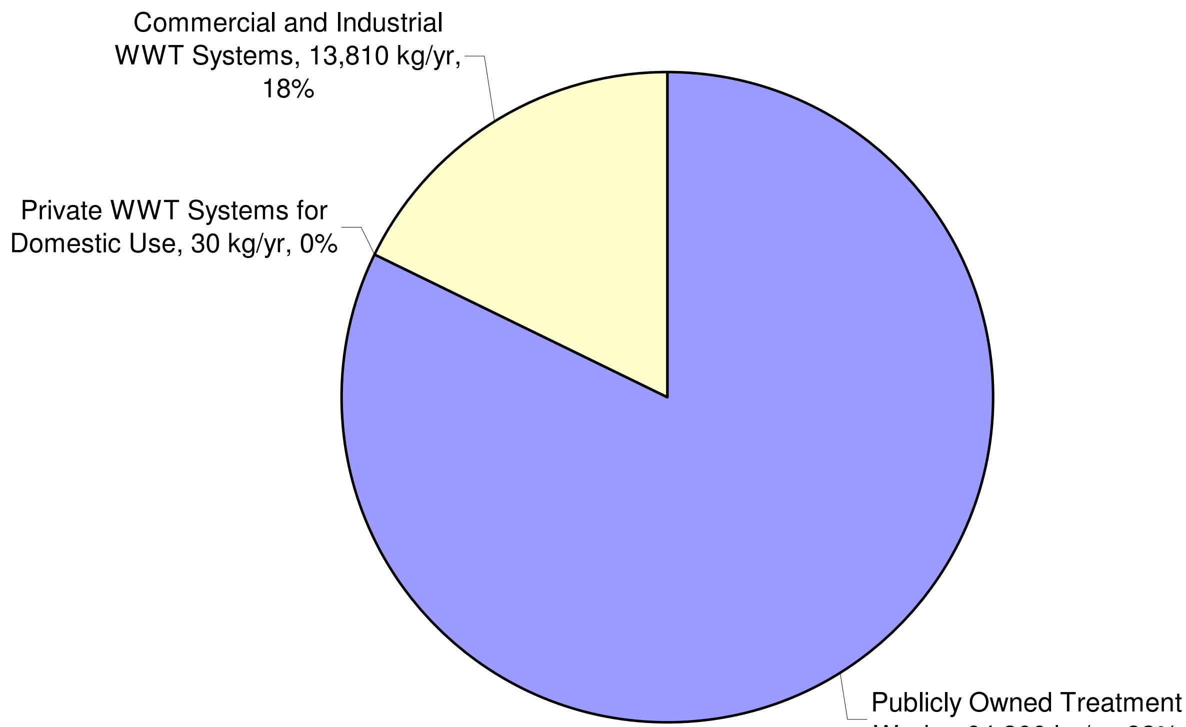


Figure 34
Point Source Phosphorus Loads Discharged to the St. Croix River Basin by Treatment Facility

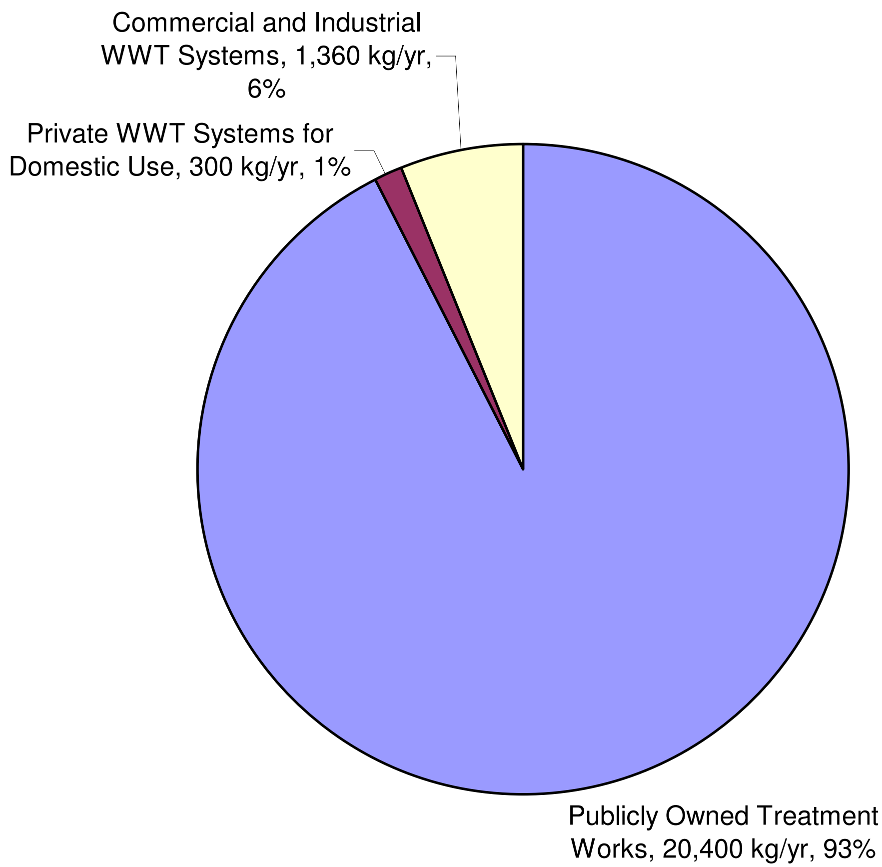


Figure 35
Point Source Phosphorus Loads Discharged to the Upper Mississippi River Basin by Treatment Facility

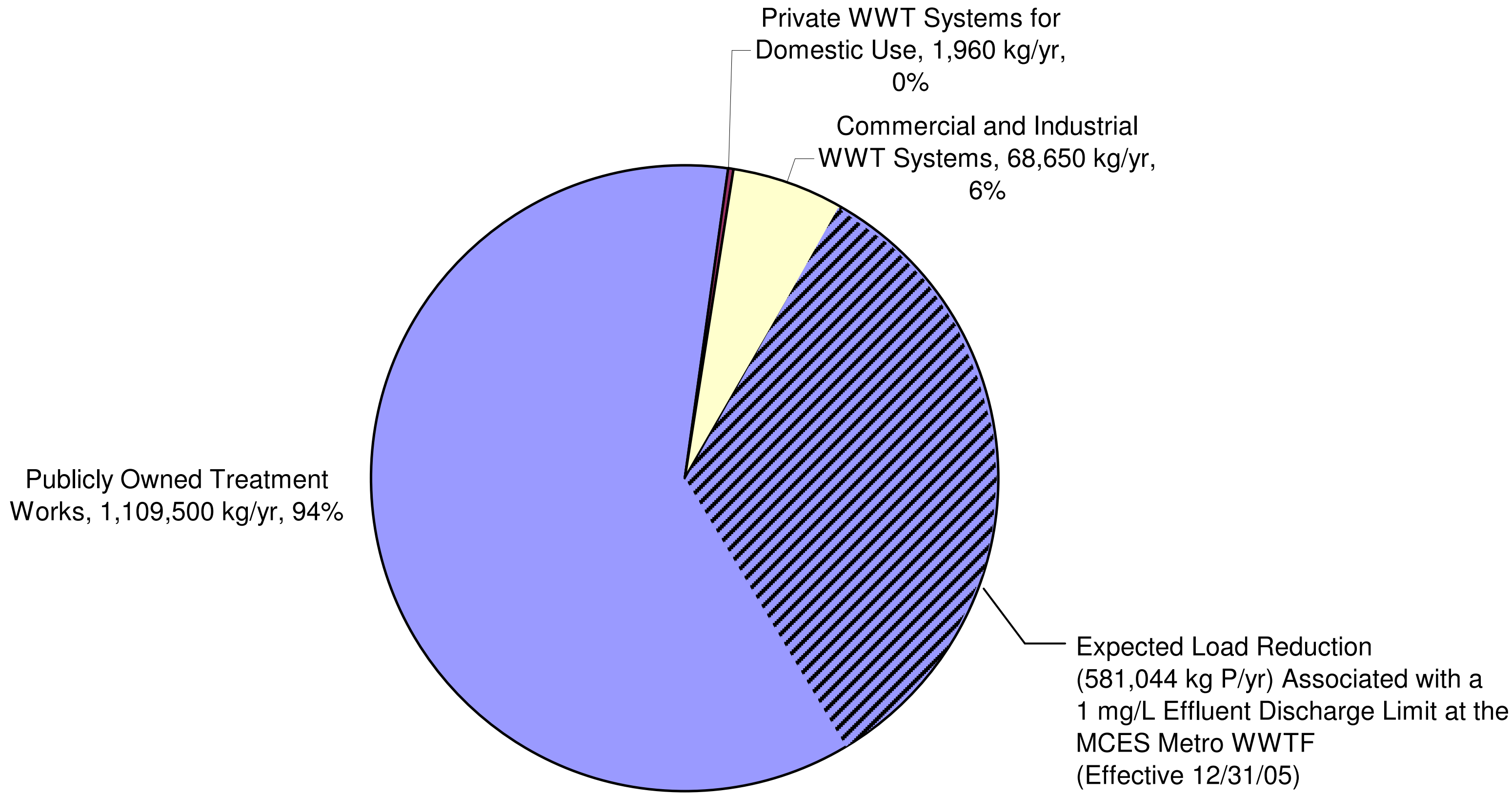
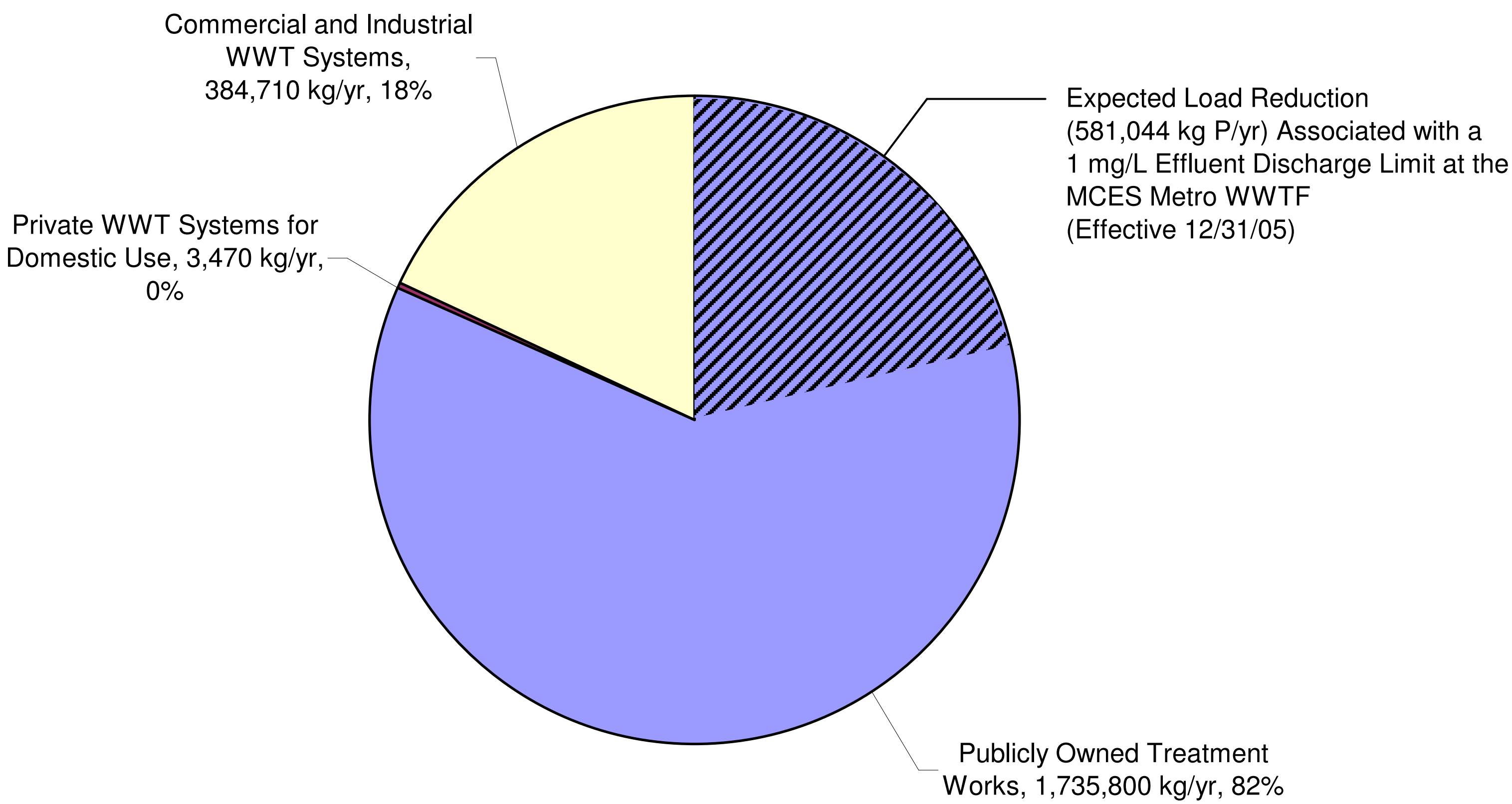


Figure 36
Point Source Phosphorus Loads Discharged Statewide by Treatment Facility



POTWs

POTWs discharge an estimated 1,736,000 kg/yr of phosphorus or just slightly more than 80 percent of the total point source phosphorus load to the watershed basins. In the Rainy River basin, POTWs accounted for only an estimated 9.3 percent of the total phosphorus loading to the basin, whereas, in the Lake Superior, St. Croix River, Missouri River, Upper Mississippi River, and Cedar River Basins, POTWs accounted for 91, 92, 94, 94 and 99 percent of the total phosphorus load, respectively.

The data used for this study is from the years 2001, 2002 and the first half of 2003. During that time period many POTWs have implemented phosphorus removal and others will begin to implement it in the future. The largest impact is probably phosphorus removal at the MCES' Metro plant, which is required to implement phosphorus removal to 1 mg/L by the end of 2005. This facility discharges to the Upper Mississippi River basin and had an average phosphorus effluent concentration for the study period of 2.97 mg/L at an average annual phosphorus load to the basin of approximately 870,000 kg/y. While the 1 mg/L limit isn't effective until the end of 2005, the MCES Metro plant has completed modifications to its facility that have enabled it to meet the 1 mg/L in December 2003 and MCES staff anticipate continuing to meet the 1 mg/L limit. A reduction in the phosphorus concentration to 1 mg/L results in a reduction of an estimated 581,044 kg of phosphorus per year. Because this one facility accounts for approximately 74 percent of the phosphorus load to the Upper Mississippi River basin and an estimated 40 percent statewide, phosphorus removal at this one facility will have a significant impact on the relative phosphorus loads in this basin and the state.

The phosphorus removal efficiency in POTWs and privately owned treatment facilities was estimated based on the estimated influent and effluent loads (see Table 36). The estimated average phosphorus removal statewide is 61 percent in POTWs.

Table 36
Phosphorus Removal in POTWs and Privately Owned Treatment Facilities

	POTW			Private		
Basin	Influent Load (kg/yr)	Effluent Load (kg/yr)	Percent Removal (%)	Influent Load (kg/yr)	Effluent Load (kg/yr)	Percent Removal (%)
Cedar River Basin	105,200	56,400	46%	0	0	
Des Moines River	46,200	15,100	67%	0	0	
Lake Superior	227,000	31,800	86%	500	40	92%
Lower Mississippi River	501,900	184,000	63%	800	300	63%
Minnesota River	952,200	237,800	75%	1,500	800	47%
Missouri River	26,400	12,400	53%	100	20	80%
Rainy River	20,100	4,100	80%	30	10	67%
Red River	150,600	64,300	57%	0	0	
St. Croix River	53,500	20,400	62%	800	300	63%
Upper Mississippi River	2,384,900	1,109,500	53%	4,300	2,000	53%
State-wide	**4,468,000**	**1,735,800**	**61%**	**8,030**	**3,470**	**57%**

The estimated point source effluent phosphorus load to each basin was categorized by POTW size and category for each of the POTW influent phosphorus source components (see Tables 37 through 39). The number of facilities in each category is given in parentheses.

1. Size (based on Average Wet Weather Design flow)
   a. Small – less than 0.2 mgd (316 facilities)
   b. Medium – from 0.2 mgd to 1.0 mgd (149 facilities)
   c. Large – greater than 1.0 mgd (68 facilities)

2. Waste Treated (% by flow volume treated)
   a. POTWs that serve mainly households and residences - less than 20 % industrial or commercial contributions (128 facilities)
   b. POTWs that have some commercial or industrial contribution – between 20% and 50% industrial or commercial contributions (207 facilities)
   c. POTWs that are dominated by a variety of commercial and industrial contributions – greater than 50% industrial or commercial contributions (198 facilities)

Approximately 88 percent of the phosphorus load discharged to the watershed basins from POTWs is from large POTWs (i.e., >1.0 mgd). While approximately 8.5 percent of the point source phosphorus load discharged to the basins is from POTWs categorized as medium (i.e., 0.2 to 1.0 mgd) and only 3.5 percent is from small POTWs (i.e., <0.2 mgd). Within the large category, POTWs that have some commercial or industrial contribution (between 20% and 50% industrial or commercial contributions) contribute the majority (72 percent) of the phosphorus load from this category to the basins. The POTWs were ranked from high to low by their phosphorus load discharged to watershed basins:

1. Large POTWs that have some commercial or industrial contribution – between 20% and 50% industrial or commercial contributions (1,100,000 kg/yr)

2. Large POTWs that are dominated by a variety of commercial and industrial contributions – greater than 50% industrial or commercial contributions (347,000 kg/yr)

3. Large POTWs that serve mainly households and residences - less than 20 % industrial or commercial contributions (83,000 kg/yr)

4. Medium POTWs that are dominated by a variety of commercial and industrial contributions – greater than 50% industrial or commercial contributions (68,000 kg/yr)

5. Medium POTWs that have some commercial or industrial contribution – between 20% and 50% industrial or commercial contributions (65,000 kg/yr)

6. Small POTWs that are dominated by a variety of commercial and industrial contributions – greater than 50% industrial or commercial contributions (23,000 kg/yr)

7. Small POTWs that have some commercial or industrial contribution – between 20% and 50% industrial or commercial contributions (22,000 kg/yr)

8. Small POTWs that serve mainly households and residences - less than 20 % industrial or commercial contributions (14,000 kg/yr)

9. Medium POTWs that serve mainly households and residences - less than 20 % industrial or commercial contributions (14,000 kg/yr)

Table 37
Phosphorus Loading to Waters of the State
Small POTW Point Sources

			Basin Name	Cedar River	Des Moines River	Lake Superior	Lower Mississippi River	Minnesota River	Missouri River	Rainy River	Red River	St. Croix River	Upper Mississippi River	Statewide
Phosphorus Sources				Total Phosphorus (kg/yr)	Total Phosphorus (kg/yr)	Total Phosphorus (kg/yr)	Total Phosphorus (kg/yr)	Total Phosphorus (kg/yr)	Total Phosphorus (kg/yr)	Total Phosphorus (kg/yr)	Total Phosphorus (kg/yr)	Total Phosphorus (kg/yr)	Total Phosphorus (kg/yr)	Total Phosphorus (kg/yr)
Phosphorus Sources to Waters of the State	Small POTWs (<0.2 mgd)	Serving Mainly Households and Residences	Residential Automatic Dishwasher Detergent	42	22	30	680	261	75	0	117	43	241	1,511
			Commercial Automatic Dishwasher Detergent	19	10	14	318	122	35	0	55	20	1,111	1,704
			Food Soils/Garbage Disposal Waste	93	49	67	1,516	582	168	1	260	95	516	3,347
			Dentifrices	6	3	4	92	35	10	0	16	6	70	242
			Human Waste	142	61	58	2,500	1,362	235	12	308	30	1,981	6,690
			Finished Water Supply	46	0	0	180	117	3	0	34	0	362	742
			Groundwater Intrusion (I&I)	0	0	0	4	1	0	0	1	0	3	10
			Commercial/Industrial Process Water	1	0	0	40	23	0	0	15	7	139	226
			Noncontact Cooling Water	0	0	0	0	0	0	0	0	0	0	0
			Sub Total	**350**	**145**	**174**	**5,330**	**2,503**	**526**	**13**	**806**	**201**	**4,423**	**14,471**
		Serving Some Commercial/ Industrial Users	Residential Automatic Dishwasher Detergent	85	73	0	178	503	143	74	389	136	250	1,832
			Commercial Automatic Dishwasher Detergent	40	34	0	83	235	67	35	182	64	1,195	1,934
			Food Soils/Garbage Disposal Waste	189	163	0	398	1,122	320	165	867	303	536	4,063
			Dentifrices	11	10	0	24	68	19	10	53	18	72	287
			Human Waste	283	336	0	1,445	3,528	452	353	1,750	612	3,310	12,068
			Finished Water Supply	35	0	0	88	285	4	38	83	69	484	1,087
			Groundwater Intrusion (I&I)	1	1	0	2	5	1	1	3	1	5	19
			Commercial/Industrial Process Water	0	0	0	61	390	13	96	150	16	216	942
			Noncontact Cooling Water	0	0	0	0	0	0	0	0	0	0	0
			Sub Total	**643**	**617**	**0**	**2,279**	**6,137**	**1,020**	**772**	**3,476**	**1,220**	**6,069**	**22,232**
		Serving Predominantly Commercial/ Industrial Users	Residential Automatic Dishwasher Detergent	61	10	189	59	324	96	26	213	58	202	1,239
			Commercial Automatic Dishwasher Detergent	29	5	88	28	151	45	12	100	27	965	1,449
			Food Soils/Garbage Disposal Waste	136	23	422	132	722	215	58	475	129	433	2,743
			Dentifrices	8	1	26	8	44	13	3	29	8	59	199
			Human Waste	184	45	1,036	762	4,210	1,057	388	2,998	562	3,092	14,333
			Finished Water Supply	53	0	122	39	190	20	38	49	2	144	658
			Groundwater Intrusion (I&I)	1	0	3	1	5	1	0	3	1	6	22
			Commercial/Industrial Process Water	0	0	12	11	317	106	0	100	0	1,332	1,878
			Noncontact Cooling Water	0	0	0	0	0	0	0	0	0	0	0
			Sub Total	**472**	**84**	**1,897**	**1,039**	**5,962**	**1,554**	**525**	**3,968**	**786**	**6,233**	**22,521**
Total				**1,464**	**846**	**2,071**	**8,648**	**14,602**	**3,100**	**1,311**	**8,249**	**2,207**	**16,725**	**59,224**

Table 38
Phosphorus Loading to Waters of the State
Medium POTW Point Sources

			Basin Name	Cedar River	Des Moines River	Lake Superior	Lower Mississippi River	Minnesota River	Missouri River	Rainy River	Red River	St. Croix River	Upper Mississippi River	Statewide
Phosphorus Sources				Total Phosphorus (kg/yr)	Total Phosphorus (kg/yr)	Total Phosphorus (kg/yr)	Total Phosphorus (kg/yr)	Total Phosphorus (kg/yr)	Total Phosphorus (kg/yr)	Total Phosphorus (kg/yr)	Total Phosphorus (kg/yr)	Total Phosphorus (kg/yr)	Total Phosphorus (kg/yr)	Total Phosphorus (kg/yr)
Phosphorus Sources to Waters of the State	Medium POTWs (0.2 to 1.0 mgd)	Serving Mainly Households and Residences	Residential Automatic Dishwasher Detergent	0	89	0	334	484	20	0	130	65	288	1,410
			Commercial Automatic Dishwasher Detergent	0	41	0	156	226	10	0	61	30	1,374	1,898
			Food Soils/Garbage Disposal Waste	0	197	0	745	1,078	46	0	290	145	617	3,118
			Dentifrices	0	12	0	45	65	3	0	18	9	83	235
			Human Waste	0	273	0	1,193	1,025	90	0	304	372	2,501	5,757
			Finished Water Supply	0	41	0	190	65	9	0	0	63	485	854
			Groundwater Intrusion (I&I)	0	1	0	2	3	0	0	1	0	3	10
			Commercial/Industrial Process Water	0	1	0	3	117	8	0	162	115	58	464
			Noncontact Cooling Water	0	0	0	0	0	0	0	0	0	0	0
			Sub Total	**0**	**656**	**0**	**2,668**	**3,063**	**185**	**0**	**965**	**799**	**5,410**	**13,746**
		Serving Some Commercial/ Industrial Users	Residential Automatic Dishwasher Detergent	0	145	151	1,703	1,407	0	0	288	498	771	4,963
			Commercial Automatic Dishwasher Detergent	0	68	70	795	657	0	0	135	233	3,681	5,639
			Food Soils/Garbage Disposal Waste	0	323	336	3,796	3,138	0	0	642	1,110	1,651	10,997
			Dentifrices	0	20	20	230	190	0	0	39	67	223	791
			Human Waste	0	1,078	433	8,235	7,723	0	0	1,411	3,283	8,906	31,069
			Finished Water Supply	0	0	74	696	631	0	0	163	76	873	2,513
			Groundwater Intrusion (I&I)	0	1	2	15	13	0	0	3	5	14	53
			Commercial/Industrial Process Water	0	611	41	3,078	1,797	0	0	221	271	2,463	8,481
			Noncontact Cooling Water	0	0	0	0	0	0	0	0	0	0	0
			Sub Total	**0**	**2,246**	**1,127**	**18,549**	**15,558**	**0**	**0**	**2,901**	**5,542**	**18,583**	**64,505**
		Serving Predominantly Commercial/ Industrial Users	Residential Automatic Dishwasher Detergent	85	40	83	532	840	83	36	419	182	274	2,575
			Commercial Automatic Dishwasher Detergent	40	19	39	249	392	39	17	196	85	1,307	2,381
			Food Soils/Garbage Disposal Waste	190	90	185	1,187	1,872	184	81	934	406	586	5,715
			Dentifrices	12	5	11	72	114	11	5	57	25	79	391
			Human Waste	1,610	295	635	4,852	6,478	911	624	6,656	3,602	9,172	34,836
			Finished Water Supply	0	0	23	491	278	89	30	273	462	498	2,144
			Groundwater Intrusion (I&I)	2	1	1	8	12	1	0	6	4	11	45
			Commercial/Industrial Process Water	84	5	9	6,250	7,335	1,014	23	1,500	290	3,876	20,385
			Noncontact Cooling Water	0	0	0	0	0	0	0	0	0	0	0
			Sub Total	**2,023**	**455**	**986**	**13,640**	**17,320**	**2,332**	**817**	**10,041**	**5,055**	**15,803**	**68,472**
Total				**2,023**	**3,357**	**2,113**	**34,857**	**35,940**	**2,517**	**817**	**13,907**	**11,396**	**39,795**	**146,723**

Table 39
Phosphorus Loading to Waters of the State
Large POTW Point Sources

All values are Total Phosphorus (kg/yr).

Phosphorus Sources			Basin Name	Cedar River	Des Moines River	Lake Superior	Lower Mississippi River	Minnesota River	Missouri River	Rainy River	Red River	St. Croix River	Upper Mississippi River	Statewide
Phosphorus Sources to Waters of the State	Large POTWs (>1.0 mgd)	Serving Mainly Households and Residences	Residential Automatic Dishwasher Detergent	0	0	77	3,989	0	0	0	0	0	1,768	5,834
			Commercial Automatic Dishwasher Detergent	0	0	36	1,863	0	0	0	0	0	8,441	10,340
			Food Soils/Garbage Disposal Waste	0	0	171	8,892	0	0	0	0	0	3,786	12,850
			Dentifrices	0	0	10	540	0	0	0	0	0	512	1,062
			Human Waste	0	0	23	29,757	0	0	0	0	0	10,599	40,379
			Finished Water Supply	0	0	0	516	0	0	0	0	0	1,191	1,707
			Groundwater Intrusion (I&I)	0	0	0	27	0	0	0	0	0	20	47
			Commercial/Industrial Process Water	0	0	0	8,731	0	0	0	0	0	1,934	10,665
			Noncontact Cooling Water	0	0	0	0	0	0	0	0	0	0	0
			Sub Total	**0**	**0**	**318**	**54,314**	**0**	**0**	**0**	**0**	**0**	**28,253**	**82,884**
		Serving Some Commercial/ Industrial Users	Residential Automatic Dishwasher Detergent	0	0	444	3,119	8,913	0	0	1,849	434	36,683	51,442
			Commercial Automatic Dishwasher Detergent	0	0	207	1,459	4,168	0	0	863	203	174,610	181,511
			Food Soils/Garbage Disposal Waste	0	0	989	6,954	19,872	0	0	4,122	967	78,321	111,224
			Dentifrices	0	0	60	422	1,206	0	0	250	59	10,596	12,593
			Human Waste	0	0	2,229	15,776	39,576	0	0	7,333	1,780	375,757	442,452
			Finished Water Supply	0	0	0	678	4,823	0	0	1,671	170	28,097	35,439
			Groundwater Intrusion (I&I)	0	0	3	33	81	0	0	16	4	713	850
			Commercial/Industrial Process Water	0	0	79	10,183	37,713	0	0	4,061	1,231	211,386	264,654
			Noncontact Cooling Water	0	0	0	0	0	0	0	0	0	0	0
			Sub Total	**0**	**0**	**4,011**	**38,624**	**116,353**	**0**	**0**	**20,165**	**4,847**	**916,164**	**1,100,164**
		Serving Predominantly Commercial/ Industrial Users	Residential Automatic Dishwasher Detergent	1,826	345	1,315	2,062	2,043	342	113	1,437	168	1,121	10,773
			Commercial Automatic Dishwasher Detergent	853	161	616	963	954	162	53	671	78	5,353	9,865
			Food Soils/Garbage Disposal Waste	4,071	769	2,931	4,597	4,556	754	238	3,203	373	2,401	23,894
			Dentifrices	247	47	178	279	276	46	15	194	23	325	1,631
			Human Waste	36,651	5,525	13,189	21,910	20,672	2,872	1,343	7,947	674	41,562	152,345
			Finished Water Supply	1,797	668	384	2,837	2,014	406	66	1,178	145	1,001	10,496
			Groundwater Intrusion (I&I)	31	5	33	29	32	5	2	17	2	62	219
			Commercial/Industrial Process Water	7,460	3,419	4,615	14,754	40,399	2,155	114	7,339	523	56,773	137,552
			Noncontact Cooling Water	0	0	0	0	0	0	0	0	0	0	0
			Sub Total	**52,937**	**10,939**	**23,261**	**47,432**	**70,946**	**6,742**	**1,945**	**21,987**	**1,987**	**108,598**	**346,774**
Total				**52,937**	**10,939**	**27,590**	**140,370**	**187,299**	**6,742**	**1,945**	**42,152**	**6,834**	**1,053,014**	**1,529,823**

Privately Owned Treatment Systems

As shown on Figures 26 through 36, privately owned treatment facilities for domestic use account for less than half of a percent of the total point source phosphorus load to waters of the state. They contribute only 3,500 kg/yr of phosphorus to waters of the state.

Commercial and Industrial Wastewater Treatment Systems

Commercial and industrial wastewater systems discharging directly to waters of the state make up the remaining point source phosphorus load, approximately 18 percent. They discharge an estimated 385,000 kg/yr to Minnesota surface waters. No attempt was made to determine the major commercial and industrial phosphorus contributors discharging directly to waters of the state.

Noncontact Cooling Water

Noncontact cooling water is a subcategory of point source commercial and industrial wastewater. The phosphorus load from cooling water dischargers to each of the basins are summarized, by basin, in Table 40.

Table 40
Summary of Estimated Commercial & Industrial Wastewater Systems Point Source Phosphorus Load

Basin	Other Commercial & Industrial Wastewater (kg/yr)	Non-contact Cooling Water (kg/yr)	Total Commercial & Industrial Wastewater (kg/yr)
Cedar River	85	304	389
Des Moines River	40,437	0	40,437
Lake Superior	2,935	35	2,970
Lower Mississippi River	81,986	1,129	83,115
Minnesota River	128,560	4,503	133,063
Missouri River	746	0	746
Rainy River	40,148	11	40,159
Red River	10,296	3,517	13,813
St. Croix River	1,361	0	1,361
Upper Mississippi River	63,873	4,779	68,652
Total	370,427	14,278	384,704

It is estimated that noncontact cooling water contributes approximately 14,000 kg/yr or approximately 0.7 percent of the total phosphorus to waters of the State. In eight of the ten basins, noncontact cooling water accounted for less than one-half of a percent of the total phosphorus load. In one basin, the Red River basin, it accounted for 4.5 percent (3,500 kg/yr) and in the remaining basin, the Minnesota River basin, it accounted for approximately 1.2 percent (4,500 kg/yr) of the total phosphorus load to the basin.

Summary of Phosphorus Loads to Basin

The total point source phosphorus load discharged to each basin and the state from each of the three types of wastewater treatment systems (POTWs, privately owned treatment systems and commercial and industrial wastewater treatment systems) is separated by source and presented in Figures 37 though 47. It was assumed that the influent components of the POTW's and privately owned treatment facility's phosphorus loads were in the treatment plant effluent in the same proportions as in the influent. It is understood that that this may not be the case, that phosphorus from the various sources may not have the same percentage of removal. However, due to the various types of treatment and their variable removal rates, it was not in the scope of this study to estimate the individual removal rates for each type of treatment system and each source of phosphorus. The commercial and industrial wastewater contributions were separated into those facilities discharging directly to a surface water under their own NPDES permit (Commercial & Industrial Wastewater Systems) and those discharging their wastewater to a POTW for treatment (Commercial and Industrial Process Wastewater).

Figure 37
Estimated Point Source Phosphorus Loads Discharged to the Cedar River Basin

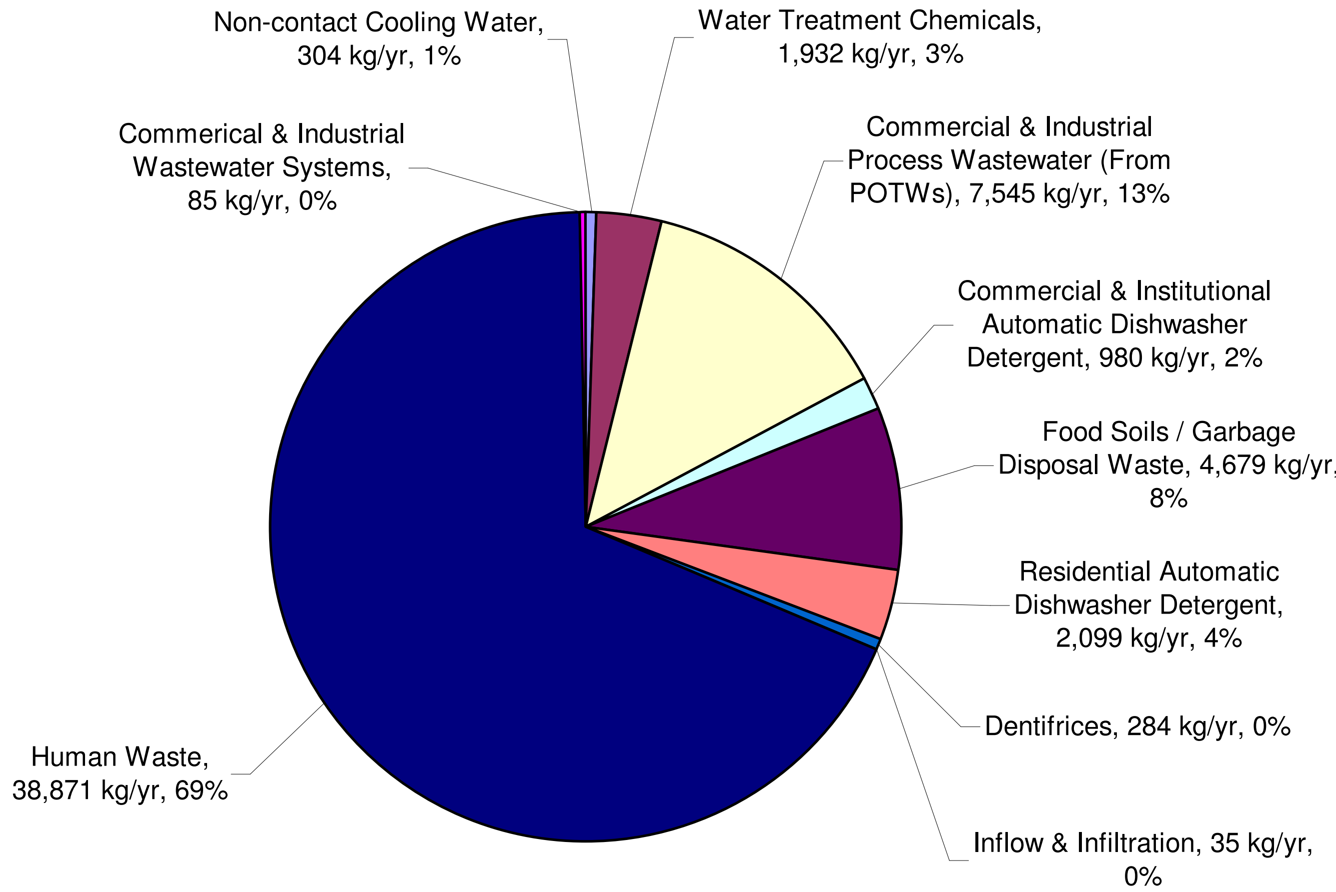


Figure 38
Estimated Point Source Phosphorus Loads Discharged to the Des Moines River Basin

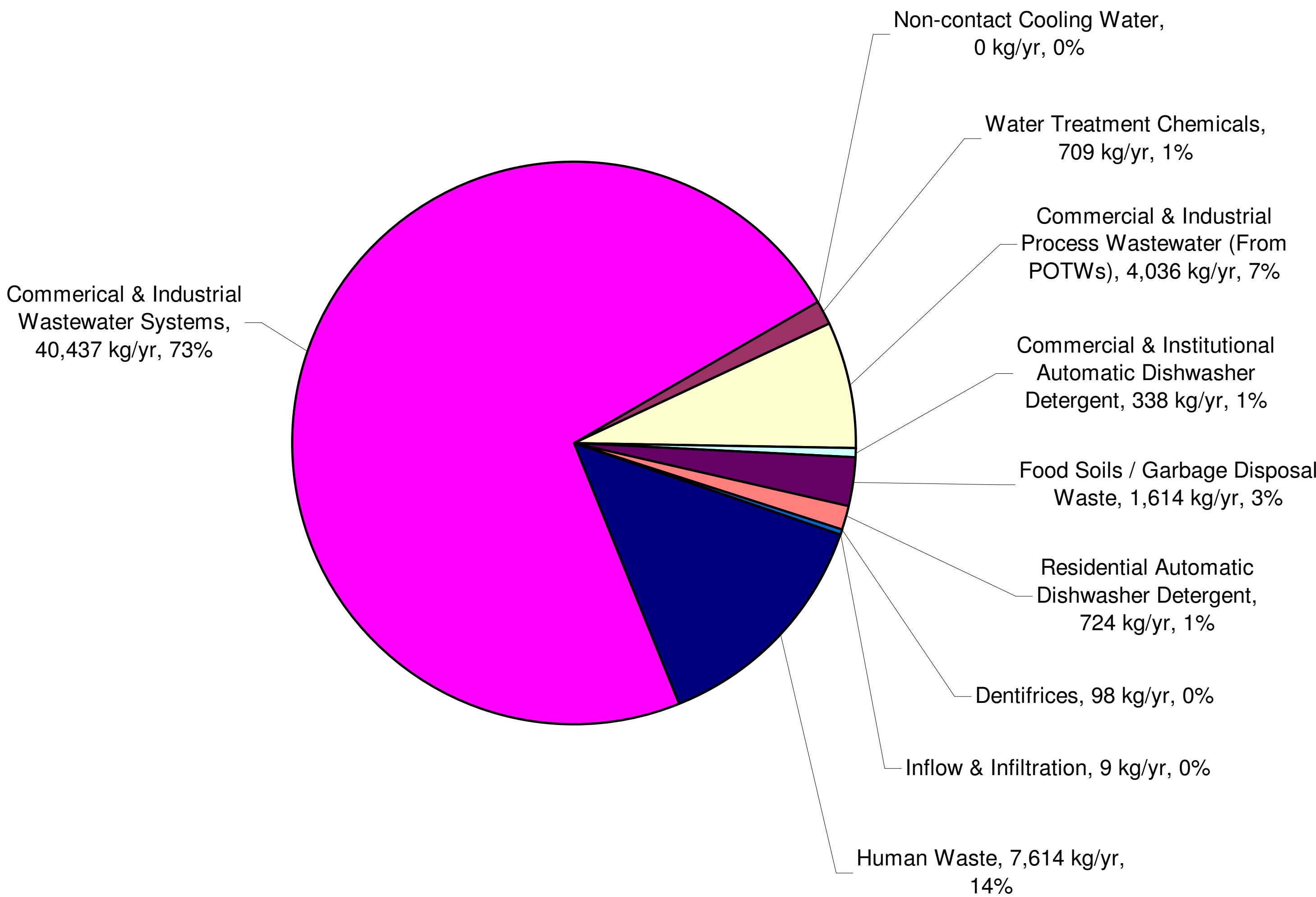


Figure 39
Estimated Point Source Phosphorus Loads Discharged to the Lake Superior River Basin

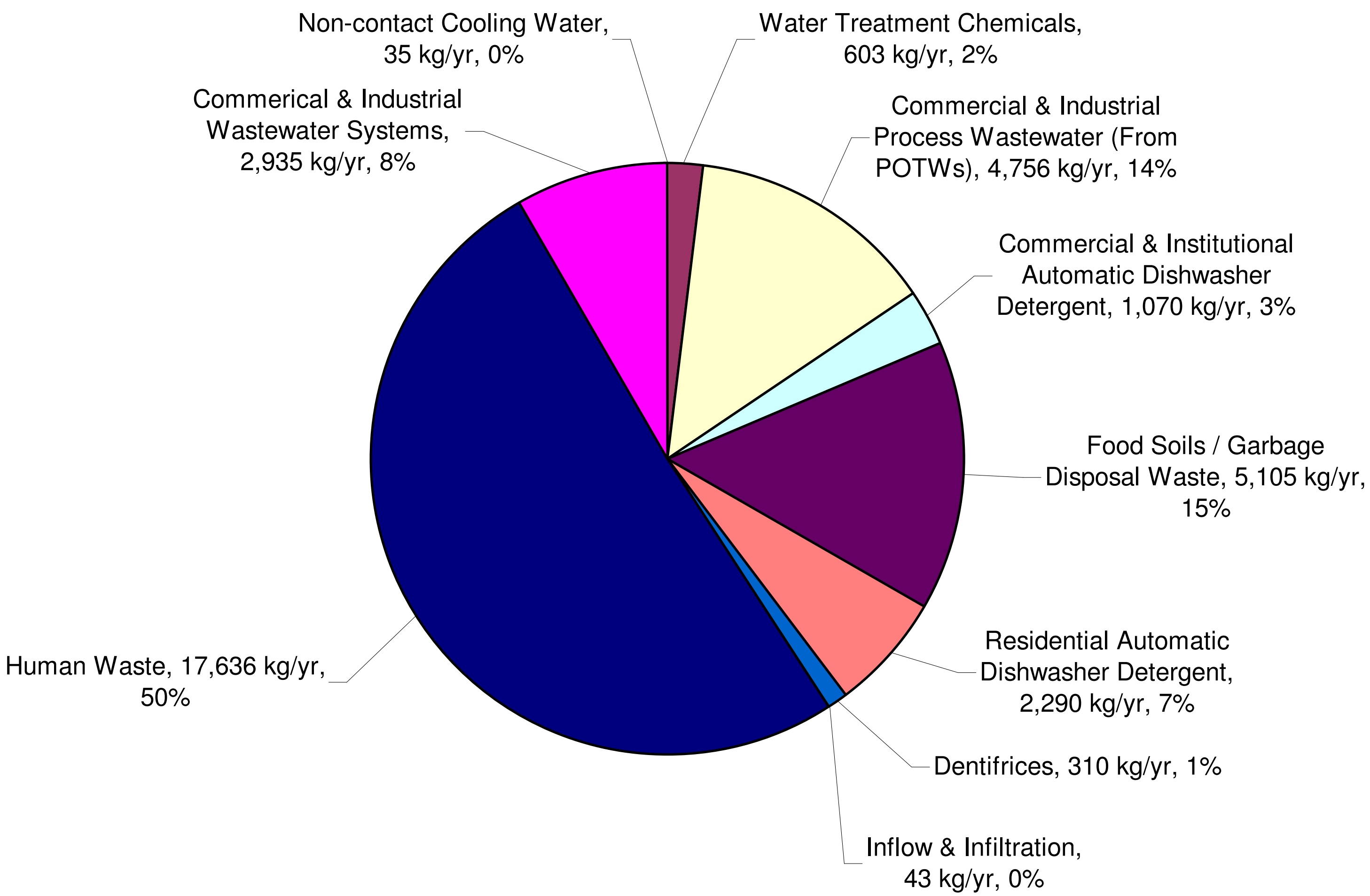


Figure 40
Estimated Point Source Phosphorus Loads Discharged to the Lower Mississippi River Basin

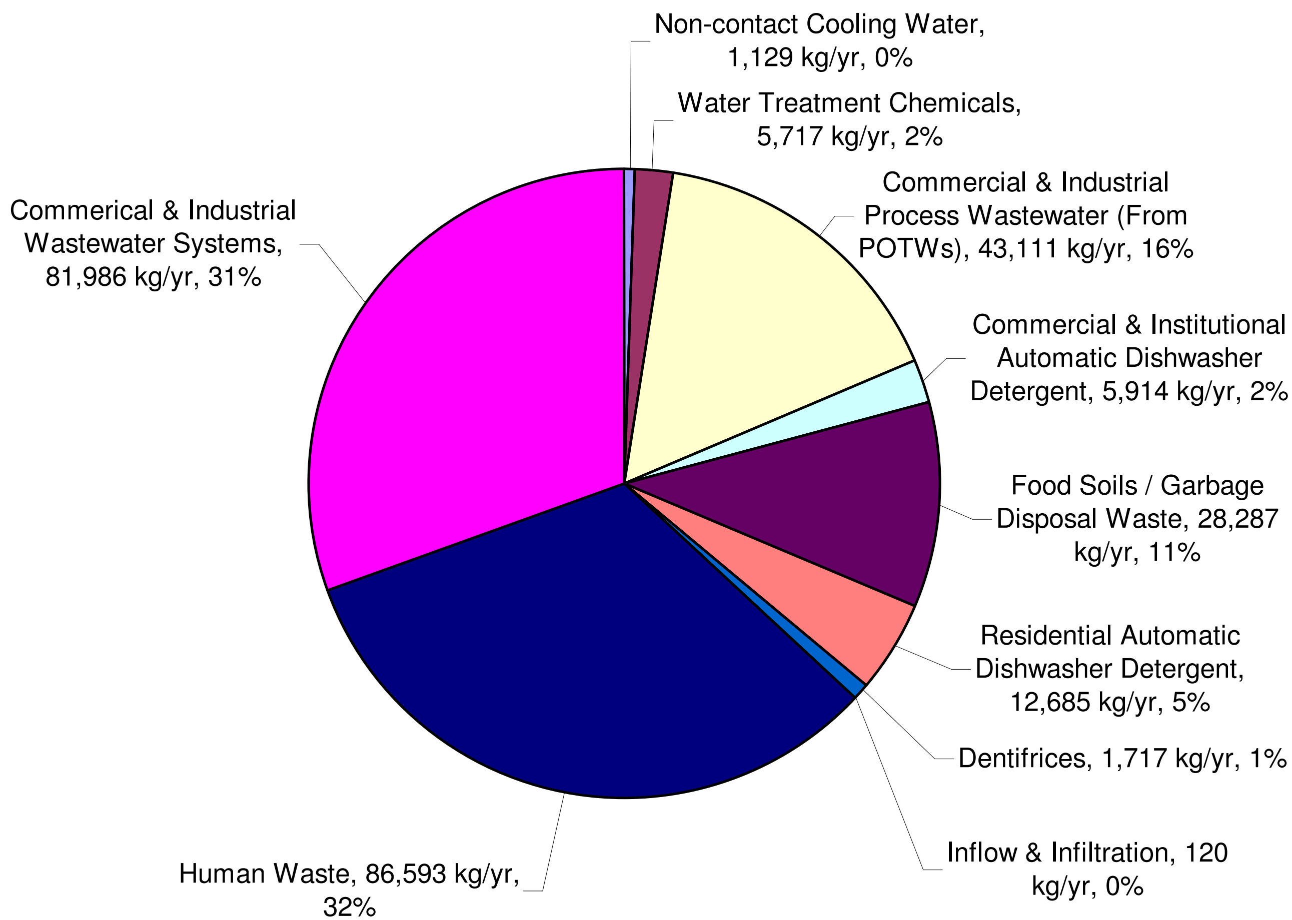


Figure 41
Estimated Point Source Phosphorus Loads Discharged to the Minnesota River River Basin

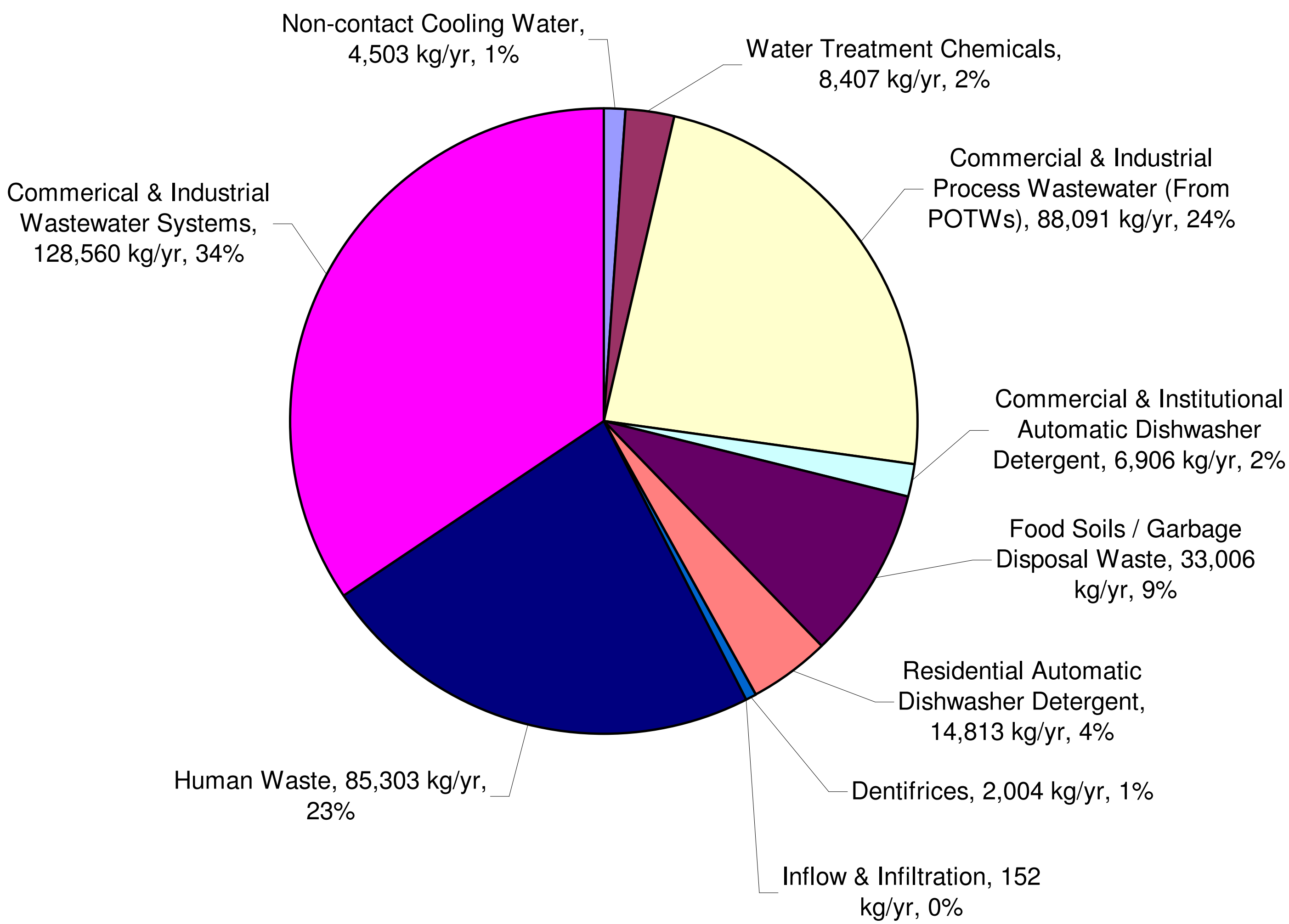


Figure 42
Estimated Point Source Phosphorus Loads Discharged to the Missouri River Basin

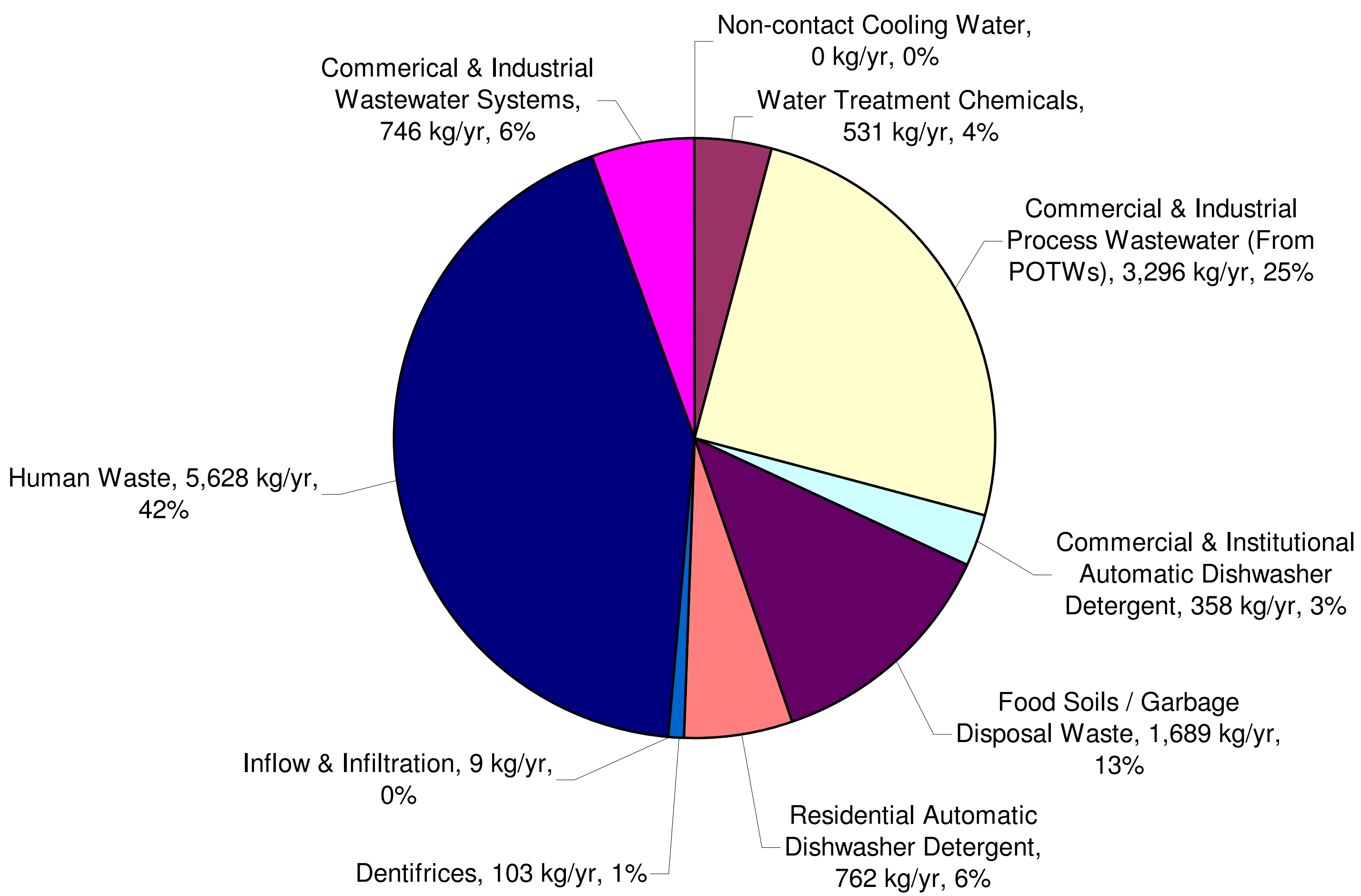


Figure 43
Estimated Point Source Phosphorus Loads Discharged to the Rainy River Basin

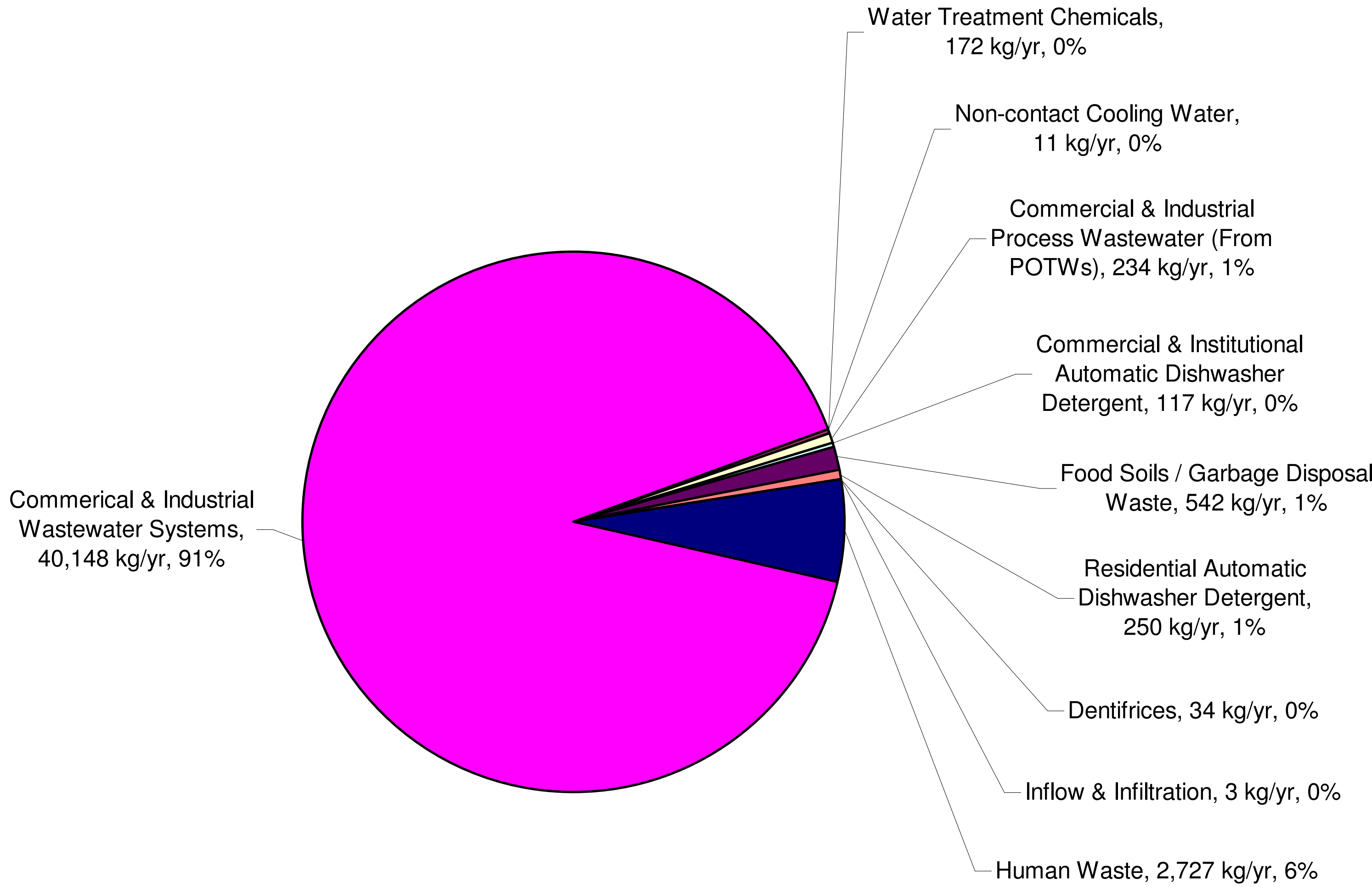


Figure 44
Estimated Point Source Phosphorus Loads Discharged to the Red River Basin

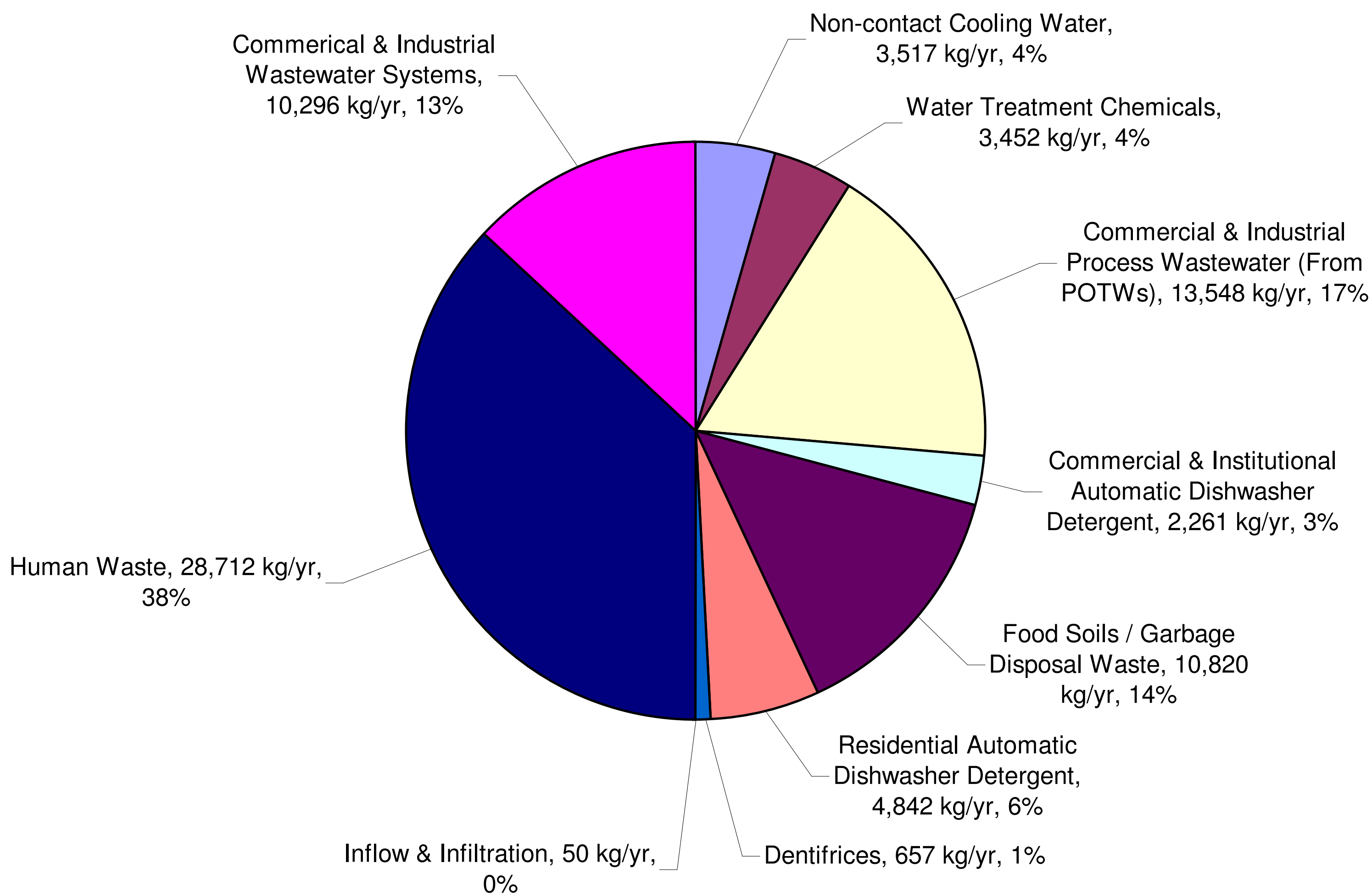


Figure 45
Estimated Point Source Phosphorus Loads Discharged to the St. Croix River Basin

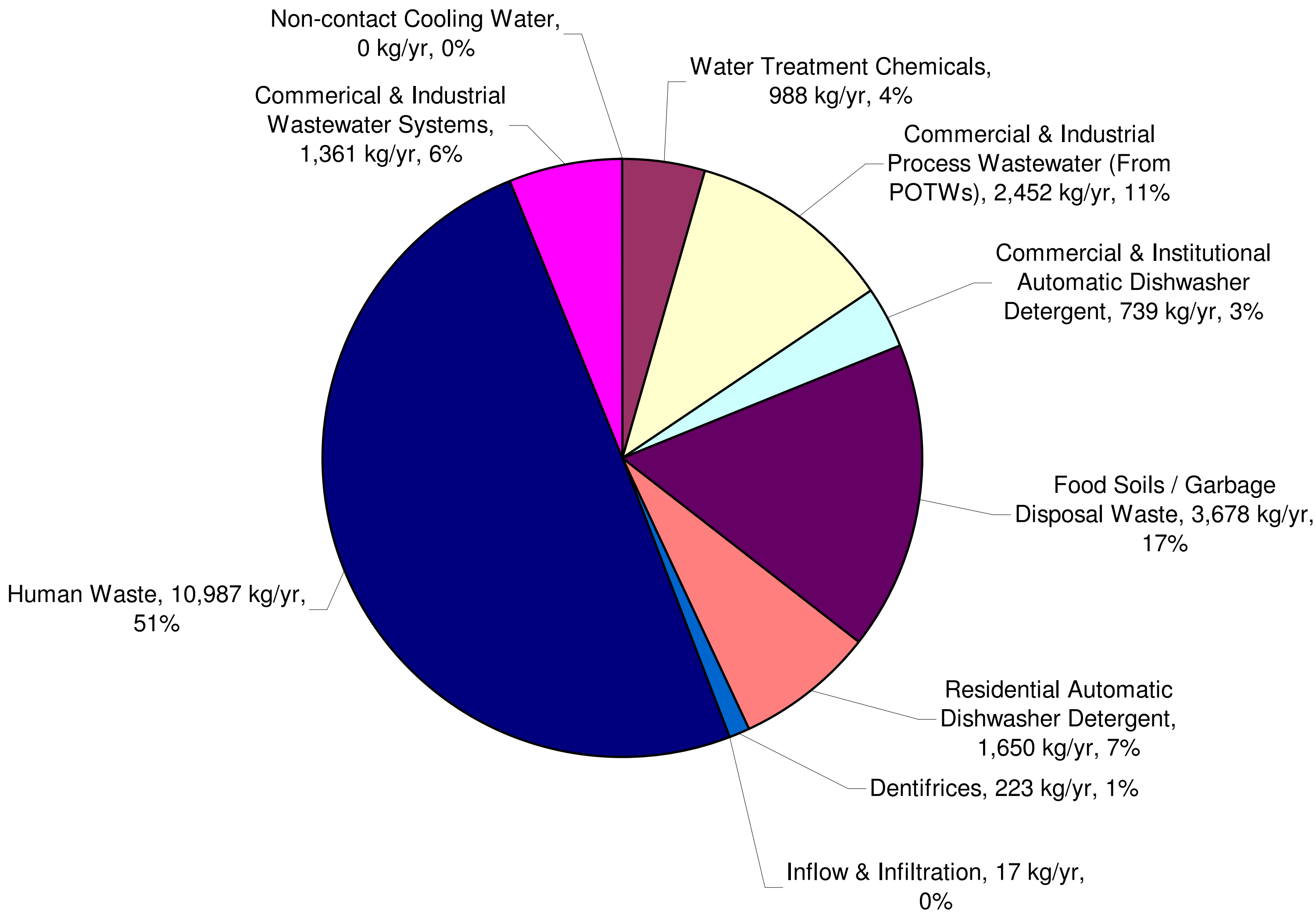


Figure 46
Estimated Point Source Phosphorus Loads Discharged to the Upper Mississippi River Basin

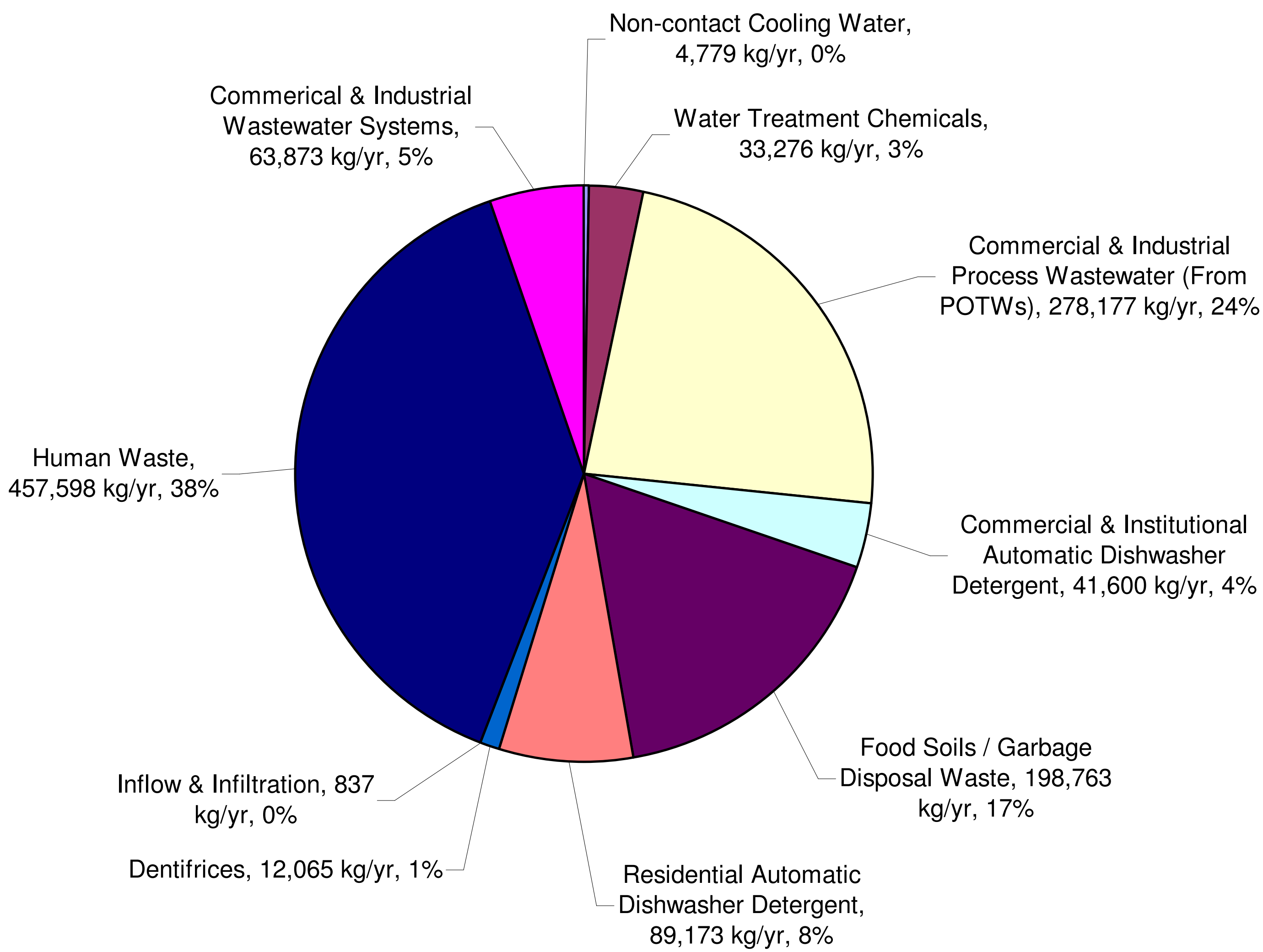
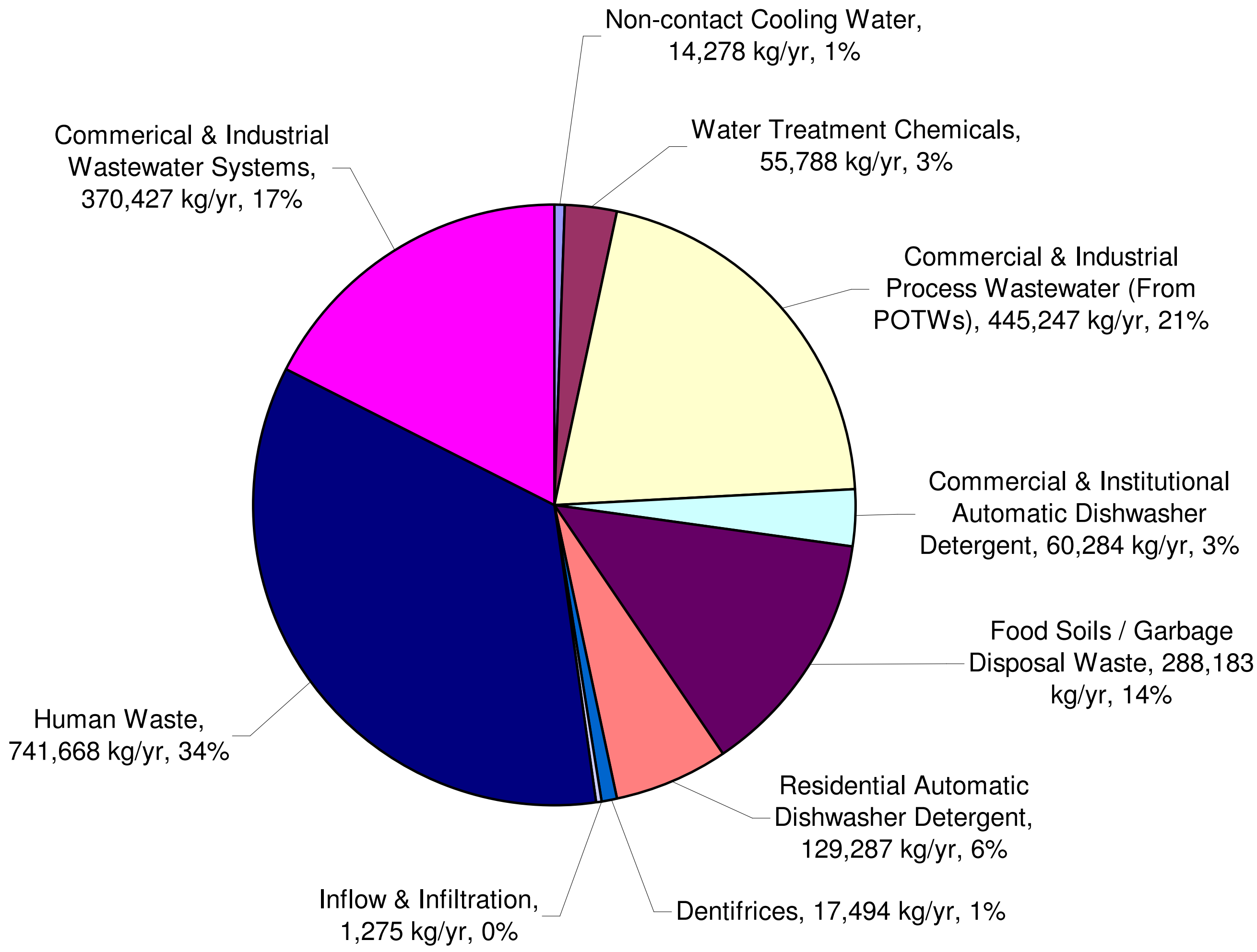


Figure 47
Estimated Point Source Phosphorus Loads Discharged to the Waters of the State of Minnesota



Point Source Phosphorus Variability and Uncertainty

The variability and uncertainty associated with the data sources has been discussed throughout this report. The following paragraphs provide a more detailed discussion of the variability and uncertainty associated with each data source.

Influent and Effluent Flow Data

Data on all municipal, private and industrial and commercial dischargers were obtained from the Delta database. Influent and/or effluent flow data were available for all permits in the Delta database. The data are submitted by the permittees for entry into Delta and there is no way to determine the accuracy of each permittee's measurements. However, most permits require regular flow measurement and had at least monthly flow data for those facilities with a continuous discharge. Pond systems that discharge infrequently may have had only one or two effluent data points available, otherwise the flow data was based on numerous data points. In addition, an attempt was made to validate the flow data. All flow values were converted to million gallons per day (mgd) and then averaged for each permit and station combination. The standard deviation was calculated for each station in a permit. Permits with high standard deviations raised concern, and the monthly flow data for the individual permits were manually reviewed. By reviewing multiple years it was relatively easy to spot the general trend in discharge rates and correct obvious errors. This process removed most of the variability from the data.

One area of some uncertainty is not the flow data itself, but which flows are discharged to surface waters. Each station under each permit in the Delta database is coded to list the type of discharge: surface water, land application, spray irrigation, internal waste stream, etc. Because this information is submitted by permittees for entry into Delta by MPCA staff, there may be some error due to interpretation and it is possible that some discharge stations may have been miscategorized.

Treatment Plant Influent and Effluent Phosphorus Loadings

There are several areas of uncertainty associated with the influent and effluent phosphorus loading estimates. These estimates are based on the flow data discussed above and the average annual phosphorus concentration. In many cases, phosphorus concentration data was limited to a few data points or not available at all. It was necessary to estimate the phosphorus concentration for many of the permittees. In addition, there was some variability among the phosphorus data for a permit when it was available. However, as noted in Table 1, there were phosphorus data for approximately one half of the facilities or approximately 88 percent of the total wastewater flow.

The method of calculating the estimated phosphorus load will impact the results. The study used annual average flow rates multiplied by the average annual phosphorus concentration to estimate the annual phosphorus load. The load could also have been calculated on a daily basis or monthly basis and then the average annual load calculated. Each method would likely result in different values. However, since there was limited data, monthly averages at best, it was decided to estimate the phosphorus load by calculating the average annual flow and multiplying it by the average annual phosphorus concentration.

Population Data

As discussed earlier in this memorandum, many of the influent phosphorus sources are based on per capita values and there is some uncertainty associated with the available population data. Approximately 230 of the 576 POTW and privately owned treatment facilities had population data listed in the Delta database. The process used to estimate the remaining population data was described in a previous section of the memorandum. As discussed, an attempt was made to validate some of the data, but due to the number of permits, it was not possible to verify all of the population data received. As a result, there is some uncertainty associated with this data.

Commercial and Industrial Wastewater

Data was collected on commercial and industrial dischargers to the MCES system. However, not all of these facilities had phosphorus monitoring data. Additional phosphorus data from commercial and dischargers was also colleted from several out-state POTWs. The phosphorus data that was available was often based on a limited number of sampling events and there was some variability between industries with similar NAICS code numbers. Other than the MCES permitted facilities and the handful of out-state communities that required their industries to monitor for phosphorus, most of the commercial and industrial process wastewater phosphorus values were estimates based on the data set collected from industrial dischargers to the MCES system and to the other communities that monitored for phosphorus. Given the limited data set, there is likely a high level of uncertainty associated with the estimates for this source.

Water Supply Treatment Chemicals

The information on the phosphorus contribution from water supply chemicals in municipal water treatment was based on information from the MDH. While the information received is likely valid, it was not complete. Phosphorus concentrations were provided for only 120 of the 360 facilities noted as adding phosphorus. The phosphorus residual in the remaining 240 water treatment facilities was based on an estimate using the average phosphorus concentration in the other 120 communities.

Residential Automatic Dishwasher Detergents (ADWD)

The phosphorus loading from residential ADWD has some uncertainty associated with it due mainly to the population estimates. While the annual consumption of phosphorus in ADWD reported (SRI, 2002) is likely an accurate number, the loading to the Minnesota basins was estimated based on a per capita value calculated from this national total. This assumes that each resident in Minnesota uses ADWD at the national average. Because this estimate also relied on population data, there is some additional uncertainty associated with it due to the uncertainty in the population data discussed in a previous paragraph.

Commercial and Institutional Automatic Dishwasher Detergents (ADWD)

The uncertainties associated with commercial and institutional ADWD are similar to those discussed for the residential ADWD in the previous paragraph.

Food Soils/Garbage Disposal Waste

The per capita value used to determine the food soils and garbage disposal waste contribution to the influent phosphorus loading to POTWs and privately owned treatment facilities was based on the average of several values obtained from studies conducted in the 1970s and 1980s. There were only three values available from the literature and these were based on a limited number of samples, but they were in fairly good agreement. Given that these data are from 20 to 30 years ago may introduce some uncertainty. Based on the SRI report, there has been a significant increase in the use of phosphorus in the food and beverage market. For example, the use of sodium phosphates in preparation of meat, seafood and poultry more than doubled between 1984 and 2000. It follows then that there may be more phosphorus in the food disposed of down the drain. What is unknown is the trend in the amount of food and beverages disposed of down the drain.

Also, because the food soils and garbage disposal wastes were based on per capita values, the loadings discharged to the treatment facilities are also based on the population served. As discussed above, there is some uncertainty associated with the population data.

Dentifrices

The method used to determine the dentifrice contribution to the influent phosphorus load to treatment facilities was based on a per capita value calculated from annual consumption in the U.S. The annual U. S. consumption was based on the data presented in the SRI report and likely quite accurate. From this information and the estimated U.S. population, the per capita phosphorus contribution from dentifrices was calculated. This method assumes that Minnesota's dentifrice use is equivalent to that as the U.S. as a whole and because this is a per capita value and there is some uncertainty due to the population data.

Inflow and Infiltration

The inflow and infiltration flow values were obtained from MCES and are estimates based on a few data points for each of their facilities. However, because the groundwater phosphorus concentration is quite low, even a large variability in the flow values will not have a large impact on the total phosphorus to the POTWs from this source.

Human Waste

The phosphorus loading from human waste was calculated by difference. That is, all other estimated sources of phosphorus were subtracted from the total influent phosphorus load for each facility. This method of estimating the human waste phosphorus contribution leaves some uncertainty since it is based on all of the other source estimates. Therefore, the phosphorus contribution from human waste obtained by difference was compared to literature values. Literature values for phosphorus in human waste ranged from 1.6 g/p·d (*Siegrist et al.*, 1976) to 2 g/p·d (*Strauss*, 2000). The statewide flow weighted average for phosphorus in human waste was 1.53 g/p·d (see Table 29).

Recommendations for Future Refinements

The following recommendations are made to improve the estimates of phosphorus point source loading to the watershed basins in Minnesota:

1. Since the commercial and industrial loadings are a significant portion of the phosphorus load, additional monitoring of industrial effluent discharged to POTWs would improve the precision of estimates presented in this component.

2. It was not within the scope of this study to present or discuss the phosphorus contribution from individual industrial contributors of phosphorus to POTWs. It would be interesting to expand this study to determine the specific industries that constitute the major phosphorus contributors.

3. This study assumed that the influent components of the POTW's and privately owned treatment plant's phosphorus from various sources were in the effluent in the same proportions as in the influent. A study on the percentage removal for the various sources at the different type of treatment plants would provide a more accurate picture of the source of phosphorus loads to the waters of the state.

4. Many of the phosphorus sources discharge to POTWs were based on per capita estimates. Improving the population served data for each of the POTWs would improve the accuracy of these estimates.

5. Phosphorus data were not available for all permits. Increased phosphorus monitoring (both influent and effluent) would improve loading estimates.

6. Calculation of phosphorus loads on a monthly basis and then totaled rather than on an annual basis would improve the estimates.

Recommendations for Lowering Phosphorus Export

The recommendations for lowering the phosphorus export are presented in two parts. The first part discusses recommendations for lowering phosphorus loading discharged to POTWs and the second part discusses recommendations for lowering the point source phosphorus load discharged to the watershed basins.

Phosphorus Loading to POTWs

The results of this study are intended to assist the MPCA in complying with MN Laws 2003, Chap. 128 Art. 1, Sec. 122.

The state goal for reducing phosphorus from non-ingested sources entering municipal wastewater treatment systems is at least a 50 percent reduction developed by the commissioner under section 166, and a reasonable estimate of the amount of phosphorus from non-ingested sources entering municipal wastewater treatment systems in calendar year 2003.

For purposes of complying with this legislation, this study has estimated that the current non-ingested phosphorus load entering POTWs is 2,573,000 kg/yr (see Table 25). A 50 percent reduction would require decreasing the phosphorus discharged to POTWs by least 1,286,000 kg/yr.

The applicability of reduction tactics for each of the non-ingested sources entering POTWs are discussed, by component, in the following paragraphs:

Residential Automatic Dishwasher Detergents (ADWD)

As discussed in a previous section, residential ADWD contributes approximately 7.3 percent or 326,000 kg/yr to the total influent phosphorus load discharged into POTWs and almost 13 percent of the non-ingested phosphorus load. Eliminating all phosphorus from residential ADWD would reduce the non-ingested phosphorus load discharged to POTWs by almost 13 percent.

Although, there has been a slight decline in the consumption of phosphorus for residential ADWD, SRI states that it is unlikely that detergents with much lower phosphorus contents will be available in the near future. However, an informal search for phosphorus-free residential ADWD found three brands of phosphorus-free detergent available in the Minneapolis area. The phosphorus free detergent was more costly than the best selling brands. The average ADWD with phosphorus cost $0.0567 per ounce less the phosphorus-free detergent. Just as with most products the cost of phosphorus-free detergent would decrease as demand increased. It should also be noted that one brand of phosphorus-free ADWD contained caustic soda which may cause issues with septic systems. As non-phosphorus residential ADWD are being developed some additional decrease may be achieved by a policy of advertising and education accompanied by prominent content labeling to aid consumers in choosing low or phosphorus-free products.

Food Soils/Garbage Disposal Waste

Food soils and garbage disposal wastes account for approximately 28 percent (725,000 kg/yr) of the non-ingested phosphorus discharged to POTWs. This is a substantial amount, but it is unlikely amenable to direct modification (e.g. product modification), or prohibiting discharge of food wastes into the sewer systems. Approximately 25 percent of the phosphorus from this source is discharged into the sewer system as garbage disposal waste. Garbage disposal waste could be sent elsewhere (trash, compost, etc.) while it would be more difficult to manage the phosphorus from dish rinsing and dish washing. Short of inducing the food product industries to reduce their use of phosphates or eliminating garbage disposals and discharge of food wastes down the drain, relatively little appears possible for reducing this phosphorus load to POTWs. Public education may be possible to reduce discharge of food wastes down the drain.

Dentifrices

Dentifrices account for less than two percent of the total non-ingested phosphorus load to POTWs. Because the phosphorus load from this source is so minimal, it does not warrant major steps to reduce phosphorus discharges from toothpastes and denture cleaners.

Commercial and Industrial Wastewater

Next to human wastes, a variety of industrial and commercial dischargers contribute the most phosphorus to POTW influent streams. The contribution of phosphorus from these commercial and industrial sources accounts for approximately 46 percent of the non-ingested phosphorus load discharged into POTWs.

Total removal of phosphorus from commercial and industrial wastewater is, of course, not an option. In most cases, reduction would have to come from resource/product substitution, improvements in technology, through recycling and reuse, and through pretreatment of wastewater prior to discharge to the POTW. However, reducing the commercial and industrial phosphorus contribution to POTWs by one half would reduce the total non-ingested phosphorus discharged to POTWs by almost 23 percent.

Animal slaughtering and processing (NAICs#3166) is the single largest commercial and industrial process wastewater contributor to POTWs and accounts for an estimated 14 percent of the total commercial and industrial process wastewater phosphorus load to POTWs. Fruit and vegetable preserving (NAICS #3114) and grain and oilseed milling (NAICS #3112) each account for approximately 11 percent of the commercial and industrial process wastewater discharged to POTWs followed closely by dairy product manufacturing (NAICS #3115) at 10 percent.

Excise taxes and/or effluent strength charges may be useful in reducing this influent source of phosphorus. At the time of this writing, it is our understanding that Mankato has implemented a program to impose a phosphorus strength charge on its industrial dischargers and other cities and sewer districts are considering implementing such charges.

Commercial and institutional Automatic Dishwasher Detergents (ADWD)

Commercial and institutional ADWD contributes a statewide average of approximately 6 percent (152,000 kg/yr) of the influent non-ingested phosphorus load discharged into POTWs. As with residential ADWD, SRI states that it is unlikely that detergents with much lower phosphorus contents will be available in the near future.

Water Supply Treatment Chemicals

The influent phosphorus loads to POTWs from water supply chemicals were estimated to average approximately 5.5 percent of the non-ingested phosphorus load to POTWs statewide. Use of phosphorus for sequestration of metals is an aesthetics issue. Iron and manganese are not a health concern, but cause undesirable effects such as undesirable tastes and odors and staining of laundry and household fixtures. On the other hand, corrosion control of lead and copper is a human health issue and is required by law for those communities that do not pass the state corrosion tests. Iron and manganese can be oxidized and removed during treatment thereby eliminating the need for sequestration chemicals. Another option would be to substitute alternative water treatment chemicals in place of the phosphorus-based ones.

Inflow and Infiltration

The results of this study indicate that inflow and infiltration contribute a negligible amount of phosphorus to POTW influent. There are reasons to limit inflow and infiltration into sewer systems, such as to prevent hydraulic overloading of treatment facilities, but the reduction of influent phosphorus is not one of them.

Summary

Given that phosphorus in food soils would be very difficult to reduce, and that dentifrices and I & I contribute so little to the influent phosphorus load discharged to POTWs, it is recommended that reduction efforts focus on residential ADWD, commercial and industrial process wastewater, commercial and institutional ADWD, and water treatment chemicals. A summary of the phosphorus load discharged to POTWs and the reduction potential is presented in Table 41.

Table 41
Phosphorus load to POTW
Reduction Potential

Summary		**Portion of Total Load to POTW**
Total Phosphorus Load Discharged to POTWs	4,468,000 kg/yr	
Human Waste	1,900,000 kg/yr	43
Non-ingested Waste	2,573,000 kg/yr	57
Phosphorus Source	**% Reduction to Non-ingested Phosphorus Load (%)**	**Cumm. Reduction to Non-ingested Phosphorus Load (%)**
Residential ADWD reduced to 0	13	13
Commercial ADWD reduced to 0	6	19
Commercial and Industrial reduced by one half	23	42
Total Reduction		**42**

If residential and commercial/institutional ADWD and water treatment chemicals were eliminated completely, the required commercial and industrial process wastewater reduction is estimated to be more than 64 percent. Given that it will be difficult, at best, to completely eliminate commercial/institutional ADWD and water treatment chemicals and reduce the commercial and industrial process wastewater reduction by more than 68 percent, a 50 percent reduction in the total non-ingested phosphorus contribution to POTWs is a very aggressive undertaking.

Reduction of Point Source Phosphorus Export to Waters of the State

POTWs

Phosphorus effluent from POTWs represents, on average, more than 80 percent of the total point source loads to waters of the state. The statewide flow weighted average phosphorus effluent concentration was 2.4 mg/L. The largest source of phosphorus is from large (> 1.0 mgd) POTWs and phosphorus reduction efforts should begin at these facilities. As discussed previously, many POTWs have implemented phosphorus removal and others will begin to implement it in the near future. The largest impact is probably phosphorus removal at the MCES' Metro plant, which is required to implement phosphorus removal to 1 mg/L by the end of 2005, but is already achieving the 1 mg/L limit. This facility discharges to the Upper Mississippi River basin and had an average phosphorus effluent concentration for the study period of 2.97 mg/L with an average annual phosphorus load to the basin of approximately 870,000 kg/y. A reduction in the phosphorus concentration to 1 mg/L will result in a reduction of an estimated 581,000 kg of phosphorus per year. Because this one facility accounts for approximately 74 percent of the phosphorus load to the Upper Mississippi River basin and an estimated 40 percent statewide, phosphorus removal at this one facility will have a significant impact on the relative phosphorus loads in this basin and the state. The reduction of the effluent phosphorus concentration to 1 mg/L at this one facility will result in the effluent phosphorus from POTWs being reduced from 80 percent to 74 percent of the point source load to waters of the state.

Privately Owned Wastewater Treatment Systems

Privately owned wastewater treatment systems account for less than 0.5 percent of the total point source phosphorus discharged to the watershed basins and increased phosphorus removal at these facilities will not have a large impact on the statewide point source phosphorus load.

Commercial and Industrial Wastewater Treatment Systems

Commercial and industrial dischargers to the watershed basins constitute approximately 18 percent of the point source phosphorus load. It was not within the scope of this study to categorize the phosphorus loading data by NAICS code number or to determine which industries are the largest contributors. However, this exercise may bring to light any industrial dischargers that make major contributions to the phosphorus load.

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Appendix A

Fields used from MPCA Delta Database

Appendix A. Fields used from MPCA Delta Database

Facility
Permit Number
Contact Name
Phone
Address 1
Address 2
City Name
Zip Code
Design Flow
Contact Role
County
First DMR
State
Population Served
Public
SIC Code
SIC Name
Watersheds
Major
Treatment Type
Domestic
Major Watershed
Major Drain

ID
Permit Number
Station ID
Start Date
End Date
Reported Value
Limit ID
Concentration ID
Analyte ID
Datasource ID
units ID
Converted P Value

Permit Number
Station ID
Local Name
Subwatershed Number
Subwatershed
Discharge
Watershed
Major Drain
Latitude
Longitude

Appendix B

Industrial Phosphorus Data Matched to MNPRO Database by NAICS

Appendix B. Industrial Phosphorus Data Matched to MNPRO Database by NAICS

ID	Facility Name	City	P_kgd	Permit_No	employee_count	NAICS Code
5592	Bridges Medical Center	Ada	0.12	MN0021709	100	622110
5593	Ada Co-op Oil Assn	Ada	0.01	MN0021709	81	325320
5594	Norman, County of	Ada		MN0021709	72	921190
5595	Ada-Borup School District	Ada		MN0021709	67	611110
5596	Ada, City of	Ada	0.04	MN0021709	29	921100
5597	Specialty Feed Products Co	Ada		MN0021709	25	311100
5598	Lee Bros. Sales Inc	Ada		MN0021709	24	441100
5599	Loretel Systems Inc	Ada		MN0021709	24	517100
5600	Norman County Implement Inc	Ada		MN0021709	22	333200
5601	Prairie Dental Center	Ada		MN0021709	22	621200
5602	Ada Feed & Seed Co	Ada	0.41	MN0021709	21	311900
5603	Kelly's Chrysler Center Inc	Ada		MN0021709	20	441100
5604	Ralph's Food Pride	Ada		MN0021709	19	445100
5605	Ada Produce Co	Ada		MN0021709	17	424400
5606	Wild Rice Dining Emporium	Ada		MN0021709	16	722100
5607	Adams Health Care Ctr	Adams		MN0021261	84	623100
5609	Southland High School	Adams		MN0021261	40	611100
5610	Schmitz Electric	Adams		MN0021261	15	238200
5611	Adams Group Home	Adams		MN0021261	10	621400
5612	Adams Farmers Division	Adams		MN0021261	8	111900
5613	Farmers St Bk of Adams	Adams		MN0021261	8	522100
5614	Wagner's Inc	Adams		MN0021261	8	445100
5615	Adams Builders Supply	Adams		MN0021261	6	444100
5616	Corky's Corner	Adams		MN0021261	6	447100
5617	Adrian Public Schools-ISD #511	Adrian		MNG580001	71	611100
5618	Arnold Mem. Hospital & Nursing Home	Adrian	0.04	MNG580001	65	622100
5619	Sailor Plastics Inc	Adrian	0.04	MNG580001	25	326100
5620	Adrian Hardware	Adrian		MNG580001	14	444100
5621	Adrian, City of	Adrian	0.02	MNG580001	13	921100
5622	Adrian Co-op Oil Co	Adrian		MNG580001	12	811100
5623	Adrian State Bank	Adrian		MNG580001	11	522100
5624	Hohn Implement	Adrian		MNG580001	11	423800
5625	Carl's Farm Store	Adrian		MNG580001	9	311100
5626	Southwest Mutual Insurance Co	Adrian		MNG580001	7	524100
5627	Judy's test business one			ISTS	15	111130
5628	Riverwood Health Care Ctr	Aitkin	0.19	MN0020095	296	622100
5629	Aitkin County	Aitkin	0.38	MN0020095	267	921100
5630	Aitkin Public Schools	Aitkin		MN0020095	190	611100
5631	Aicota Health Care Ctr	Aitkin		MN0020095	120	623100
5632	Aitkin Iron Works Inc	Aitkin	0.00	MN0020095	75	332700
5633	Woodland Container Inc	Aitkin		MN0020095	75	321900
5634	Paulbeck's Super Valu	Aitkin		MN0020095	70	445100
5635	Lake States Lumber Inc	Aitkin		MN0020095	60	444100
5636	Intercon 1	Aitkin	0.04	MN0020095	50	334500
5637	Mille Lacs Electric Cooperative	Aitkin		MN0020095	47	221100
5638	Pamida Discount Ctr	Aitkin		MN0020095	44	452100
5639	Aitkin Discount Foods/IGA	Aitkin		MN0020095	42	445100
5640	Stern Rubber	Aitkin		MN0020095	40	326200
5641	Garrison Disposal	Aitkin		MN0020095	35	562100
5642	Cummings Oil, Inc.	Aitkin		MN0020095	25	324100
5643	Albany Area Schools	Albany		MN0020575	253	611100
5644	Mother Of Mercy Nursing Home	Albany		MN0020575	130	623100
5645	Albany Area Hospital	Albany	0.07	MN0020575	104	622100
5646	Kraft Food Group	Albany	5.62	MN0020575	90	311500
5647	Stearns Bank N.A.	Albany		MN0020575	63	522100
5648	Master Mark Plastic Products	Albany	0.05	MN0020575	60	325200
5649	Ramler Trucking	Albany	1.71	MN0020575	33	484100
5650	Wood Shop Of Avon Inc	Albany		MN0020575	25	321900
5651	Stearns County Publishing Inc	Albany		MN0020575	15	511100
5652	Albany Mutual Telephone Assn	Albany		MN0020575	12	517100
5653	Albert Lea Medical Center	Albert Lea	0.74	MN0041092	1141	622100
5654	Streator Store Fixtures	Albert Lea		MN0041092	500	423300
5655	Albert Lea Public School Dist. #241	Albert Lea		MN0041092	480	611500
5657	Good Samaritan Center	Albert Lea		MN0041092	300	621400
5658	St John's Lutheran Home	Albert Lea		MN0041092	295	623100
5659	Lou-Rich Machine Tool	Albert Lea	0.00	MN0041092	199	332700
5660	Ventura Foods LLC	Albert Lea		MN0041092	188	445100
5661	Alliant Energy	Albert Lea		MN0041092	150	221100

Appendix B. Industrial Phosphorus Data Matched to MNPRO Database by NAICS

ID	Facility Name	City	P_kgd	Permit_No	employee_count	NAICS Code
5662	Progress Casting Group Inc	Albert Lea		MN0041092	133	331300
5663	Mrs. Gerry's Kitchen, Inc.	Albert Lea	5.35	MN0041092	115	311400
5664	Larson Contracting	Albert Lea		MN0041092	110	236200
5665	Minnesota Corrugated Box Inc	Albert Lea		MN0041092	106	322200
5666	Thorne Crest Retirement	Albert Lea		MN0041092	98	623100
5667	Alamco Wood Products, Inc.	Albert Lea		MN0041092	90	444100
5668	Outlets At Albertville	Albertville		MN0050954	800	452900
5669	ISD #885- St. Michael/Albertville	Albertville		MN0050954	275	611110
5670	HGP	Albertville		MN0050954	135	327200
5671	Truss Manufacturing Company	Albertville		MN0050954	50	321200
5672	Land of Lakes Tile & Stone	Albertville		MN0050954	40	327300
5673	Fraser Steel Inc	Albertville		MN0050954	32	333200
5674	DJ' S Heating & Airconditioning	Albertville		MN0050954	20	423700
5675	Don's Bus Service	Albertville		MN0050954	20	485400
5676	Omann Brothers	Albertville		MN0050954	20	238300
5677	DJ'S Home Care Center	Albertville	0.01	MN0050954	14	331316
5678	Radiation Product, Inc.	Albertville	0.40	MN0050954	14	339100
5679	Franklin Outdoor Advertising Co.	Albertville		MN0050954	12	541800
5680	Sunrise Plumbing	Albertville		MN0050954	12	238200
5681	Tele-Ad Co.	Albertville		MN0050954	10	541800
5682	Eull Concrete Products, Co.	Albertville	0.01	MN0050954	9	334500
5683	Alden-Conger Public Schools	Alden		MN0020605	46	611100
5684	Petro Pumper	Alden		MN0020605	11	447100
5685	Alden Co-op Elevator Co	Alden		MN0020605	10	493100
5686	Hemmingsen's Transfer	Alden		MN0020605	10	485400
5687	Main Street Bar & Grill	Alden		MN0020605	8	722400
5688	American Legion	Alden		MN0020605	6	813400
5689	Alden Concrete Products	Alden		MN0020605	5	327300
5690	Alden Medical Ctr	Alden	0.01	MN0020605	5	621100
5691	Elaine's Day Care	Alden		MN0020605	5	624400
5692	Old Reliable Transportation	Alden	0.26	MN0020605	5	484100
5693	Alden Advance	Alden		MN0020605	4	511100
5694	Alden Oil Co	Alden		MN0020605	4	811100
5695	Frantum Sanitation	Alden		MN0020605	4	562100
5696	Redeemer Lutheran Church	Alden		MN0020605	4	813100
5697	Alden Dental Office	Alden		MN0020605	3	621200
5698	Douglas County Hospital	Alexandria	0.43	MN0040738	660	622100
5699	Alexandria Public Schools-ISD#206	Alexandria		MN0040738	625	611110
5700	Douglas Machine	Alexandria	7.85	MN0040738	467	333993
5701	Douglas, County of	Alexandria		MN0040738	350	921190
5702	Alexandria Extrusion Co	Alexandria	0.13	MN0040738	286	331316
5703	Tastefully Simple	Alexandria	1.47	MN0040738	276	454390
5705	Knute Nelson Memorial Home	Alexandria		MN0040738	247	623110
5706	Arrowwood Resort and Conference Center	Alexandria		MN0040738	240	721100
5707	Rural Cellular Corp	Alexandria		MN0040738	240	517212
5708	Central Specialties	Alexandria		MN0040738	235	237310
5709	Alexandria Clinic	Alexandria	0.27	MN0040738	199	621100
5710	Donnelly Manufacturing Co.	Alexandria		MN0040738	195	326199
5711	Alexandria Technical College	Alexandria		MN0040738	191	611519
5712	Brenton Engineering Co	Alexandria	2.59	MN0040738	154	333993
5713	Annandale Public Schools-ISD #876	Annandale		MN0021229	233	611100
5714	Annandale Care Ctr	Annandale		MN0021229	161	623100
5715	Malco Products Inc	Annandale		MN0021229	150	424900
5716	RM Johnson Co	Annandale		MN0021229	75	811100
5717	Market Place II	Annandale		MN0021229	62	445100
5718	Lakedale Telephone Co	Annandale		MN0021229	50	517100
5719	M & M Express Inc	Annandale		MN0021229	45	485400
5720	Truk-Mate Vans Inc	Annandale		MN0021229	45	811100
5721	Mid Minnesota Hot Mix	Annandale		MN0021229	40	423300
5722	Annandale St Bk	Annandale		MN0021229	34	522100
5723	Annandale Sod & Contracting	Annandale		MN0021229	30	561700
5724	RR Howell Co	Annandale	0.13	MN0021229	30	445200
5725	Minnesota Meat Masters	Annandale		MN0021229	25	424400
5726	Lundeen Brothers Inc	Annandale		MN0021229	21	441100
5727	Country Chevrolet	Annandale		MN0021229	20	441100
5728	Anoka, County of	St. Paul	2.67	MN0029815	1900	921100
5730	Hoffman Engineering Co	St. Paul	6.88	MN0029815	1000	332900
5732	Lund International Holdings	St. Paul		MN0029815	250	336300

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ID	Facility Name	City	P_kgd	Permit_No	employee_count	NAICS Code
5733	Anoka-Hennepin Technical College	St. Paul		MN0029815	230	611300
5734	Anoka, City of	St. Paul	0.28	MN0029815	202	921100
5735	Rainbow Signs	St. Paul		MN0029815	180	339900
5736	Copper Sales	St. Paul		MN0029815	170	423500
5737	Lakeland Tool & Engineering	St. Paul	0.12	MN0029815	150	325200
5738	Rural Community Insurance Svcs	St. Paul		MN0029815	150	524100
5739	West Publishing	St. Paul		MN0029815	125	511100
5740	First Team Sports	St. Paul		MN0029815	100	339900
5741	Royal Engineering & Mfg	St. Paul	0.15	MN0029815	46	541700
5742	Carbide Tool Services Inc	St. Paul		MN0029815	45	811200
5743	Prairie Correctional Facility	Appleton		MN0021890	350	922140
5744	Appleton Municipal Hospital	Appleton	0.18	MN0021890	148	622110
5745	Econar Energy Systems	Appleton	0.09	MN0021890	25	333415
5747	Del Dee Foods	Appleton	3.16	MN0021890	20	311514
5748	Otter Tail Power Co	Appleton		MN0021890	10	221122
5752	Pioneer Public TV	Appleton		MN0021890	25	515120
5754	Otter Tail Power Co	Appleton		MN0021890	10	221122
5757	Syntegra	St. Paul		MN0029815	750	334100
5758	MSI Insurance	St. Paul		MN0029815	640	524100
5759	Manufacturer's Services	St. Paul		MN0029815	600	339900
5760	Fair Isaac	St. Paul		MN0029815	500	541600
5761	Presbyterian Homes-Johanna Shores	St. Paul		MN0029815	500	623900
5762	Sims Deltec	St. Paul	0.39	MN0029815	500	334500
5763	Argyle Public School Dist. #2856	Argyle		MN0052451	46	611100
5764	Marshall County Group Home	Argyle		MN0052451	19	623900
5765	Rivard's Quality Seeds	Argyle		MN0052451	19	115100
5766	Farmer Dell Restaurant	Argyle		MN0052451	16	722100
5767	Argyle Building Center	Argyle		MN0052451	10	444100
5768	Argyle State Bank	Argyle		MN0052451	10	522100
5769	Sundby's Cafe	Argyle		MN0052451	10	722100
5770	Argyle Co-op Warehouse Assn	Argyle		MN0052451	8	493100
5771	Sorenson Construction	Argyle		MN0052451	8	236200
5772	Cassie Company Mfg	Argyle	0.05	MN0052451	7	332900
5773	Argyle, City of	Argyle	0.01	MN0052451	6	921100
5774	Northstar Services	Argyle		MN0052451	6	812300
5775	Borowicz Construction	Argyle		MN0052451	5	236200
5776	Valley Best Potatoes Inc	Argyle		MN0052451	5	111200
5777	Hammerback Welding	Argyle	0.02	MN0052451	3	332900
5778	ACGC North Elementray	Atwater		MN0022659	54	611100
5779	Jennie-O Feed Mill	Atwater		MN0022659	27	311100
5780	Presbyterian Family Services	Atwater		MN0022659	23	623900
5781	Holm Brothers Plumbling & Heating	Atwater		MN0022659	21	238200
5782	St. Francis House	Atwater		MN0022659	17	623900
5783	American Industrial Refrigeration	Atwater		MN0022659	15	423700
5784	Discount Grain	Atwater		MN0022659	15	115100
5785	Kandiyohi DAC	Atwater		MN0022659	13	624300
5786	Atwater State Bank	Atwater		MN0022659	12	522100
5787	Cenral Lake Cooperative	Atwater		MN0022659	12	115100
5788	Audubon Engineering	Audubon		MN0022675	250	332300
5789	Audubon, City of	Audubon	0.00	MN0022675	250	332700
5790	Audubon Co-Op Elevator Association	Audubon		MN0022675	14	424900
5791	Mesabi East Schools	Aurora		MN0020494	167	611100
5792	White Community Hospital	Aurora	0.09	MN0020494	144	622100
5793	Mesabi Electronics Inc	Aurora		MN0020494	40	425100
5794	US Forest Service	Aurora		MN0020494	21	115300
5795	Zup's Supermarket	Aurora		MN0020494	21	445100
5796	East Range Clinics Ltd	Aurora	0.02	MN0020494	12	621100
5798	Quality Pork Processors	Austin	41.08	MN0022683	725	311600
5799	Austin Medical Center	Austin	0.95	MN0022683	700	621100
5801	Austin Public Schools - ISD #492	Austin		MN0022683	550	611100
5802	Austin, City of	Austin	0.37	MN0022683	260	921100
5803	Mower, County of	Austin	0.33	MN0022683	235	921100
5804	St Mark's Lutheran Home	Austin		MN0022683	230	623100
5805	Riverland Community/Technical College	Austin		MN0022683	210	611300
5806	Complete Packaging Service Inc	Austin		MN0022683	180	561900
5807	Weyerhaeuser Co	Austin		MN0022683	159	322100
5808	REM - Minnesota	Austin		MN0022683	125	623900
5809	Holiday Inn	Austin		MN0022683	120	721100

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ID	Facility Name	City	P_kgd	Permit_No	employee_count	NAICS Code
5810	Burr Oak Manor	Austin		MN0022683	110	623100
5811	McFarland Truck Lines	Austin		MN0022683	110	488400
5812	Gerard of Minnesota	Austin		MN0022683	85	624200
5813	Cedar Valley Services	Austin		MN0022683	78	624300
5814	KAAL Television	Austin		MN0022683	62	515100
5815	Robinson Business Forms	Austin		MN0022683	55	323100
5816	Mower House Color Graphics	Austin		MN0022683	50	323100
5817	Avoca Municipal Liquor	Slayton		MN0022004	6	445300
5818	Columbia Gear Div	Avon		MN0047325	210	333600
5819	D H Blattner & Sons Inc	Avon		MN0047325	59	238100
5820	Avon Elementary School	Avon		MN0047325	47	611100
5821	Lumber One Inc	Avon		MN0047325	41	236100
5822	NOVA Fabricating Inc	Avon	0.00	MN0047325	35	332700
5823	Avon St Bk	Avon		MN0047325	20	522100
5824	Budde Trucking	Avon	0.36	MN0047325	7	484100
5825	Avon Elevator	Avon		MN0047325	5	493100
5826	Northwest Rule Die	Avon	0.00	MN0047325	5	332700
5827	Northshore Mining Co	Babbitt		MN0020656	165	212200
5828	Babbitt School	Babbitt		MN0020656	61	611100
5829	Kasson Manufacturing Inc	Babbitt		MN0020656	32	339900
5830	Zupancich Brothers	Babbitt		MN0020656	31	445100
5831	Babbitt, City of	Babbitt	0.04	MN0020656	26	921100
5832	Rollins Resources	Babbitt		MN0020656	25	326200
5833	Babbitt Short Stop	Babbitt		MN0020656	19	447100
5834	Babbitt Bar & Bowling Alley	Babbitt		MN0020656	17	722400
5835	Blomberg & Sons	Babbitt		MN0020656	15	454300
5836	Benville Service	Babbitt		MN0020656	12	447100
5837	Babbitt Cafe	Babbitt		MN0020656	10	722100
5838	Babbitt Steelworkers Credit Union	Babbitt		MN0020656	5	522100
5839	Babbitt Drug	Babbitt		MN0020656	4	446100
5840	First Bank Babbitt	Babbitt		MN0020656	4	522100
5841	State Farm Ins - Babbitt	Babbitt		MN0020656	4	524100
5842	His 'N Hers	Babbitt		MN0020656	3	453200
5843	Shear Harmony	Babbitt	0.01	MN0020656	3	812100
5844	Billie's	Babbitt		MN0020656	2	453100
5845	Culbert Realty	Babbitt		MN0020656	2	531200
5846	Jean's Hair Shoppe	Babbitt	0.00	MN0020656	1	812100
5847	Backus Elementary School			ISTS	42	611100
5848	Bruce's Contracting			ISTS	30	238100
5849	Eveland's Inc		2.04	ISTS	27	336200
5850	Backus Corner Store & Restaurant		9.45	ISTS	25	445200
5851	Foot Hills Saloon & Restaurant			ISTS	25	722400
5852	Godfrey's Super Valu			ISTS	25	445100
5853	Red Pine Log Homes			ISTS	10	321900
5854	US Post Office			ISTS	9	491100
5855	Cass Co Land Dept			ISTS	8	924100
5856	First NB of Walker at Backus			ISTS	6	522100
5857	MN Dept of Natural Resources			ISTS	6	924100
5858	Backus Bar			ISTS	5	722400
5859	Backus, City of		0.01	ISTS	5	921100
5860	Backus Lumber & Supply			ISTS	4	444100
5861	Beckler Masonry			ISTS	4	238100
5862	Chitwood Oil Co			ISTS	4	424900
5863	Backus Locker		0.17	ISTS	3	311600
5864	Cass County HRA		0.00	ISTS	3	921100
5865	Clearwater, County of	Bagley	0.56	MN0022691	400	921100
5866	Team Industries-Bagley	Bagley	1.54	MN0022691	295	541700
5867	Bagley Public Schools-ISD #162	Bagley		MN0022691	155	611100
5868	Gesell Concrete Products Inc	Bagley		MN0022691	45	327300
5869	Kubiak's Family Foods	Bagley		MN0022691	40	445100
5870	Bagley Hardwood Products Inc	Bagley		MN0022691	37	423300
5871	Galen's Super Valu	Bagley		MN0022691	35	445100
5872	First NB	Bagley		MN0022691	24	522100
5873	Bagley, City of	Bagley	0.03	MN0022691	21	921100
5874	Clearwater-Polk Electric Coop Inc	Bagley		MN0022691	16	221100
5875	Bagley Dental	Bagley		MN0022691	12	621200
5876	Hillside Lumber, Inc.	Bagley		MN0022691	12	423300
5877	Bagley Mercantile Hardware Hank	Bagley		MN0022691	11	444100

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ID	Facility Name	City	P_kgd	Permit_No	employee_count	NAICS Code
5878	Larson Lumber Co	Bagley		MN0022691	10	423300
5879	US Post Office	Bagley		MN0022691	10	491100
5880	Galli Furniture & Appliance	Bagley		MN0022691	7	442100
5881	Barnesville Good Samaritan Ctr	Barnesville		MN0022501	101	623100
5882	Barnesville Public School District	Barnesville		MN0022501	100	611100
5883	Barnesville, City of	Barnesville	0.05	MN0022501	33	921100
5884	Dean's Bulk Oil Services	Barnesville		MN0022501	29	454300
5885	Barnesville Super Value	Barnesville		MN0022501	25	445100
5886	Mike Layton Co.	Barnesville	0.70	MN0022501	15	311400
5887	Cenex General Store	Barnesville	0.06	MN0022501	14	445200
5888	Barnesville Area Clinic	Barnesville	0.02	MN0022501	13	621100
5889	Wells Fargo	Barnesville		MN0022501	13	522100
5890	Midwest Bank	Barnesville		MN0022501	8	522100
5892	Lakewood Health Care Ctr	Baudette	0.08	MN0029599	130	622100
5893	Baudette Public Schools-ISD #390	Baudette		MN0029599	105	611100
5894	Lake of the Woods, County of	Baudette	0.10	MN0029599	74	921100
5895	Baudette, City of	Baudette	0.05	MN0029599	36	921100
5896	Erickson Timber Products	Baudette		MN0029599	21	423900
5897	North Star Electric Co-op	Baudette		MN0029599	20	221100
5898	Northern National Bank	Baudette		MN0029599	19	522100
5899	Fleet Farm	Brainerd		MN0049328	309	452900
5900	Wal-Mart	Brainerd		MN0049328	300	452100
5901	Nor-Son Inc	Brainerd		MN0049328	177	236100
5902	MN Dept of Transportation	Brainerd		MN0049328	175	926100
5903	Good Neighbor Home Health Care	Brainerd		MN0049328	150	621600
5904	Target	Brainerd		MN0049328	147	452100
5905	Menards	Brainerd		MN0049328	136	444100
5906	Home Depot	Brainerd		MN0049328	125	444100
5907	Cub Foods	Brainerd		MN0049328	120	445100
5908	Crow Wing Power	Brainerd		MN0049328	107	423600
5909	Super One	Brainerd		MN0049328	104	445100
5910	Reichert Enterprises Inc	Brainerd		MN0049328	100	485400
5911	Widseth Smith Nolting & Assoc	Brainerd		MN0049328	60	541300
5912	K Mart	Brainerd		MN0049328	58	452100
5913	Infotel Communications/Integra	Brainerd		MN0049328	50	517100
5914	Bonanza Restaurant	Brainerd		MN0049328	36	722100
5915	Viking Coke	Brainerd	2.36	MN0049328	35	312100
5918	First St Bk of Bayport	St. Paul		MN0029998	45	522100
5919	Bayport Marina	St. Paul		MN0029998	20	483200
5920	Bayport Printing	St. Paul		MN0029998	17	323100
5921	Bayport, City of	St. Paul	0.02	MN0029998	13	921100
5922	Beardsley Public School Dist #57			ISTS	26	611100
5923	Security St Bk of Beardsley			ISTS	8	522100
5924	Beardsley Farmers Elevator			ISTS	6	493100
5925	Tri-County Cooperative			ISTS	3	424900
5926	Cove Point	Beaver Bay		MN0040754	20	721100
5927	Holiday Station Store	Beaver Bay		MN0040754	12	447100
5928	Beaver Bay Inn & Motel	Beaver Bay		MN0040754	11	722100
5929	Northern Lights Cafe	Beaver Bay		MN0040754	10	722100
5930	Beaver Bay Liquor Store	Beaver Bay		MN0040754	7	445300
5931	Beaver Bay Mobil Mart & Deli	Beaver Bay		MN0040754	6	447100
5932	Beaver Bay Sports Inc	Beaver Bay		MN0040754	4	451100
5933	Beaver River Deli	Beaver Bay		MN0040754	4	722100
5934	Computerized Creation	Beaver Bay		MN0040754	4	323100
5935	Momma's Table	Beaver Bay		MN0040754	4	722100
5936	Superior Auto	Beaver Bay		MN0040754	4	811100
5937	Bay Antique	Beaver Bay		MN0040754	3	453300
5938	Beaver Bay Agate	Beaver Bay		MN0040754	3	453200
5939	The Cedar Chest	Beaver Bay		MN0040754	3	453200
5940	Beaver Bay Electric	Beaver Bay		MN0040754	2	238200
5942	Becker Furniture World	Becker		MN0025666	255	442100
5943	Becker Public Schools	Becker		MN0025666	220	611100
5944	Becker, City of	Becker	0.15	MN0025666	104	921100
5945	Liberty Paper Inc.	Becker		MN0025666	98	322100
5946	Becker Truss	Becker		MN0025666	66	444100
5947	T.J. Potter Trucking	Becker	3.41	MN0025666	66	484100
5948	Jubilee Foods	Becker		MN0025666	52	445100
5949	Darter Plastics	Becker	0.04	MN0025666	50	325200

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ID	Facility Name	City	P_kgd	Permit_No	employee_count	NAICS Code
5950	Country Lumber	Becker		MN0025666	33	444100
5952	Roseville Greenhouse Inc	Becker		MN0025666	26	332300
5953	Structural Buildings Inc	Becker		MN0025666	26	236200
5954	Plymouth Foam Products	Becker		MN0025666	25	444100
5955	Belgrade Nursing Home			MN0051381	150	623100
5956	Bayer Built Woodwork			MN0051381	120	321900
5957	Belgrade Schools (BBE)			MN0051381	107	611100
5958	Menards			MN0051381	50	444100
5959	Belgrade Coop Assn			MN0051381	28	454300
5960	Belgrade Steel Tank Inc			MN0051381	25	336900
5961	North American St Bk			MN0051381	21	522100
5962	Belgrade Milling Co			MN0051381	9	424900
5963	Belgrade Grain & Feed			MN0051381	6	424900
5964	Belle Plaine Lutheran Home	Belle Plaine		MN0022772	276	623100
5965	Belle Plaine Public Schools-ISD #716	Belle Plaine		MN0022772	90	611100
5966	Emma Krumbee's Family Restaurant	Belle Plaine		MN0022772	85	722100
5967	Wendt Laboratories	Belle Plaine		MN0022772	30	325400
5968	Huber's SuperValu	Belle Plaine		MN0022772	25	445100
5969	State Bk of Belle Plaine	Belle Plaine		MN0022772	21	522100
5970	Kluver Mechanical Construction	Belle Plaine		MN0022772	20	238200
5971	Valley View Golf Club	Belle Plaine		MN0022772	20	713900
5972	Belle Plaine Co-op	Belle Plaine		MN0022772	18	493100
5973	Keup Motors	Belle Plaine		MN0022772	17	441100
5974	Seimon Implement	Belle Plaine		MN0022772	17	423800
5975	Belle Plaine, City of	Belle Plaine	0.02	MN0022772	15	921100
5976	Hardee's	Belle Plaine		MN0022772	15	722100
5977	Subway	Belle Plaine		MN0022772	13	722100
5978	Belle Plaine Clinic	Belle Plaine	0.02	MN0022772	12	621100
5979	Creative Tool & Engineering	Belle Plaine	0.00	MN0022772	12	332700
5980	Kyes Automatic Products	Belle Plaine	0.00	MN0022772	11	332700
5981	Prairie Farm Supply	Belle Plaine		MN0022772	11	424900
5982	Westerman Lumber	Belle Plaine		MN0022772	10	444100
5983	Parkview Home	Belview		MNG580003	95	623100
5984	Belview Liquor Store	Belview		MNG580003	14	722400
5985	Parkwood Apartments	Belview		MNG580003	10	623300
5986	MinnWest Bank	Belview		MNG580003	7	521100
5987	North Country Health Services	Bemidji	0.55	MN0022462	850	622100
5988	Bemidji Public School	Bemidji		MN0022462	810	611100
5989	Bemidji State University	Bemidji		MN0022462	550	611300
5990	Bemidji Clinic/ Merit Care	Bemidji		MN0022462	402	621111
5991	Beltrami, County of	Bemidji	0.51	MN0022462	360	921100
5992	Potlatch Corp	Bemidji		MN0022462	326	423300
5993	Johanneson's Incorporated	Bemidji		MN0022462	282	445100
5994	Nortech Systems Inc	Bemidji	0.26	MN0022462	229	335900
5995	Northstar Materials Inc.	Bemidji		MN0022462	190	237300
5996	Havenwood Care Center	Bemidji		MN0022462	150	623900
5997	Northwood Panelboard	Bemidji		MN0022462	141	423300
5998	Episcopal Community Services	Bemidji		MN0022462	110	623900
5999	Northwest Juvenile Training Center	Bemidji		MN0022462	100	922100
6000	Synergy Solutions	Bemidji		MN0022462	100	517200
6001	Bemidji, City of	Bemidji	0.13	MN0022462	93	921100
6002	Department of Natural Resources-Bemidji	Bemidji		MN0022462	90	924100
6003	CNH	Benson		MN0020036	300	333111
6004	Benson Public Schools	Benson		MN0020036	180	611110
6005	Red Ball LLC	Benson		MN0020036	170	333111
6006	Swift County-Benson Hospital	Benson	0.12	MN0020036	98	622110
6007	Meadow Lane Healthcare Ctr	Benson		MN0020036	83	623110
6008	Future Products Inc	Benson		MN0020036	82	315299
6009	Custom Roto Mold	Benson		MN0020036	69	326199
6010	Chippewa Valley Ethanol Co	Benson		MN0020036	35	339999
6011	Lorenz Manufacturing Co	Benson		MN0020036	30	333111
6012	Ron Carlson Machine	Benson	0.00	MN0020036	9	332721
6013	Monitor Printing	Benson	0.02	MN0020036	6	323119
6014	Page & Hill Forest Products	Big Falls	0.04	MN0022802	50	321912
6015	Willow Creek Furniture	Big Falls	0.41	MN0022802	15	337122
6016	671 Cafe	Big Falls		MN0022802	10	722110
6017	City of Big Falls Liquor Store	Big Falls		MN0022802	10	722410
6018	North Itasca Health Care Center	Big Falls		MN0022802	7	621111

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ID	Facility Name	City	P_kgd	Permit_No	employee_count	NAICS Code
6019	ISD No 727	Big Lake		MN0041076	230	611100
6020	Remmele Engineering Inc	Big Lake	0.00	MN0041076	185	332700
6021	Connections, etc. (fka Sherburne Tele. Sys. Inc.)	Big Lake		MN0041076	63	517100
6022	City of Big Lake	Big Lake	0.04	MN0041076	31	921100
6023	Options, Inc.	Big Lake		MN0041076	30	624300
6024	Preferred Bank	Big Lake		MN0041076	23	522100
6025	Steven's Super Value	Big Lake		MN0041076	21	445100
6026	Cargill/Nutrena Feeds	Big Lake		MN0041076	17	424900
6027	Shade Tree	Big Lake		MN0041076	17	451100
6028	Big Lake Lumber Center	Big Lake		MN0041076	14	444100
6029	Paragon Store Fixtures, Inc.	Big Lake		MN0041076	8	423300
6030	The Stampin Place	Big Lake		MN0041076	7	453900
6031	West Sherburne Tribune	Big Lake		MN0041076	7	511100
6032	Audio Communications, Inc.	Big Lake		MN0041076	6	517200
6033	Madsen Boatworks, Inc.	Big Lake		MN0041076	6	336600
6034	Perf-Form Products, Inc.	Big Lake		MN0041076	5	336900
6035	Big Lake Hardware Hank	Big Lake		MN0041076	4	444100
6036	Carousell Works, Inc.	Big Lake		MN0041076	2	562100
6037	L & S Tool and Design	Big Lake	0.00	MN0041076	2	332700
6038	Big Lake Machine	Big Lake		MN0041076	1	811300
6039	Faith Christian High School			ISTS	12	611100
6040	Russell Drainage Co.			ISTS	5	237100
6041	United Co-op Elevator			ISTS	5	424900
6042	Bigelow Post Office			ISTS	4	491100
6043	City of Bigelow		0.00	ISTS	3	921100
6044	The Bergquist Co	Bigfork		MN0022811	204	334100
6046	Bigfork Public Schools - Dist #318	Bigfork		MN0022811	75	611100
6047	Rajala Mill Co	Bigfork		MN0022811	55	423300
6048	Kocian's IGA	Bigfork		MN0022811	25	445100
6049	North Itasca Electric Coop	Bigfork		MN0022811	20	221100
6050	First St Bk of Big Fork	Bigfork		MN0022811	11	522100
6051	BOLD School District	Bird Island		MN0022829	150	611110
6052	Renville County Community Residence	Bird Island		MN0022829	60	623210
6053	Bob's Country Market/Bottle Shoppe	Bird Island		MN0022829	30	445110
6054	St Mary's School	Bird Island		MN0022829	26	611110
6055	Glesener's Inc	Bird Island		MN0022829	25	623990
6056	Athmann's Inn/Island Ballroom	Bird Island		MN0022829	24	722110
6057	Island Manor Healthcare	Bird Island		MN0022829	22	623110
6058	Rural Computer Consultants	Bird Island		MN0022829	17	541511
6059	State Bank of Bird Island	Bird Island		MN0022829	15	522110
6060	Bird Island Handi Stop	Bird Island		MN0022829	13	447110
6061	The Learning Funhouse, Inc.	Bird Island		MN0022829	12	624410
6062	George Paur Insurance Agency	Bird Island		MN0022829	11	524210
6063	Greater Minnesota Family Services	Bird Island		MN0022829	10	623311
6064	Bird Island Soil Service	Bird Island		MN0022829	9	115112
6065	Rob Saunders Accounting	Bird Island		MN0022829	8	541211
6066	The Broaster	Bird Island		MN0022829	8	722110
6067	Health Enhancement	Bird Island		MN0022829	7	621310
6068	Kibble Equipment	Bird Island		MN0022829	7	423820
6069	Bob's Body Shop	Bird Island		MN0022829	6	811121
6070	George Plass Sales & Service	Bird Island		MN0022829	6	423820
6071	Bird Island Farmer's Elevator	Bird Island		MN0022829	4	493130
6072	Electric Motor Shop	Bird Island		MN0022829	4	811219
6073	Giants Ridge Recreation Area	Biwabik		MN0053279	30	721100
6074	Anderberg Communications	Biwabik		MN0053279	22	517200
6075	Merritt House	Biwabik		MN0053279	12	621400
6076	Biwabik ShortStop	Biwabik		MN0053279	10	447100
6077	Edwards Spur	Biwabik		MN0053279	10	424900
6078	Jamboree Foods	Biwabik		MN0053279	10	445100
6079	Paul J Stark DDS	Biwabik		MN0053279	8	621200
6080	SalznWalz Restaurant	Biwabik		MN0053279	7	722100
6081	Alden's Cafe	Biwabik		MN0053279	6	722100
6082	Biwabik Lodge	Biwabik		MN0053279	5	721100
6083	Northern Lights Surveying & Mapping	Biwabik		MN0053279	5	541300
6084	Poor Gary's Pizza	Biwabik		MN0053279	5	722100
6085	Vi's Pizza	Biwabik		MN0053279	5	722100
6086	Biwabik Times	Biwabik		MN0053279	4	511100
6087	Herrmann Electric	Biwabik		MN0053279	4	238200

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ID	Facility Name	City	P_kgd	Permit_No	employee_count	NAICS Code
6088	Biwabik Motel	Biwabik		MN0053279	3	721100
6089	Black Diamond Chalet & Lounge	Biwabik		MN0053279	3	722400
6090	Kenny K's	Biwabik		MN0053279	3	722400
6091	Mountain Iron First State Bk - Biwabik	Biwabik		MN0053279	3	522100
6092	US Post Office	Biwabik		MN0053279	3	491100
6093	Anderson Fabrics Inc			ISTS	275	314100
6094	Blackduck Public Schools			ISTS	137	611100
6095	Northern Pines Good Samaritan			ISTS	85	623300
6096	Blackduck District Ranger Station			ISTS	30	115300
6097	Palmer Nursery			ISTS	20	561700
6098	Blackduck, City of		0.02	ISTS	15	921100
6099	Blackduck Co-op Ag Service			ISTS	7	424900
6100	DNR District Forestry Office			ISTS	6	115300
6102	General Pattern	St. Paul	1.17	MN0029815	170	332900
6103	National Sports Center	St. Paul		MN0029815	137	711300
6104	Carley Foundry Inc	St. Paul		MN0029815	130	331500
6106	Parker Hannifin Corp.	St. Paul		MN0029815	102	423900
6108	Advance Tool Inc	St. Paul	0.00	MN0029815	100	332700
6109	Excel Dental Studios, Inc.	St. Paul	2.60	MN0029815	90	339100
6111	Artistic Screening	St. Paul		MN0029815	80	323100
6112	Sunrise Packaging, Inc	St. Paul	0.06	MN0029815	70	325200
6113	Earle M. Jorgensen Co.	St. Paul		MN0029815	68	213100
6114	Turfco Manufacturing Inc	St. Paul		MN0029815	65	423800
6115	Green Lights Recycling, Inc.	St. Paul		MN0029815	60	423900
6116	Overnite Transport	St. Paul		MN0029815	53	488400
6117	Cemstone Products Co.	St. Paul		MN0029815	50	327300
6118	Diesel Cast Welding Inc	St. Paul		MN0029815	50	333900
6119	Security Products Co.	St. Paul	0.34	MN0029815	50	332900
6120	BGK Finishing Systems Inc	St. Paul		MN0029815	45	333900
6121	Riverside Color Corp	St. Paul		MN0029815	35	323100
6122	Blooming Prairie School Dist #756	Blooming Prairie		MN0021822	120	611100
6123	Prairie Manor Nursing Home	Blooming Prairie		MN0021822	110	623100
6124	Elf Atochem North America Inc	Blooming Prairie	0.28	MN0021822	54	541700
6125	Tandem Products Inc	Blooming Prairie		MN0021822	50	326200
6126	Central Coop Oil	Blooming Prairie		MN0021822	34	115100
6127	Metal Services	Blooming Prairie	0.16	MN0021822	23	332900
6128	Main Street Dental	Blooming Prairie		MN0021822	14	621200
6129	Lysne Construction Inc	Blooming Prairie		MN0021822	12	236200
6130	GTE	Blooming Prairie		MN0021822	10	517100
6131	SCSI	Blooming Prairie	0.01	MN0021822	10	325200
6133	Ceridian Corp	St. Paul		MN0030007	1900	334100
6134	Bloomington Public Schools	St. Paul		MN0030007	1450	611100
6135	Health Partners Inc	St. Paul		MN0030007	1352	524100
6137	Holiday Companies	St. Paul		MN0030007	918	447100
6139	Donaldson Companies Inc	St. Paul		MN0030007	821	333200
6140	VTC Inc	St. Paul		MN0030007	550	334400
6141	Bloomington, City of	St. Paul	0.73	MN0030007	519	921100
6142	Normandale Community College	St. Paul		MN0030007	450	611300
6143	Fourth Shift Corp	St. Paul		MN0030007	420	541500
6144	Jostens	St. Paul		MN0030007	359	339900
6146	St Paul Fire & Marine Ins	St. Paul		MN0030007	350	524100
6147	Health Systems Integration Inc	St. Paul		MN0030007	335	541500
6150	Northwest Racquet, Swim & Health	St. Paul		MN0030007	50	713900
6152	Telex Communications Inc	Blue Earth		MN0020532	300	334300
6153	St Lukes Lutheran Care Ctr	Blue Earth		MN0020532	250	623100
6154	Blue Earth Public Schools	Blue Earth		MN0020532	199	611100
6155	Custom Food Processors	Blue Earth	5.07	MN0020532	185	311200
6156	United Hospital-Blue Earth	Blue Earth	0.11	MN0020532	166	622100
6157	Wal-Mart	Blue Earth		MN0020532	85	452100
6158	Tafco Equipment Co	Blue Earth		MN0020532	60	423800
6159	Blue Earth Valley Telephone Co	Blue Earth		MN0020532	43	517100
6160	Hybrid Microcircuits Inc	Blue Earth		MN0020532	30	334400
6161	Winnebago Mfg Co	Blue Earth		MN0020532	30	811300
6163	Central Graphics Inc	Blue Earth		MN0020532	26	323100
6164	Custom Built Pneumatics	Blue Earth		MN0020532	10	423800
6165	Papa D's Pizza Wholesale	Blue Earth	0.46	MN0020532	10	311400
6166	East Central Energy	Braham		MN0022870	160	221100
6167	Braham Area School District #314	Braham		MN0022870	133	611100

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ID	Facility Name	City	P_kgd	Permit_No	employee_count	NAICS Code
6168	Five County Mental Health Center	Braham		MN0022870	54	621300
6169	Aurelius Manufacturing Co	Braham		MN0022870	39	333900
6170	Ercoa Industries	Braham		MN0022870	30	336600
6171	Lepinski Pallet	Braham		MN0022870	25	321900
6172	Design Engineering & Mfg Inc	Braham		MN0022870	17	332300
6173	Premier Products	Braham		MN0022870	16	326200
6174	Rural American Bank-Braham	Braham		MN0022870	16	522100
6175	Genesis Technologies/YouBet!Net	Braham		MN0022870	11	517200
6176	Braham Food Locker	Braham	0.57	MN0022870	10	311600
6177	Braham Monument Co	Braham		MN0022870	10	327900
6178	Braham Step Company	Braham		MN0022870	10	327900
6179	Brainerd Public Schools-#181	Brainerd		MN0049328	950	611100
6181	Brainerd Regional Human Svc Ctr	Brainerd		MN0049328	677	622200
6182	Maddens, Inc.	Brainerd		MN0049328	500	721100
6183	Crow Wing, County of	Brainerd	0.63	MN0049328	450	921100
6184	Bisys	Brainerd		MN0049328	404	561400
6185	Bethany Good Samaritan Village	Brainerd		MN0049328	325	623300
6186	Central Lakes Comm College- Brainerd	Brainerd		MN0049328	313	611300
6187	Brainerd Medical Ctr	Brainerd	0.39	MN0049328	285	621100
6188	Anderson Bros Construction Co	Brainerd		MN0049328	160	237300
6189	Keystone Automotive Industties, INC	Brainerd	1.74	MN0049328	157	332800
6190	Woodland Good Samaritan Village	Brainerd		MN0049328	150	623300
6191	Brainerd, City of	Brainerd	0.21	MN0049328	148	921100
6192	Bang Printing Co	Brainerd		MN0049328	145	323100
6193	A-Tek Inc	Brainerd	0.14	MN0049328	125	335900
6194	Burlington Northern/Santa Fe Railroad	Brainerd	0.06	MN0049328	125	482100
6195	Missota	Brainerd		MN0049328	120	322100
6196	Cub Foods	Brainerd		MN0049328	110	445100
6197	Herberger's	Brainerd		MN0049328	105	452100
6198	Brainerd Daily Dispatch	Brainerd		MN0049328	101	511100
6199	US Post Office	Brainerd		MN0049328	80	491100
6200	Dept. of Natural Resources	Brainerd		MN0049328	77	924100
6201	St Francis Medical Ctr/Home/Appletree Crt.	Breckenridge		MN0022900	397	623100
6202	Breckenridge Schools-ISD #846	Breckenridge		MN0022900	143	611100
6203	Red River Valley & Western Railroad	Breckenridge		MN0022900	95	336500
6204	Wilkin, County of	Breckenridge	0.09	MN0022900	65	921100
6205	Sigco Sun Products Inc	Breckenridge	1.01	MN0022900	52	311900
6206	Breckenridge, City of	Breckenridge	0.06	MN0022900	45	921100
6207	Bremer Bank	Breckenridge		MN0022900	32	522100
6208	Minn-Kota Ag Products	Breckenridge		MN0022900	30	111900
6209	Breezy Point Resort			MN0047457	205	721100
6210	Narvson Mgmt			MN0047457	59	721100
6211	Commander Bar			MN0047457	20	721100
6212	Breezy Oasis			MN0047457	19	445100
6213	Breezy Point, City of		0.02	MN0047457	12	921100
6214	Primetime Charlies			MN0047457	12	722100
6215	Pelican Square			MN0047457	10	424900
6216	SVRLB School	Brewster		MN0021750	30	611100
6217	First National Bank of Brewster	Brewster		MN0021750	6	522100
6218	Silver Bucket Bar Inc.	Brewster		MN0021750	4	722400
6219	City of Brewster	Brewster	0.00	MN0021750	3	921100
6220	Brewster Agency, Inc.	Brewster		MN0021750	2	524100
6221	Brewster Lumber Co.	Brewster		MN0021750	2	444100
6222	Bush Pioneer Seed	Brewster		MN0021750	2	454300
6223	Silvers's Computer Shop	Brewster		MN0021750	2	541500
6224	Brewster Electric	Brewster		MN0021750	1	238200
6225	Brewster Legion	Brewster		MN0021750	1	813400
6226	Jim's Standard Station	Brewster		MN0021750	1	447100
6227	Pat's Welding & Repair Inc	Brewster		MN0021750	1	238900
6228	Owatonna Canning	Bricelyn	1.16	MN0022918	25	311400
6229	State Bk of Bricelyn	Bricelyn		MN0022918	20	522100
6230	USC Elementary School	Bricelyn		MN0022918	16	611100
6231	Cannon Valley Marketing	Bricelyn		MN0022918	15	711300
6232	Bricelyn Pub	Bricelyn		MN0022918	10	722400
6233	Bud's Cafe	Bricelyn		MN0022918	10	722100
6234	Chuck's Food Store	Bricelyn		MN0022918	10	445100
6235	Wantonwan Farm Service	Bricelyn		MN0022918	9	493100
6236	Cannon Valley Telecom Inc	Bricelyn		MN0022918	8	517100

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ID	Facility Name	City	P_kgd	Permit_No	employee_count	NAICS Code
6237	American Legion	Bricelyn		MN0022918	6	813400
6238	Glenn's Cenex	Bricelyn		MN0022918	5	424900
6239	Main Street Clinic	Bricelyn	0.01	MN0022918	5	621100
6240	Bruss-Heitner Funeral Home	Bricelyn		MN0022918	4	812200
6241	Dr Jack Peterson	Bricelyn		MN0022918	4	541900
6242	Rural America Supply	Bricelyn		MN0022918	3	444100
6243	Bricelyn Insurance Agency	Bricelyn		MN0022918	2	524100
6244	Jacobson Oil	Bricelyn		MN0022918	2	424900
6245	Beckman Repair	Bricelyn		MN0022918	1	811100
6246	Sens Electric	Bricelyn		MN0022918	1	238200
6247	Storage Tek	St. Paul		MN0029815	1200	425100
6248	Target Corporation	St. Paul		MN0029815	1200	452100
6251	Siemens Empros Systems Intl	St. Paul		MN0029815	404	423400
6252	Medical Arts Press	St. Paul		MN0029815	375	323100
6253	Recovery Engineering	St. Paul		MN0029815	375	333300
6255	Wal-Mart	St. Paul		MN0029815	300	452100
6256	Unisource Worldwide	St. Paul	7.63	MN0029815	264	339100
6258	Target	St. Paul		MN0029815	225	452100
6259	Varitronic Systems Inc	St. Paul		MN0029815	175	541400
6260	Wilson's	St. Paul		MN0029815	150	448100
6261	TL Systems Corp	St. Paul		MN0029815	140	333900
6262	Creative Carton	St. Paul		MN0029815	135	322200
6263	Crow River Industries Inc	Brooten	0.42	MN0025909	80	541700
6264	Northern Lights Food Processing	Brooten	1.80	MN0025909	80	311400
6265	Brooten Public Schools	Brooten		MN0025909	30	611100
6266	Offutt R D Co	Brooten		MN0025909	25	111200
6267	Bonanza Valley State Bank	Brooten		MN0025909	11	522100
6268	Brooten Industries	Brooten		MN0025909	10	333400
6269	Browns Valley Health Ctr/Nursing Home		0.10	ISTS	75	621100
6270	EDW Blanck & Associates			ISTS	75	711300
6271	Browns Valley Public Schools			ISTS	30	611100
6272	Cenex Cooperative			ISTS	10	424900
6273	BW Inc			ISTS	8	441300
6274	Maynard's Food Ctr			ISTS	8	445100
6275	Union St Bk of Browns Valley			ISTS	8	522100
6276	Browns Valley Community Elevator			ISTS	6	493100
6277	Hanson Chevrolet			ISTS	6	441100
6278	Hardware Hank			ISTS	5	444100
6279	I. B. Industries, Inc.	Brownsdale		MN0022934	120	518200
6280	Akkerman Mfg CO	Brownsdale		MN0022934	55	333100
6281	Gerlach Bus	Brownsdale		MN0022934	25	485400
6282	Farmers & Merchant St. Bank- Brownsdale	Brownsdale		MN0022934	10	522100
6283	Greenway Co-op	Brownsdale		MN0022934	8	424900
6284	Krueger Trucking Company	Brownsdale	0.00	MN0022934	8	484100
6285	Farm Bureau Insurance	Brownsdale		MN0022934	4	524100
6286	US Post Office	Brownsdale		MN0022934	4	491100
6287	Brownsdale Co-op	Brownsdale		MN0022934	3	424900
6288	Brownsdale Motor	Brownsdale		MN0022934	2	811200
6289	First American Insurance	Brownsdale		MN0022934	2	524100
6290	Brownsdale Motor Service	Brownsdale		MN0022934	1	811200
6291	McCloud Public School	Brownton		MN0022951	40	611100
6292	Brownton Coop Ag Center	Brownton		MN0022951	15	424900
6293	Lake Marion Supper Club	Brownton		MN0022951	15	722100
6294	Shade Tree Retirement Center	Brownton		MN0022951	10	623100
6295	Security Bank and Trust	Brownton		MN0022951	8	522100
6296	Buffalo Public Schools-ISD #877	Buffalo		MN0040649	514	611100
6297	Wright, County of	Buffalo	0.63	MN0040649	450	921100
6298	Buffalo Hospital	Buffalo	0.16	MN0040649	240	622100
6299	Wal-Mart	Buffalo		MN0040649	200	452100
6300	Target	Buffalo		MN0040649	185	452100
6301	Universal Circuits	Buffalo		MN0040649	125	334400
6302	Ebenezer Covenant Home	Buffalo		MN0040649	115	623100
6303	Buffalo Bituminous Inc	Buffalo		MN0040649	100	237300
6304	Econofoods - Buffalo	Buffalo		MN0040649	100	445100
6305	Buffalo Clinic	Buffalo	0.11	MN0040649	79	621100
6306	Von Ruden Mfg	Buffalo		MN0040649	67	333600
6307	Whirltronics Inc	Buffalo		MN0040649	60	423800
6308	Ryan Chevrolet Oldsmobile Geo	Buffalo		MN0040649	58	441100

Appendix B. Industrial Phosphorus Data Matched to MNPRO Database by NAICS

ID	Facility Name	City	P_kgd	Permit_No	employee_count	NAICS Code
6309	Buffalo Family & Specialty Care Ctr	Buffalo	0.07	MN0040649	50	621100
6310	Buffalo Veneer & Plywood Co	Buffalo		MN0040649	50	321200
6311	Buffalo Lake Nursing Home	Buffalo Lake		MN0050211	111	623100
6312	Minnesota Beef Industry Inc	Buffalo Lake		MN0050211	106	311600
6313	Farmers Co-op Elevator Co	Buffalo Lake		MN0050211	55	493100
6314	Buffalo Lake Schools-ISD #647	Buffalo Lake		MN0050211	41	611100
6315	Duane Kottke Trucking	Buffalo Lake		MN0050211	40	484100
6317	D & D Stark	Buffalo Lake		MN0050211	15	237300
6318	Maynard's	Buffalo Lake		MN0050211	10	445100
6319	CenBank	Buffalo Lake		MN0050211	6	522100
6320	Mesabi Academy	Buhl		MN0022969	90	624200
6321	Burnsville Public Schools-ISD #191	St. Paul		MN0030007	1600	611100
6324	Northern Hydraulics Inc	St. Paul		MN0030007	500	333200
6325	Yellow Freight System Inc	St. Paul		MN0030007	500	488400
6326	CUB Foods	St. Paul		MN0030007	300	452100
6327	Asset Marketing Services Inc	St. Paul		MN0030007	275	451100
6328	City of Burnsville	St. Paul	0.38	MN0030007	268	921100
6329	Byerly's Co	St. Paul		MN0030007	250	445100
6330	Frontier Communications of MN	St. Paul		MN0030007	234	517100
6331	Park Nicollet Medical Ctr	St. Paul	0.30	MN0030007	225	621100
6332	Target	St. Paul		MN0030007	200	452100
6333	Ebenezer Ridges Care Center	St. Paul		MN0030007	180	623100
6334	Caire Inc	St. Paul	0.14	MN0030007	175	334500
6336	Kavouras Inc	St. Paul		MN0030007	150	334200
6337	Rainbow Foods	St. Paul		MN0030007	148	445100
6338	Schmidt Printing Inc	Byron		MN0049239	450	323100
6339	Byron Public Schools	Byron		MN0049239	198	611100
6340	Agriland Elevators Inc	Byron		MN0049239	45	493100
6341	Byron, City of	Byron	0.05	MN0049239	36	921100
6342	Olmsted Co Lumber Mart Inc	Byron		MN0049239	35	444100
6343	Byron Food Ctr	Byron		MN0049239	30	445100
6344	Zumbro Education District	Byron		MN0049239	30	611500
6345	Bob Braaten Construction Inc	Byron		MN0049239	23	238900
6346	Country Cabinetry Inc	Byron		MN0049239	22	337100
6347	Northwest Camper Sales	Byron		MN0049239	20	441200
6348	Byron Dairy Queen	Byron		MN0049239	18	722100
6349	Floors & More	Byron		MN0049239	15	444100
6350	First Security Bk	Byron		MN0049239	14	522100
6351	Marquette Grain Systems Inc	Byron		MN0049239	11	493100
6352	Byron Dental Group	Byron		MN0049239	10	621200
6353	US Post Office	Byron		MN0049239	9	491100
6354	Frederick W Nolting DDS	Byron		MN0049239	8	621200
6355	Joel Bigelow & Sons Enterprises Inc	Byron		MN0049239	8	236100
6356	Midwest Fuel	Byron		MN0049239	8	424700
6357	Strains Body Shop	Byron		MN0049239	8	811100
6358	Amazing Kids	Byron		MN0049239	6	624400
6359	Olmsted Medical Ctr-Byron	Byron	0.01	MN0049239	6	621100
6360	Able, INC.	Caledonia	0.59	MN0020231	200	812100
6361	Houston County	Caledonia	0.22	MN0020231	160	921100
6362	Caledonia Schools	Caledonia		MN0020231	150	611100
6363	Caledonia Haulers	Caledonia		MN0020231	136	484100
6364	Sagebrush	Caledonia		MN0020231	135	541500
6365	Lutheran Home	Caledonia		MN0020231	109	623100
6366	Houston Co. Group Homes	Caledonia		MN0020231	80	621600
6367	Woodland Industries	Caledonia		MN0020231	55	624300
6368	Quillin's IGA	Caledonia		MN0020231	52	445100
6369	APN, Inc.	Caledonia		MN0020231	40	481100
6370	Bonanza Grain, Inc.	Caledonia	1.16	MN0020231	25	311400
6371	State of Minnesota	Caledonia	0.04	MN0020231	25	921100
6372	Nelson Construction	Caledonia		MN0020231	24	236200
6373	Franciscan Skemp Healthcare/Clinic	Caledonia		MN0020231	23	621300
6374	Merchants National Bank	Caledonia		MN0020231	22	522100
6375	City of Caledonia	Caledonia	0.03	MN0020231	21	921100
6376	AmericInn	Caledonia		MN0020231	17	721100
6377	U. S. Post Office	Caledonia		MN0020231	15	491100
6378	Community First Bank	Caledonia		MN0020231	12	522100
6379	Cambridge Medical Center	Cambridge	0.60	MN0020362	931	622100
6380	I.S.D. No. 911 (Cambridge-Isanti)	Cambridge		MN0020362	800	611100

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ID	Facility Name	City	P_kgd	Permit_No	employee_count	NAICS Code
6381	Wal-Mart	Cambridge		MN0020362	425	452100
6382	Grandview Christian Ministries	Cambridge		MN0020362	358	623100
6383	Cambridge Metals & Plastics	Cambridge	1.91	MN0020362	277	332900
6384	Motek Engineering & Mfg CO	Cambridge	0.42	MN0020362	215	333500
6385	Minnesota Extended Treatment Options	Cambridge		MN0020362	200	622200
6386	Isanti, County of	Cambridge	0.27	MN0020362	195	921100
6387	Target	Cambridge		MN0020362	180	452100
6388	County Market	Cambridge		MN0020362	155	445100
6389	Cambridge Health Care	Cambridge		MN0020362	150	623100
6390	Arrow Tank & Engineering CO	Cambridge		MN0020362	145	332400
6391	Menards Mega Store	Cambridge		MN0020362	130	444100
6392	More 4	Cambridge		MN0020362	120	445100
6393	McDonalds Restaurant	Cambridge		MN0020362	80	722100
6394	Perkins Restaurant	Cambridge		MN0020362	80	722100
6395	Industries Incorporated	Cambridge	0.00	MN0020362	75	332700
6396	Schlagel Inc.	Cambridge	0.00	MN0020362	72	332700
6397	Cambridge Campus ARCC	Cambridge		MN0020362	65	611300
6398	Park Manufacturing	Cambridge	0.07	MN0020362	65	335900
6399	City of Cambridge	Cambridge	0.07	MN0020362	53	921100
6400	Bindery	Cambridge		MN0020362	45	323100
6401	John Hirsch's Cambridge Motors	Cambridge		MN0020362	45	336100
6402	North Star Media	Cambridge		MN0020362	40	511100
6403	Midwest of Cannon Falls Inc	Cannon Falls		MN0022993	375	424900
6404	Cannon Equipment Co	Cannon Falls	0.00	MN0022993	315	332700
6405	Cannon Falls Public Schools-ISD#252	Cannon Falls		MN0022993	240	611100
6406	Kid Duds	Cannon Falls		MN0022993	175	315200
6407	Fil-Mor Express Inc	Cannon Falls		MN0022993	170	484100
6408	Gemini Inc	Cannon Falls		MN0022993	160	339900
6409	Cannon Valley Woodwork Inc	Cannon Falls		MN0022993	135	337100
6410	Bergquist Co	Cannon Falls		MN0022993	100	425100
6411	Our Lady of the Angels	Cannon Falls		MN0022993	95	623100
6412	Community Hospital	Cannon Falls	0.06	MN0022993	90	622100
6413	Plastics Profiles Inc/Amesbury Group Inc	Cannon Falls	0.07	MN0022993	85	325200
6414	Alliant Food Service	Cannon Falls		MN0022993	70	311600
6416	Write On	Cannon Falls		MN0022993	42	313200
6417	Medical Safety Systems	Cannon Falls		MN0022993	23	562100
6418	Natural Fertilizer of America Inc	Cannon Falls		MN0022993	23	325300
6419	Thrall Process Services Inc	Cannon Falls		MN0022993	15	811200
6420	Hancock Concrete Products	Cannon Falls		MN0022993	14	327300
6421	Strike Tool Inc	Cannon Falls	0.00	MN0022993	12	332700
6422	Johnson Logging	Cannon Falls		MN0022993	11	113300
6423	Carlton, County of	Duluth	0.38	MN0049786	270	921100
6424	Stearns Manufacturing Co	Duluth		MN0049786	160	451100
6425	Carlton Nursing Home	Duluth		MN0049786	102	623100
6426	Carlton Public Schools-ISD #93	Duluth		MN0049786	102	611100
6427	CHEMSTAR	Duluth		MN0049786	13	213100
6428	Eagle Trucking	St. Paul	3.10	MN0029815	60	484100
6429	Waterworks Beach Club	St. Paul		MN0029815	47	722400
6430	Rehbein Inc	St. Paul		MN0029815	30	562100
6431	Kelly's Korner	St. Paul		MN0029815	16	722400
6432	Ro-So Contracting	St. Paul		MN0029815	15	237100
6433	Reel Manufacturing	St. Paul	0.00	MN0029815	14	332700
6434	Centerville Pizza & Video	St. Paul		MN0029815	12	722100
6435	Corner Express	St. Paul		MN0029815	11	447100
6436	Lake Area Utility Contracting	St. Paul		MN0029815	10	237100
6437	Northern Forest Products	St. Paul		MN0029815	10	444100
6438	Jim Stevens Construction	St. Paul		MN0029815	9	238100
6439	Tom Thumb	St. Paul		MN0029815	9	445100
6440	Noble Welding	St. Paul		MN0029815	7	811300
6441	Arcade Asphalt	St. Paul		MN0029815	6	324100
6442	Comfort Plus Heating & Cooling	St. Paul		MN0029815	6	238200
6443	Rivard Electric	St. Paul		MN0029815	5	238200
6444	APW McLean	St. Paul		MN0029815	425	423700
6445	Lifetime Fitness	St. Paul		MN0029815	160	812900
6446	County Market	St. Paul		MN0029815	134	445100
6447	Johansen Bus Service	St. Paul		MN0029815	95	485400
6448	Scherer Brothers Far North Windows	St. Paul		MN0029815	95	444100
6449	Champlin, City of	St. Paul	0.13	MN0029815	94	921100

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ID	Facility Name	City	P_kgd	Permit_No	employee_count	NAICS Code
6451	Secoa	St. Paul		MN0029815	50	711300
6452	Cardinal Health	St. Paul	0.15	MN0029815	45	541700
6453	Allina Medical Clinic-Champlin	St. Paul	0.04	MN0029815	33	621100
6454	Trails Best	Chandler	0.55	MN0039748	275	311600
6455	Prins Feed & Grain	Chandler		MN0039748	11	493100
6456	Schuur Concrete	Chandler		MN0039748	11	493100
6457	Chandler Coop	Chandler		MN0039748	9	447100
6458	Chandler Feed & Grain	Chandler		MN0039748	9	493100
6459	State Bank of Chandler	Chandler		MN0039748	9	522100
6460	Chandler Machine Shop	Chandler		MN0039748	4	333200
6463	Super Value Headquarters	St. Paul		MN0029882	650	445110
6465	Entegris	St. Paul	2.00	MN0029882	350	325211
6466	Banta	St. Paul	1.00	MN0029882	300	323119
6467	Bloomberg Companies	St. Paul		MN0029882	275	531120
6468	Young America Corp.	St. Paul		MN0029882	200	561499
6469	ABC/Lyman Lumber	St. Paul		MN0029882	180	321999
6470	MA Gedney Co	St. Paul	0.08	MN0029882	70	311421
6472	Fluoroware Inc	St. Paul		MN0029882	800	334400
6473	Lake Region Mfg Inc	St. Paul	0.58	MN0029882	745	334500
6474	Sanofi Diagnostic Pasteur Inc	St. Paul	0.32	MN0029882	415	334500
6475	Carver, County of	St. Paul	0.54	MN0029882	383	921100
6476	Mammoth Inc	St. Paul		MN0029882	350	423700
6477	Pie's Inc	St. Paul		MN0029882	200	311800
6478	Sprint	St. Paul		MN0029882	200	517100
6479	Preferred Products	St. Paul	0.23	MN0029882	135	326100
6481	Advanced Flex	St. Paul		MN0029882	90	334400
6482	Lewis Engineering Co	St. Paul		MN0029882	90	332300
6483	Van den Bergh Foods Co	St. Paul		MN0029882	90	311800
6484	Galtek Corp.	St. Paul	2.31	MN0029882	80	339100
6486	Oak Ridge Conference Center	St. Paul		MN0029882	80	561900
6487	Chaska, City of	St. Paul	0.11	MN0029882	76	921100
6488	Jonaco Machines Inc	St. Paul		MN0029882	65	333200
6489	Dyna-Graphics Corp	St. Paul		MN0029882	63	323100
6490	Dataforms Inc	St. Paul		MN0029882	55	323100
6491	Laser Engineering Inc	St. Paul	0.00	MN0029882	50	332700
6492	Olsen Tool & Plastics Inc	St. Paul	0.04	MN0029882	50	325200
6493	AFC Div - Morrison Molded Fiberglass Co	Chatfield	0.16	MN0021857	200	325200
6494	Tuohy Furniture Corp	Chatfield		MN0021857	200	337200
6495	Chosen Valley Care Center	Chatfield		MN0021857	130	623100
6496	Chosen Valley Public Schools	Chatfield		MN0021857	100	611100
6497	Root River State Bank	Chatfield		MN0021857	22	522100
6498	Darling International	Chatfield		MN0021857	16	316100
6499	Bob's Food Pride	Chatfield		MN0021857	15	445100
6500	Subway	Chatfield		MN0021857	15	722100
6501	Huckstadt Meat Processing Inc	Chatfield	0.51	MN0021857	9	311600
6502	Snider Publishing Co Inc	Chatfield		MN0021857	9	323100
6503	All American Co-op	Chatfield		MN0021857	8	424900
6504	Chisago Health Services	Center City	0.03	MN0055808	40	622100
6505	Chisago Lakes Distributing	Center City	2.70	MN0055808	40	312100
6506	Haus Specialty Mfg	Center City	0.00	MN0055808	35	541700
6507	Hibbing Taconite Co	Chisholm		MN0020117	1006	212200
6508	Northwest Airlines	Chisholm		MN0020117	600	481100
6509	Ironworld	Chisholm		MN0020117	150	713900
6510	Range Center	Chisholm		MN0020117	140	611500
6511	Chisholm Public Schools	Chisholm		MN0020117	105	611100
6512	Heritage Manor	Chisholm		MN0020117	100	623100
6513	Minnesota Twist Drill	Chisholm	0.00	MN0020117	80	332700
6514	Creative Garments	Chisholm		MN0020117	76	315200
6515	Chisholm, City of	Chisholm	0.07	MN0020117	50	921100
6516	Mickman Brothers	Chisholm		MN0020117	50	444100
6517	U.S.Post Office- Chisholm	Chisholm		MN0020117	50	491100
6518	First NB of Chisholm	Chisholm		MN0020117	40	522100
6519	Jubilee Foods	Chisholm		MN0020117	30	445100
6520	Buchanan Nursing Home	Chisholm		MN0020117	25	623100
6521	Bank Windsor	Chisholm		MN0020117	5	522100
6522	American Guidance	St. Paul		MN0029815	125	611500
6523	Golden Lake Elementary	St. Paul		MN0029815	75	611100
6524	McDonalds	St. Paul		MN0029815	70	722100

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ID	Facility Name	City	P_kgd	Permit_No	employee_count	NAICS Code
6525	Frattallone's Ace Hardware	St. Paul		MN0029815	30	444100
6526	Circle Pines, City of	St. Paul	0.03	MN0029815	22	921100
6527	Circle Pines Credit Union	St. Paul		MN0029815	18	522100
6528	Firstar Bank of MN NA	St. Paul		MN0029815	16	522100
6529	Al-Corn Clean Fuel	Claremont	0.15	MN0022187	29	541700
6530	Hodgman Drainage Co	Claremont		MN0022187	15	238900
6531	Huntting Elevator	Claremont		MN0022187	14	493100
6532	Magnum Products	Claremont	0.01	MN0022187	13	325200
6533	Claremont Service Ctr	Claremont		MN0022187	12	447100
6534	Greenway Co-op	Claremont		MN0022187	11	424900
6535	Claremont Pub	Claremont		MN0022187	10	722400
6536	JED Welding	Claremont	0.00	MN0022187	10	332700
6537	Security St Bk of Claremont	Claremont		MN0022187	8	522100
6538	Dickie Equipment	Claremont	0.00	MN0022187	7	332700
6539	Hometown Market	Claremont		MN0022187	7	445100
6540	Highway 14 Country Cafe	Claremont		MN0022187	4	722100
6541	Coffee Cup Cafe	Claremont		MN0022187	3	722100
6542	Central Todd Care Center	Clarissa		MNG580008	100	623100
6543	Glen Mac Inc	Clarissa		MNG580008	13	423800
6544	Jon & Rita's Super Valu	Clarissa		MNG580008	12	445100
6545	Battle Lake Outdoors	Clarissa		MNG580008	9	339900
6546	Agri-Valley Farm Center	Clarissa		MNG580008	6	424900
6547	Hansen Lumber & Hardware	Clarissa		MNG580008	6	444100
6548	Independent News Herald	Clarissa		MNG580008	6	511100
6549	Clarissa Meat Market	Clarissa	0.02	MNG580008	5	445200
6550	Fond Du Lac Indian Reservation	Duluth	1.72	MN0049786	1225	921100
6551	Sappi Fine Paper	Duluth		MN0049786	580	322100
6553	Cloquet Public Schools-ISD #94	Duluth		MN0049786	400	611100
6554	Diamond Brands Inc	Duluth		MN0049786	285	444100
6555	Community Memorial Hospital	Duluth	0.18	MN0049786	275	622100
6556	Boldt Construction	Duluth		MN0049786	210	236200
6557	Upper Lakes Foods Inc	Duluth		MN0049786	195	445100
6558	Wal-Mart	Duluth		MN0049786	184	452100
6559	Human Services Ctr	Duluth		MN0049786	88	923100
6560	Super One Foods	Duluth		MN0049786	78	445100
6561	Nels Nelson & Sons	Duluth		MN0049786	71	236200
6562	Cloquet Co-op Credit Union	Duluth		MN0049786	58	522100
6563	Pinewood Learning Ctr	Duluth		MN0049786	50	624300
6564	Raiter Clinic	Duluth	0.07	MN0049786	50	621100
6565	Fond du Lac Tribal & Comm College	Duluth		MN0049786	47	611300
6566	Wear-A-Knit Corp	Duluth		MN0049786	45	315100
6567	Nelson Motor Co	Duluth		MN0049786	30	441100
6568	Little Store	Duluth		MN0049786	24	445100
6569	Bergquist Imports Inc	Duluth		MN0049786	16	424900
6570	Cokato Public Schools-ISD #466	Cokato		MN0049204	275	611100
6571	Cokato Manor Inc	Cokato		MN0049204	100	623100
6572	CTS Corp	Cokato		MN0049204	100	334400
6573	Market Place	Cokato		MN0049204	90	445100
6574	Faribault Foods	Cokato	2.70	MN0049204	58	311400
6575	Airtex Consumer Products	Cokato		MN0049204	54	424600
6576	Norseman Restaurant Inc	Cokato		MN0049204	44	722100
6577	CAM Manufacturing Inc	Cokato		MN0049204	40	333900
6578	Ingredient Supply Inc	Cokato	1.63	MN0049204	35	311400
6579	Raydot Inc	Cokato		MN0049204	35	333400
6580	Home Health Care	Cokato		MN0049204	30	621600
6581	Saunatec Inc	Cokato		MN0049204	30	423700
6582	Dairy Queen	Cokato		MN0049204	25	722100
6583	Holt Motors Inc	Cokato		MN0049204	25	441100
6584	Olsen Chain & Cable Co	Cokato		MN0049204	19	333200
6585	Cokato Motor Sales	Cokato		MN0049204	15	441100
6586	Cokato, City of	Cokato	0.02	MN0049204	12	921100
6587	Tepley Equipment	Cokato		MN0049204	9	423800
6590	Cold Spring ISD #750	Cold Spring		MN0023094	285	611100
6591	Assumption Campus	Cold Spring		MN0023094	112	623100
6592	Cold Spring, City of	Cold Spring	0.10	MN0023094	68	921100
6593	Cold Spring Creamery	Cold Spring		MN0023094	65	424900
6594	Blue Heron	Cold Spring		MN0023094	54	722100
6595	Cold Spring Bakery	Cold Spring		MN0023094	50	311800

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ID	Facility Name	City	P_kgd	Permit_No	employee_count	NAICS Code
6597	Hardee's	Cold Spring		MN0023094	40	722100
6598	Marnanteli's	Cold Spring		MN0023094	39	722100
6599	Cold Spring Electric	Cold Spring		MN0023094	31	221100
6600	Lumber One Inc	Cold Spring		MN0023094	31	444100
6601	First NB of Cold Spring	Cold Spring		MN0023094	27	521100
6602	Vogt Food Market	Cold Spring		MN0023094	25	445100
6603	State Bk of Cold Spring	Cold Spring		MN0023094	16	521100
6604	Cold Spring Medical Clinic	Cold Spring	0.02	MN0023094	15	621100
6605	Stewart Cabinets	Cold Spring		MN0023094	13	238900
6606	Willenbring Law Office	Cold Spring		MN0023094	13	541100
6607	Mark Twain Cable	Cold Spring		MN0023094	10	515200
6608	Coleraine School District #316	Coleraine		MN0053341	130	611100
6609	University of Minnesota Research	Coleraine		MN0053341	26	611300
6610	Minnesota Power	Coleraine		MN0053341	17	221100
6611	First NB of Coleraine	Coleraine		MN0053341	13	522100
6613	Anoka-Hennepin School District #11	St. Paul		MN0029815	1166	611100
6615	Coon Rapids Medical Center	St. Paul	0.62	MN0029815	460	621100
6616	Anoka-Ramsey Comm College	St. Paul		MN0029815	380	611300
6617	John Roberts Co	St. Paul		MN0029815	320	323100
6619	Vincent Metals	St. Paul		MN0029815	237	423500
6620	Coon Rapids, City of	St. Paul	0.29	MN0029815	206	921100
6621	Ramsey Technology Inc	St. Paul	0.22	MN0029815	195	335900
6623	Camilia Rose Convalescent Ctr	St. Paul		MN0029815	166	623100
6624	Mary T. Inc	St. Paul		MN0029815	150	623900
6625	Diversified Adjustment Services Inc	St. Paul		MN0029815	133	561400
6626	Plastics Inc	St. Paul	0.10	MN0029815	130	325200
6627	Possis Medical	St. Paul	0.10	MN0029815	130	334500
6628	Merit Corp	St. Paul	0.07	MN0029815	95	334500
6629	Steinwall Inc	St. Paul	0.06	MN0029815	75	325200
6630	Juno Enterprises Inc	St. Paul	0.08	MN0029815	70	335900
6631	Dynamic Engineering Inc	St. Paul	0.05	MN0029815	60	325200
6632	U.M.C		2.60	ISTS	90	339100
6633	Hicks Concrete			ISTS	50	327300
6634	Cosmos Healthcare Ctr	Cosmos		MNG580056	75	623100
6635	Uni-Hydro Inc	Cosmos		MNG580056	65	237900
6636	ACGC South Elementary	Cosmos		MNG580056	48	611100
6637	Raske Building Systems	Cosmos		MNG580056	25	236200
6638	Nystrom's Restaurant	Cosmos		MNG580056	18	722100
6639	4 & 7 Corner Mart	Cosmos		MNG580056	15	445100
6640	American Legion Club	Cosmos		MNG580056	15	813400
6641	Koch's Warehouse	Cosmos		MNG580056	13	493100
6642	Farmer's Co-op Elevator	Cosmos		MNG580056	9	493100
6643	School District 833	St. Paul		MN0029815	1081	611100
6645	Up North Plastics Inc	St. Paul	11.37	MN0029815	280	325900
6646	Renewal by Andersen	St. Paul		MN0029815	250	321900
6647	Target	St. Paul		MN0029815	212	452100
6648	Cub Foods	St. Paul		MN0029815	208	445100
6649	Commercial Carriers Inc	St. Paul	10.35	MN0029815	200	484100
6650	Menard's	St. Paul		MN0029815	200	444100
6651	Rainbow Foods	St. Paul		MN0029815	200	445100
6652	Aggregate Industries	St. Paul		MN0029815	165	212300
6653	Allina Medical Clinic	St. Paul	0.17	MN0029815	125	621100
6654	City of Cottage Grove	St. Paul	0.17	MN0029815	120	921100
6656	US Postal Services	St. Paul	0.05	MN0029815	35	921100
6657	CCE Technologies	St. Paul		MN0029815	30	327900
6658	Orkin Pest Control	St. Paul		MN0029815	30	561700
6659	Cogentrix	St. Paul		MN0029815	20	333600
6660	Norcraft Companies	Cottonwood		MNG580010	225	337100
6661	North Star Companies	Cottonwood		MNG580010	113	524100
6662	Lakeview School	Cottonwood		MNG580010	50	611100
6663	Cottonwood Coop Oil Co	Cottonwood		MNG580010	25	424900
6664	Empire St Bk	Cottonwood		MNG580010	15	522100
6665	Farmers Coop Elevator Co	Cottonwood		MNG580010	15	493100
6666	Extreme Panel Technologies	Cottonwood		MNG580010	10	339900
6667	Cottonwood, City of	Cottonwood	0.01	MNG580010	9	921100
6668	Centrol Inc	Cottonwood		MNG580010	8	115100
6669	Minnesota Hardwood Inc			ISTS	50	321200
6670	CN Labs		13.49	ISTS	25	541700

Appendix B. Industrial Phosphorus Data Matched to MNPRO Database by NAICS

ID	Facility Name	City	P_kgd	Permit_No	employee_count	NAICS Code
6671	Courtland Industries Inc			ISTS	20	327300
6672	Crow Bar			ISTS	9	722100
6673	Swany's Pub			ISTS	8	722400
6674	Voges Construction			ISTS	7	236100
6675	Courtland State Bank			ISTS	5	522100
6676	Immanuel Lutheran Church			ISTS	5	813100
6677	Renner's Feed Service			ISTS	5	424900
6678	Courtland Evangelical Lutheran Church			ISTS	4	813100
6679	Courtland Waste Handling Inc			ISTS	4	562100
6680	Frank Bode Trucking		0.10	ISTS	2	484100
6681	Courtland Hardware Store			ISTS	1	444100
6682	Cromwell Schools	Cromwell		MN0051101	60	611100
6683	Villa Vista Nursing Home	Cromwell		MN0051101	36	623100
6684	Michigan Peat	Cromwell		MN0051101	21	212300
6685	American Furniture	Cromwell		MN0051101	20	442100
6686	Farmers Co-op Store/Station	Cromwell		MN0051101	18	445100
6687	Peatrex	Cromwell		MN0051101	15	212300
6688	Country Inn	Cromwell		MN0051101	13	722100
6689	Cromwell, City of	Cromwell	0.02	MN0051101	8	813900
6690	Cromwell Liquor Store	Cromwell		MN0051101	6	445300
6691	Trolley Station/Store	Cromwell		MN0051101	5	452100
6692	First State Bank of Finlayson-Cromwell	Cromwell		MN0051101	4	522100
6693	Riverview Healthcare Assn	Crookston	0.60	MN0021423	500	622110
6694	Crookston Public Schools	Crookston		MN0021423	300	611110
6695	American Crystal Sugar Co	Crookston	2.81	MN0021423	250	311313
6696	University of Minnesota-Crookston	Crookston	2.65	MN0021423	240	611310
6697	New Flyer of America (MN) Inc	Crookston		MN0021423	212	336211
6698	Villa St Vincent	Crookston		MN0021423	175	623110
6699	Dahlgren & Co	Crookston	6.15	MN0021423	163	311911
6700	Dee Inc Foundry & Mfg	Crookston	0.19	MN0021423	160	331521
6701	Hugo's	Crookston		MN0021423	100	445110
6702	Phoenix Industries of Crookston Ltd.	Crookston		MN0021423	100	326199
6703	Occupational Development Ctr	Crookston		MN0021423	80	624310
6704	Tri-Valley Opportunity Council Inc	Crookston		MN0021423	70	624190
6705	Altru Clinic	Crookston		MN0021423	68	621111
6706	Bremer Bank-Crookston	Crookston		MN0021423	65	522190
6707	Crookston, City of	Crookston		MN0021423	65	923130
6708	Crookston Super Valu	Crookston		MN0021423	30	445110
6709	Crookston Welding & Machine	Crookston		MN0021423	30	811310
6710	Mid-Valley Grain Coop	Crookston		MN0021423	30	424910
6711	Red Power Intl Inc	Crookston	0.01	MN0021423	30	333298
6712	Otter Tail Power Co	Crookston		MN0021423	19	221121
6713	Crookston Implement	Crookston	0.01	MN0021423	18	333298
6714	Eickhof Columbaria	Crookston		MN0021423	10	236220
6715	Cuyuna Regional Medical Ctr	Crosby	0.25	MN0058122	390	622100
6716	Crosby Public Schools-ISD #182	Crosby		MN0058122	255	611100
6717	Riverwood International USA	Crosby		MN0058122	190	333900
6718	Central Lakes Medical Ctr	Crosby	0.07	MN0058122	55	621100
6719	Super Valu	Crosby		MN0058122	41	445100
6720	First NB of Crosby	Crosby		MN0058122	17	522100
6721	Minnesota Power & Light	Crosby		MN0058122	9	221100
6722	Reeds Market	Crosslake		MN0021491	50	445100
6723	Pine Peaks Restaurant	Crosslake		MN0021491	30	722100
6724	Crosslake Construction	Crosslake		MN0021491	20	236100
6725	Crosslake Sheet Metal Inc.	Crosslake	0.14	MN0021491	20	332900
6726	Simonson Lumber	Crosslake		MN0021491	18	444100
6727	Mezzenga Distributing	Crosslake		MN0021491	16	444200
6728	Build All Lumber	Crosslake		MN0021491	15	444100
6729	Crosslake Water Slides	Crosslake		MN0021491	15	713900
6730	Crosslake Communications	Crosslake		MN0021491	13	517100
6731	NMN Inc	Crosslake		MN0021491	12	452900
6732	Moonlight Bay Family Restaurant	Crosslake		MN0021491	10	722100
6733	Cub Foods	St. Paul		MN0029815	295	445100
6734	TimeSavers Inc	St. Paul		MN0029815	235	333200
6735	Crystal Care Center	St. Paul		MN0029815	200	623100
6736	Target	St. Paul		MN0029815	200	452100
6737	US West	St. Paul		MN0029815	115	517100
6738	Featherlite Exhibits	St. Paul		MN0029815	105	711300

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ID	Facility Name	City	P_kgd	Permit_No	employee_count	NAICS Code
6739	Thrift-Way Supermarket	St. Paul		MN0029815	67	445100
6740	Crystal SuperValu	St. Paul		MN0029815	63	445100
6741	Norwest Bank	St. Paul		MN0029815	27	522100
6742	Casting Technology Inc	St. Paul		MN0029815	20	331500
6743	Wiltec Industries	St. Paul		MN0029815	20	333200
6745	Crystal Shamrock	St. Paul		MN0029815	17	336400
6746	Benchmark Industries	St. Paul		MN0029815	14	337100
6747	Brad Kelvington	Danube	0.00	MNG580057	47	325320
6748	Brlys Bar and Grill	Danube		MNG580057	10	722400
6749	Kay Krueger	Danube		MNG580057	10	452100
6750	Allen Larson	Danube		MNG580057	5	522100
6751	Phil Stanfield	Danube		MNG580057	4	493100
6752	John Veglahn	Danube		MNG580057	2	441100
6753	Commerford Gravel Inc.	Appleton		MN0025593	25	212321
6754	Commerford Construction Inc	Appleton		MN0025593	10	237310
6755	State Bank of Danvers	Appleton		MN0025593	9	522110
6756	Syngenta Seeds	Appleton		MN0025593	8	115114
6757	American Time & Signal Co	Dassel	0.06	MN0054127	75	334500
6758	Crest Electronics	Dassel	0.05	MN0054127	60	334500
6759	Miller Manufacturing Co	Dassel		MN0054127	48	333200
6760	Jay-Dee Industries Inc	Dassel		MN0054127	40	333200
6762	Johnson Mem Hospital/Nursing Home	Dawson	0.13	MN0021881	200	622100
6763	Viessman Trucking Inc	Dawson		MN0021881	200	488400
6764	AG Processing Inc	Dawson		MN0021881	95	424900
6765	Midwest Truck & Parts	Dawson		MN0021881	25	441100
6766	Dawson ICF-MR	Dawson		MN0021881	20	621400
6767	Land O'Lakes Inc	Dawson		MN0021881	18	424900
6768	Dawson Engineering	Dawson	0.10	MN0021881	15	332900
6769	Deer River Healthcare	Deer River	0.16	MN0051616	250	622100
6770	Deer River Schools-Dist #317	Deer River		MN0051616	135	611100
6771	Rajala Timber Co	Deer River		MN0051616	50	423900
6772	Rajala Lumber Co	Deer River		MN0051616	32	444100
6773	Wille Transport Inc	Deer River	1.55	MN0051616	30	484100
6774	Trout Post & Pole	Deer River	0.00	MN0051616	28	484100
6775	Deer River Folio Co Inc	Deer River		MN0051616	14	322200
6776	Itasca Sash & Door	Deer River		MN0051616	5	321900
6777	Landscape Structures Inc	Delano		MN0051250	350	451100
6778	Delano Public Schools-ISD #879	Delano		MN0051250	300	611100
6779	Coborns	Delano		MN0051250	170	445100
6780	Randy's Sanitation Inc	Delano		MN0051250	90	562100
6781	Delano Healthcare Ctr	Delano		MN0051250	70	623100
6782	Industrial Louvers Inc	Delano		MN0051250	61	444100
6783	Arctic Fox Heaters	Delano		MN0051250	60	336300
6784	DB Direct	Delano		MN0051250	50	561400
6785	Star West Chevrolet Oldsmobile	Delano		MN0051250	43	441100
6786	Building Materials Inc	Delano		MN0051250	40	321900
6787	Modern Molding	Delano	0.03	MN0051250	40	325200
6788	Stahlke Bus Service	Delano		MN0051250	35	485400
6789	Circuit Research Corp	Delano		MN0051250	29	424600
6790	Kalco Recovery Inc	Delano		MN0051250	25	423900
6791	State Bk of Delano	Delano		MN0051250	20	522100
6792	Loon Photographic	Delano		MN0051250	16	541900
6793	Crow River St Bk	Delano		MN0051250	15	522100
6794	Delano Theatre	Delano		MN0051250	14	512100
6795	Delano Dodge-Chrysler-Plymouth	Delano		MN0051250	10	441100
6796	Quik Shop 66 Pizzeria & Deli	Delano		MN0051250	10	447100
6797	Detroit Lakes Public Schools	Detroit Lakes		MN0020192	476	611100
6798	St. Mary's Regional Health Ctr	Detroit Lakes	0.24	MN0020192	372	622100
6799	BTD Mfg. Inc	Detroit Lakes	1.46	MN0020192	280	541700
6800	Snappy Air Distribution Products	Detroit Lakes	1.82	MN0020192	265	332900
6801	Emmanuel Nursing Center	Detroit Lakes		MN0020192	250	623100
6802	Lakeshirts	Detroit Lakes		MN0020192	190	454100
6803	SJ Electro Systems Inc	Detroit Lakes	0.13	MN0020192	170	334500
6804	Dakota Clinic	Detroit Lakes	0.17	MN0020192	125	621100
6805	DL Manufacturing, Inc	Detroit Lakes	0.00	MN0020192	105	332700
6806	MN Dept of Transportation	Detroit Lakes		MN0020192	100	926100
6807	Dynamic Homes, Inc	Detroit Lakes		MN0020192	97	236100
6808	Bergen's Greenhouses	Detroit Lakes		MN0020192	80	332300

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ID	Facility Name	City	P_kgd	Permit_No	employee_count	NAICS Code
6809	Lakes Offset	Detroit Lakes		MN0020192	70	323100
6810	Merit Care Clinic	Detroit Lakes	0.09	MN0020192	67	621100
6811	DL Printing	Detroit Lakes		MN0020192	45	323100
6812	Friesens	Detroit Lakes	0.07	MN0020192	34	333500
6813	Burlington Northern/Santa Fe Railroad	Moorhead	0.17	MN0049069	375	482100
6814	Wal-Mart	Moorhead		MN0049069	225	452100
6815	Dilworth Public Schools	Moorhead		MN0049069	95	611100
6816	F-M Asphalt Inc	Moorhead		MN0049069	85	324100
6817	Howard Johnson's/Paisano's	Moorhead		MN0049069	72	721100
6818	Bargain's	Moorhead		MN0049069	35	452100
6819	Slumberland	Moorhead		MN0049069	30	442100
6820	Terra Fertilizer	Moorhead		MN0049069	22	424900
6821	Janesville Auto	Moorhead	1.03	MN0049069	20	484100
6822	Northwestern St Bank of Ulen - Dilworth	Moorhead		MN0049069	16	522100
6823	Weivoda Carpets	Moorhead		MN0049069	13	442200
6824	Dairy Queen	Moorhead		MN0049069	12	722100
6825	Stop-N-Go	Moorhead		MN0049069	11	445100
6826	Cenex Convenience Store	Moorhead		MN0049069	10	424900
6827	First National Bank - Dilworth	Moorhead		MN0049069	10	522100
6828	Food-N-Fuel	Moorhead		MN0049069	9	424900
6829	Mc Neilus Companies	Dodge Center		MN0021016	650	333200
6830	Mc Neilus Steel Inc	Dodge Center		MN0021016	175	332300
6831	Triton School District #2125	Dodge Center		MN0021016	170	611100
6832	Owatonna Canning Co	Dodge Center	2.48	MN0021016	110	311400
6833	Fairview Nursing Home	Dodge Center		MN0021016	100	623100
6834	Energy Economics Inc	Dodge Center	0.06	MN0021016	73	334500
6835	RDM of Minnesota	Dodge Center	0.00	MN0021016	70	332700
6836	John's Super Valu Foods	Dodge Center		MN0021016	36	445100
6837	Corey's Companies	Dodge Center		MN0021016	29	812300
6838	Dickie Equipment	Dodge Center		MN0021016	20	333100
6839	Greene Doors & Hardware	Dodge Center		MN0021016	17	238900
6840	Norwest Bk MN Southeast NA	Dodge Center		MN0021016	14	522100
6841	The Turkey Store Company	Dodge Center		MN0021016	12	311800
6842	Dodge Veterinary Clinic	Dodge Center		MN0021016	11	541900
6843	Southern Minnesota Machinery Sales	Dodge Center		MN0021016	10	333900
6844	Bowie and Mosier CPA	Dodge Center		MN0021016	9	541200
6845	Freerksen Trucking	Dodge Center	0.41	MN0021016	8	484100
6846	Mc Neilus Auto & Truck Parts	Dodge Center		MN0021016	8	441100
6847	Welsh Equipment	Dodge Center		MN0021016	8	423800
6848	Terra International	Dodge Center		MN0021016	6	424900
6849	St. Mary's/Duluth Clinic	Duluth	5.14	MN0049786	3800	621100
6850	Duluth Public Schools-ISD#709	Duluth		MN0049786	1700	611100
6851	St. Louis, County of	Duluth	2.31	MN0049786	1640	921100
6852	University of Minnesota-Duluth	Duluth		MN0049786	1571	611300
6853	St. Luke's Hospital	Duluth	0.74	MN0049786	1143	622100
6854	Duluth, City of	Duluth	1.49	MN0049786	1060	921100
6855	US Post Office-Main	Duluth		MN0049786	930	491100
6856	Uniprise (United HealthCare)	Duluth		MN0049786	900	524100
6857	US Government	Duluth	1.19	MN0049786	850	921100
6858	Allete (Minnesota Power)	Duluth		MN0049786	768	221100
6859	Duluth Missabe Iron Range Railway Co	Duluth	0.30	MN0049786	680	482100
6860	Cirrus Design	Duluth		MN0049786	550	336400
6861	Grandma's Restaurants	Duluth		MN0049786	450	722100
6862	Minnesota Air National Guard	Duluth		MN0049786	450	928100
6863	USPS Remote Encoding Center	Duluth		MN0049786	450	491100
6864	Wells Fargo	Duluth		MN0049786	429	522100
6865	College of St Scholastica	Duluth		MN0049786	425	611300
6866	Northwest Airlines	Duluth		MN0049786	425	336400
6867	Stora Enso	Duluth		MN0049786	325	322100
6868	ZMC Hotels	Duluth		MN0049786	325	721100
6869	Advanstar Communications Inc	Duluth		MN0049786	309	511100
6870	Benedictine Health System	Duluth	0.19	MN0049786	290	622100
6871	Target	Duluth		MN0049786	275	452100
6872	Perkins Family Restaurants	Duluth		MN0049786	265	722100
6873	Luigino's Inc	Duluth		MN0049786	240	722100
6874	Duluth News Tribune	Duluth		MN0049786	235	511100
6875	Monson Trucking	Duluth	11.64	MN0049786	225	484100
6876	MN Dept. of Transportation	Duluth		MN0049786	200	926100

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ID	Facility Name	City	P_kgd	Permit_No	employee_count	NAICS Code
6878	Lakeshore Lutheran Home	Duluth		MN0049786	170	623100
6879	City of Dundee		0.00	ISTS	3	921100
6880	DJ's Tap			ISTS	3	722400
6881	Brenda's Gas & Grocery			ISTS	2	722100
6882	New Vision Co-op			ISTS	1	424900
6883	West Information Publishing Group	St. Paul		MN0030007	7000	511100
6884	Blue Cross & Blue Shield	St. Paul		MN0030007	3000	524100
6885	Lockheed Martin Tactical Defense Sys	St. Paul		MN0030007	1750	334100
6886	United Parcel Service	St. Paul		MN0030007	1435	492100
6888	Cray Research Inc	St. Paul		MN0030007	900	334100
6889	Coca-Cola Bottling Co	St. Paul	59.71	MN0030007	885	312100
6890	Unisys Corp	St. Paul		MN0030007	736	443100
6891	US Post Service Bulk Mail Center	St. Paul		MN0030007	680	491100
6892	Kraft American	St. Paul	24.97	MN0030007	400	311500
6893	Freightmasters Inc	St. Paul	16.29	MN0030007	315	484100
6894	Lull Industries Inc	St. Paul		MN0030007	250	333100
6895	Wal-Mart	St. Paul		MN0030007	240	452100
6898	3M - Hearing Health	St. Paul	0.08	MN0030007	100	334500
6900	Ergotron Inc	St. Paul		MN0030007	100	337200
6901	Bird & Cronin Medical Products	St. Paul	2.37	MN0030007	82	339100
6902	Eagle Valley School	Eagle Bend		MN0023248	42	611100
6903	Blombeck Construction	Eagle Bend		MN0023248	16	237300
6904	Bisel's Supermarket	Eagle Bend		MN0023248	12	445100
6905	Petro Express/Jenny's Cafe	Eagle Bend		MN0023248	12	447100
6906	Northland Dairy Supply	Eagle Bend		MN0023248	11	424900
6907	Central Ag Service	Eagle Bend		MN0023248	9	115100
6908	Hess White Farm Implement	Eagle Bend		MN0023248	9	424900
6909	Eagle Bend Metal	Eagle Bend		MN0023248	7	811300
6910	Eagle Bend Municipal Liquor Store	Eagle Bend		MN0023248	7	445300
6911	Sir Anthony's Family Restaurant	Eagle Bend		MN0023248	7	722100
6912	Eagle Bend Veteran's Club Inc	Eagle Bend		MN0023248	6	813400
6913	Tri-cap Senior Ctr	Eagle Bend		MN0023248	6	813400
6914	Eagle Bend Farm & Lumber Supply	Eagle Bend		MN0023248	5	444100
6915	Eagle Bend Welding	Eagle Bend		MN0023248	5	811300
6916	Jerry's Body Shop	Eagle Bend		MN0023248	5	811100
6917	Neil's Service Ctr	Eagle Bend		MN0023248	5	811100
6918	Shirley's Gas & Groceries	Eagle Bend		MN0023248	5	447100
6919	Engebretson Motors	Eagle Bend		MN0023248	4	811100
6920	Lakewood Clinic	Eagle Bend	0.01	MN0023248	4	621100
6921	NAPA Auto Parts	Eagle Bend		MN0023248	4	441300
6922	Micro-Trak Systems Inc				40	423800
6923	Eagle's Nest				23	445300
6924	American Legion Post 617				20	813400
6925	Eagle Lake, City of		0.03		19	921100
6926	Uncle Albert's Cafe				15	722100
6927	Chuck's Body Shop				10	811100
6928	Eagle Express				10	424900
6929	Eagle Lake Amoco				10	447100
6930	Hughes Automotive				10	811100
6931	Gene's Repair Inc				6	811100
6932	Pierce Enterprises				6	811200
6933	Allied Overhead Door				5	332300
6934	Skelgas				5	454300
6935	Peoples State Bank				4	522100
6936	Melchior Tree Service				2	561700
6937	Al's Hair Shop		0.00		1	812100
6938	Baurer's Specialty				1	811200
6939	Hair Affair		0.00		1	812100
6940	Judy's Cuts & Curls		0.00		1	812100
6941	Anoka/Isanti School Dist. 15			ISTS	186	611100
6942	Park Manufacturing			ISTS	33	238200
6943	East Bethel Theatre			ISTS	30	512100
6944	Arrow Fence & Sign			ISTS	20	339900
6945	Sylvester Lumber			ISTS	20	444100
6946	Peoples Bank of Commerce			ISTS	4	522100
6947	American Crystal Sugar Company	East Grand Forks	0.15	MN0021814	420	311300
6948	East Grand Forks Public Schools	East Grand Forks		MN0021814	340	611100
6949	City of East Grand Forks	East Grand Forks	0.27	MN0021814	190	921100

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ID	Facility Name	City	P_kgd	Permit_No	employee_count	NAICS Code
6950	American Federal Savings Bank	East Grand Forks		MN0021814	128	522100
6951	Vigen Construction, Inc.	East Grand Forks		MN0021814	125	236200
6952	Hugo's	East Grand Forks		MN0021814	115	445100
6953	Northwest Technical College	East Grand Forks		MN0021814	107	611500
6954	Cabela's	East Grand Forks		MN0021814	100	451100
6955	R. J. Zavoral & Sons, Inc.	East Grand Forks	0.06	MN0021814	80	238910
6956	Whitey's Cafe	East Grand Forks		MN0021814	70	722100
6957	Mc Donalds	East Grand Forks		MN0021814	65	722200
6958	Lumber Mart , Inc.	East Grand Forks		MN0021814	35	423300
6959	Mayo Manufacturing, Inc.	East Grand Forks		MN0021814	35	333200
6960	Pamida	East Grand Forks		MN0021814	35	452100
6961	PRACS Institute, Ltd.	East Grand Forks		MN0021814	25	621500
6962	Valley Truck Parts & Service	East Grand Forks		MN0021814	25	441300
6963	Bert's Truck Equipment, Inc.	East Grand Forks		MN0021814	24	336300
6964	MeritCare Clinic	East Grand Forks	0.03	MN0021814	22	621100
6965	MTS Systems Corp	St. Paul		MN0029882	1700	541500
6966	Eden Prairie School District #272	St. Paul		MN0029882	1200	611100
6968	Super Valu Stores Inc	St. Paul		MN0029882	1100	445100
6969	Best Buy Co Inc	St. Paul		MN0029882	900	443100
6970	GE Capital Fleet Service	St. Paul		MN0029882	800	532100
6971	Eaton Corp	St. Paul		MN0029882	642	333900
6972	American Family Insurance	St. Paul		MN0029882	470	524100
6973	TCF Financial Corporation	St. Paul		MN0029882	400	522100
6974	Anagram International Inc	St. Paul	2.58	MN0029882	375	332900
6975	Pillsbury Bakery	St. Paul		MN0029882	340	311800
6976	Perkin Elmer	St. Paul	0.26	MN0029882	335	334500
6978	Challenge Printing Inc	St. Paul		MN0029882	245	323100
6979	Viking Press	St. Paul		MN0029882	238	323100
6981	Jerry's Enterprises Inc	St. Paul		MN0030007	2000	445100
6982	Golden Valley Microwave Foods	St. Paul		MN0030007	650	445100
6983	Health Risk Management Inc	St. Paul		MN0030007	552	524100
6984	Dayton's	St. Paul		MN0030007	500	452100
6985	JC Penney Co	St. Paul		MN0030007	400	452100
6986	Norwest Funding	St. Paul		MN0030007	358	541600
6987	Nash Finch Co	St. Paul		MN0030007	350	445100
6988	International Dairy Queen Inc	St. Paul		MN0030007	300	722100
6989	Roach Organization Inc	St. Paul		MN0030007	140	443100
6990	Techpower Inc	St. Paul		MN0030007	120	561300
6991	Kurk Trucking	Eitzen		MN0049531	85	484100
6992	Eitzen State Bank	Eitzen		MN0049531	11	522100
6993	Hammell Equipment	Eitzen		MN0049531	6	444200
6994	Mike's Meats	Eitzen	0.02	MN0049531	5	445200
6995	D&L's Bordertown Inn	Eitzen		MN0049531	3	722100
6996	Maggie's Dugout	Eitzen		MN0049531	3	722100
6997	MC Service	Eitzen		MN0049531	3	811100
6998	Wiebke Fur	Eitzen		MN0049531	3	315200
6999	Amundson Equipment	Elbow Lake		MN0051535	50	423800
7000	C. I. Construction	Elbow Lake		MN0051535	50	236100
7001	City of Elbow Lake	Elbow Lake	0.07	MN0051535	50	921100
7002	Cosmos Enterprises	Elbow Lake		MN0051535	50	332100
7003	Elbow Lake Coop Grain	Elbow Lake		MN0051535	50	111900
7004	Elbow Lake Ford and Mercury, Inc.	Elbow Lake		MN0051535	50	441100
7005	ELEAH Medical Center	Elbow Lake	0.07	MN0051535	50	621100
7006	Farm and Home Oil Co.	Elbow Lake		MN0051535	50	424700
7007	Farm Power	Elbow Lake		MN0051535	50	423800
7008	Farmer's Co-op Oil Assn.	Elbow Lake	0.13	MN0051535	50	813900
7009	Grant County Offices	Elbow Lake	0.07	MN0051535	50	921100
7010	Lake Region Veterinary Center, LLC	Elbow Lake		MN0051535	50	541900
7011	Leis Motors	Elbow Lake		MN0051535	50	441100
7012	MInnesota Rural Water	Elbow Lake		MN0051535	50	813300
7013	Runestone Telephone Association	Elbow Lake		MN0051535	50	517100
7014	West Central Area School	Elbow Lake		MN0051535	50	611100
7015	West Central MN Community Action	Elbow Lake		MN0051535	50	624100
7016	EM School District	Plainview		MN0055361	55	611100
7018	Gusa Electric	Plainview		MN0055361	8	238200
7019	Region Millworks	Plainview		MN0055361	8	321900
7020	Beck Implement	Plainview		MN0055361	6	423800
7021	Greenway Co-op	Plainview		MN0055361	6	424900

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ID	Facility Name	City	P_kgd	Permit_No	employee_count	NAICS Code
7022	All American Co-op	Plainview		MN0055361	5	493100
7023	Hope Medical Center	Plainview	0.01	MN0055361	5	621100
7024	Cutrite Customs	Plainview		MN0055361	4	337100
7025	DataSmart Computers	Plainview		MN0055361	4	811200
7026	Elgin Liquor Store	Plainview		MN0055361	4	445300
7027	People's St Bk of Plainview at Elgin	Plainview		MN0055361	4	522100
7028	US Post Office	Plainview		MN0055361	4	491100
7029	Elgin Vet Clinic	Plainview		MN0055361	2	541900
7030	Main Street Studio	Plainview		MN0055361	2	541900
7031	Bill Sims Accounting	Plainview		MN0055361	1	541200
7032	Elk River-ISD #728	Elk River		MN0020788	1160	611100
7033	Sherburne, County of	Elk River	0.69	MN0020788	490	921100
7034	Guardian Angels	Elk River		MN0020788	372	621400
7036	Wal-Mart	Elk River		MN0020788	325	452100
7037	Cub Foods	Elk River		MN0020788	200	445100
7038	Menards	Elk River		MN0020788	195	444100
7039	Tescom Corp	Elk River	1.30	MN0020788	189	332900
7040	Coborns	Elk River		MN0020788	180	445100
7041	Alltool Design & Manufacturing	Elk River	0.81	MN0020788	155	541700
7042	Cretex Companies	Elk River		MN0020788	130	327300
7043	E & O Tool and Plastics	Elk River	0.10	MN0020788	125	325200
7044	Elk River Machine Company	Elk River	0.00	MN0020788	80	332700
7045	Metal Craft Machine & Engineering	Elk River	0.00	MN0020788	52	332700
7046	J & J Machine	Elk River	0.05	MN0020788	45	335900
7047	Dynetic Systems	Elk River		MN0020788	35	335300
7048	MN Fabrication & Machine	Elk River	0.00	MN0020788	30	332700
7049	Harvest States Cooperative	Elkton		MNG580013	12	424900
7050	Farmers St Bk of Elkton	Elkton		MNG580013	9	522100
7051	The Port	Elkton		MNG580013	4	722100
7052	Deb's Hair Designs	Elkton	0.00	MNG580013	1	812100
7053	NRHEG School District	Ellendale		MN0041564	70	611100
7054	North Central Plastics Inc	Ellendale		MN0041564	50	424600
7055	Ellendale Farmers Union Co-op	Ellendale		MN0041564	20	424900
7056	Steve's Meat Market Inc	Ellendale	0.07	MN0041564	15	445200
7057	Parkview Manor Nursing Home	Ellsworth		MNG580015	66	623100
7058	Ellsworth Public School	Ellsworth		MNG580015	36	611100
7059	Domeyer Implement	Ellsworth		MNG580015	9	423800
7060	Ellsworth State Bank	Ellsworth		MNG580015	9	522100
7061	Short Stop	Ellsworth		MNG580015	8	445100
7062	Elmore Academy-YSI, Inc.	Elmore		MN0021920	50	923110
7063	Elmore Truck Accessories	Elmore	0.11	MN0021920	20	325211
7064	Pioneer Bank	Elmore		MN0021920	8	522110
7065	Ely Bloomenson Community Hosp	Ely	0.29	MN0020508	240	622110
7066	Vermilion Comm College	Ely		MN0020508	111	611210
7067	Ely Public Schools-Dist #696	Ely		MN0020508	109	611100
7068	Irresistible Ink/Hallmark Cards, Inc.	Ely		MN0020508	100	561431
7069	Sato Travel/Navigant	Ely		MN0020508	100	561599
7070	Leustek& Sons Inc	Ely		MN0020508	75	237310
7071	MN Dept of Revenue	Ely		MN0020508	57	921190
7072	Holiday Inn Suspree Resort	Ely		MN0020508	55	721100
7073	Iga Foodliner	Ely		MN0020508	50	445100
7074	US Forest Svc Ranger Station	Ely		MN0020508	50	115300
7075	Zup's Food Market	Ely		MN0020508	47	445100
7076	Ely, City of	Ely	0.06	MN0020508	43	921100
7077	Wintergreen Designs	Ely		MN0020508	41	315200
7078	St Louis County	Ely		MN0020508	39	624200
7079	Ely Medical Center	Ely	0.05	MN0020508	35	621100
7080	Piragis Northwoods Co.	Ely		MN0020508	35	454100
7081	Hardee's	Ely		MN0020508	30	722100
7082	Steger Designs	Ely		MN0020508	25	448100
7083	Pizza Hut	Ely		MN0020508	21	722100
7084	Ely Echo	Ely		MN0020508	20	511100
7085	Norwest Bank Ely	Ely		MN0020508	14	522100
7086	Boundary Waters State Bank	Ely		MN0020508	12	522100
7087	Lake Country Sales Inc.	Elysian	0.03	MN0041114	33	325200
7088	Crestview Manor Health Care	Evansville		MNG580074	62	623100
7089	Evansville Public Schools	Evansville		MNG580074	50	611100
7090	Farmers St Bk of Evansville	Evansville		MNG580074	8	522100

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ID	Facility Name	City	P_kgd	Permit_No	employee_count	NAICS Code
7091	Chris Mitchell CPA	Evansville		MNG580074	7	541200
7092	Englund Construction	Evansville		MNG580074	5	236100
7093	Quinn Construction	Evansville		MNG580074	3	236100
7094	Eveleth-Gilbert School	Eveleth		MN0023337	280	611100
7095	Arrowhead Health Care Centers	Eveleth		MN0023337	175	623100
7096	Days Inn	Eveleth		MN0023337	80	721100
7097	Minnesota Power	Eveleth		MN0023337	49	221100
7098	Iron Range Resources & Rehabilitation	Eveleth		MN0023337	46	926100
7099	Eveleth Health Services Park	Eveleth	0.06	MN0023337	45	621100
7100	Utility Systems of America	Eveleth		MN0023337	40	237100
7101	F.A.S.T. Inc.	Eveleth		MN0023337	35	333200
7102	Lundgren Motors	Eveleth		MN0023337	34	441100
7103	OSI Environmental, Inc.	Eveleth		MN0023337	27	562100
7104	Servicemaster & Merry Maids	Eveleth		MN0023337	21	561700
7105	Chicagami Children's Center	Eveleth		MN0023337	15	624400
7106	Five Seasons Sports Center	Eveleth		MN0023337	15	423800
7107	Wells Fargo	Eveleth		MN0023337	14	522100
7108	Tufco, Inc.	Eveleth		MN0023337	10	326200
7109	Dover-Eyota Public Schools	St. Charles		MN0046868	178	611100
7110	Dave Higgins Home Builder	St. Charles		MN0046868	26	236100
7111	Kwik Trip	St. Charles		MN0046868	12	447100
7112	Beckman Siding	St. Charles		MN0046868	11	238100
7113	Pennington Hardware	St. Charles		MN0046868	7	444100
7114	Petit Music	St. Charles		MN0046868	7	451100
7115	All American Elevator	St. Charles		MN0046868	5	493100
7116	Country Cafe	St. Charles		MN0046868	5	722100
7117	Country Curtains & Crafts	St. Charles		MN0046868	3	453200
7118	Fairfax Community Home Inc	Fairfax		MNG580060	68	623100
7119	Schweiss Distributing	Fairfax		MNG580060	50	444100
7120	GFW Middle School	Fairfax		MNG580060	38	611100
7121	Cherrington Corp	Fairfax	0.00	MNG580060	19	332700
7122	South Central Coop	Fairfax		MNG580060	18	424900
7123	Deming Construction	Fairfax		MNG580060	12	236200
7124	Wendinger Bldg & Remodeling	Fairfax		MNG580060	10	236100
7125	Hawkeye Tile	Fairfax		MNG580060	8	327100
7126	Fairmont Medical Center-Mayo Health Systems	Fairmont	0.40	MN0030112	620	622100
7127	Weigh-Tronix Inc	Fairmont	2.57	MN0030112	375	311821
7128	Fairmont Tamper	Fairmont		MN0030112	350	336500
7130	Lakeview Methodist Health Care Facility	Fairmont		MN0030112	215	623100
7131	W Hodgman & Sons Inc	Fairmont		MN0030112	200	237300
7132	REM Heartland	Fairmont		MN0030112	180	621400
7134	Aerospace Systems Div	Fairmont	0.16	MN0030112	143	335900
7135	Tyco Plastics Inc	Fairmont	0.23	MN0030112	135	326100
7136	MRCI/Tri-County Industries	Fairmont		MN0030112	115	333200
7137	Hancor Inc	Fairmont	0.07	MN0030112	85	325200
7138	Greenlee Fairmont	Fairmont		MN0030112	75	332200
7139	Rosen's Inc	Fairmont		MN0030112	35	424600
7140	Minnesota State Fair	St. Paul		MN0029815	2500	713900
7141	University of Minnesota	St. Paul		MN0029815	1500	611300
7143	Hewlett-Packard	St. Paul		MN0029815	300	334100
7144	Hermes Floral	St. Paul		MN0029815	50	453100
7145	Faribault Public Schools	Faribault		MN0030121	560	611100
7146	McQuay International	Faribault		MN0030121	480	333400
7147	MN State Corrections Facility	Faribault		MN0030121	470	922100
7148	Rust Consulting	Faribault		MN0030121	450	541100
7150	Rice, County of	Faribault	0.53	MN0030121	375	921100
7151	District One Hospital	Faribault	0.20	MN0030121	301	622100
7153	Wal-Mart	Faribault		MN0030121	290	452100
7154	Academies for the Deaf/Blind	Faribault		MN0030121	260	611500
7155	Met-Con Companies	Faribault		MN0030121	260	236200
7156	Hy-Vee Food Stores	Faribault		MN0030121	257	445100
7157	Mercury Minnesota Inc	Faribault	1.72	MN0030121	250	332900
7158	Crown Cork & Seal Co	Faribault		MN0030121	225	332400
7159	K-Bar Industries	Faribault		MN0030121	200	333900
7160	Viratec Thin Films Inc	Faribault		MN0030121	200	327200
7161	Wilson Center	Faribault		MN0030121	175	622200
7162	Faribault Woolen Mill Co	Faribault		MN0030121	163	313200
7163	Allina Medical Clinic	Faribault	0.20	MN0030121	150	621100

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ID	Facility Name	City	P_kgd	Permit_No	employee_count	NAICS Code
7165	Rainbow Foods	Faribault		MN0030121	135	445100
7166	Farmington Public Schools-ISD #192	St. Paul		MN0045845	595	611100
7167	Federal Aviation Administration	St. Paul		MN0045845	495	926100
7168	Dakota Electric Assn	St. Paul		MN0045845	230	221100
7169	Lexington Standard Corp	St. Paul	0.83	MN0045845	120	332900
7171	Duo Products Inc	St. Paul	0.07	MN0045845	90	325200
7172	Marschall Line Inc	St. Paul		MN0045845	68	485400
7173	Farmington, City of	St. Paul	0.09	MN0045845	63	921100
7174	Peerless Plastics	St. Paul	0.05	MN0045845	60	325200
7175	Controlled Air	St. Paul		MN0045845	37	238900
7176	PIC Inc	St. Paul		MN0045845	37	238900
7177	CG Construction	St. Paul		MN0045845	32	238100
7179	Lake Region Hospital	Fergus Falls	0.71	MN0050628	588	622110
7180	Otter Tail, County of	Fergus Falls		MN0050628	506	921190
7182	Fergus Falls Public Schools	Fergus Falls		MN0050628	334	611110
7183	Fergus Falls Regional Treatment Ctr	Fergus Falls		MN0050628	318	622210
7184	Fergus Falls Medical Group PA	Fergus Falls		MN0050628	242	621112
7185	Broen Memorial Home	Fergus Falls		MN0050628	230	623110
7186	Northern Contours	Fergus Falls	0.20	MN0050628	230	321911
7187	Pioneer Home Inc	Fergus Falls		MN0050628	204	623110
7188	ShoreMaster Inc	Fergus Falls	2.70	MN0050628	156	332999
7189	Minnesota State Community/Technical College	Fergus Falls	1.71	MN0050628	155	611310
7190	Veterans Home	Fergus Falls		MN0050628	151	623110
7191	Fergus Falls, City of	Fergus Falls		MN0050628	137	921190
7192	Lakeland Mental Health Center	Fergus Falls		MN0050628	126	621420
7193	Sara Lee Bakery Group	Fergus Falls	0.46	MN0050628	120	311811
7194	Lakes Country Service Cooperative	Fergus Falls		MN0050628	106	561499
7195	Banner Engineering Co	Fergus Falls	1.38	MN0050628	73	334413
7197	Otter Tail Coaches, Inc.	Fergus Falls		MN0050628	57	485410
7198	Thiele Engineering Co-Fergus Fls	Fergus Falls	0.92	MN0050628	55	333993
7199	Fair Meadow Nursing Home	Fertile		MN0052370	124	623100
7200	Fertile-Beltrami School	Fertile		MN0052370	90	611100
7201	Christian Motors	Fertile		MN0052370	22	441100
7202	Christian Transport	Fertile	1.14	MN0052370	22	484100
7203	TDS Fertilizer	Fertile		MN0052370	15	424900
7204	First St Bk of Fertile	Fertile		MN0052370	12	522100
7205	Bauer Honey	Fertile		MN0052370	11	424400
7206	Leiting Honey	Fertile		MN0052370	5	424400
7207	Floodwood Public Schools	Floodwood		MNG580048	50	611100
7208	Bridgeman's	Floodwood		MNG580048	15	722100
7209	First St Bk of Floodwood	Floodwood		MNG580048	15	522100
7210	Floodwood DAC	Floodwood		MNG580048	15	611500
7211	Floodwood Food-N-Fuel	Floodwood		MNG580048	10	447100
7212	Floodwood, City of	Floodwood	0.01	MNG580048	10	921100
7213	MN Dept of Transportation	Floodwood		MNG580048	10	926100
7214	Savanna Portage Supper Club	Floodwood		MNG580048	10	722100
7215	St Louis Co Hwy Dept	Floodwood		MNG580048	10	926100
7216	Foley Public Schools	Foley		MN0023451	204	611100
7217	Benton, County of	Foley	0.26	MN0023451	186	921100
7218	Foley Nursing Ctr	Foley		MN0023451	160	623100
7219	Willmar Poultry Co/Foley	Foley		MN0023451	60	112300
7220	Gor-Fol Mfg	Foley	0.09	MN0023451	53	326100
7221	Dombrovski Meats Inc	Foley	2.44	MN0023451	43	311600
7222	Coborn's Grocery	Foley		MN0023451	36	445100
7223	Rural American Bk-Foley/Gilman	Foley		MN0023451	26	522100
7224	Blow Molded Specialties	Foley	0.01	MN0023451	18	325200
7225	Foley Lumber Do-It Ctr	Foley		MN0023451	15	444100
7226	T.L.C. University	Foley		MN0023451	15	624400
7227	Mid-State Custom Cabinetry	Foley		MN0023451	12	337100
7228	Murphy Chevrolet	Foley		MN0023451	10	441100
7229	First Care Medical Services	Fosston		MN0022128	183	621111
7230	Fosston School District	Fosston		MN0022128	107	611110
7231	Stenberg Welding & Fabricating, Inc.	Fosston	0.04	MN0022128	88	332911
7232	Palubicki's Food & Deli	Fosston		MN0022128	60	445110
7233	Polk Solid Waste Management	Fosston		MN0022128	28	562111
7234	Don's Machine Shop	Fosston		MN0022128	17	811111
7235	Northern Food & Dairy	Fosston	1.16	MN0022128	16	311511
7236	Franklin Health Care Center	Franklin		MN0021083	82	623100

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ID	Facility Name	City	P_kgd	Permit_No	employee_count	NAICS Code
7237	Cedar Mountain Elementary School	Franklin		MN0021083	45	611100
7238	Good Time Transport	Franklin		MN0021083	15	493100
7239	Gedney Pickles	Franklin	0.56	MN0021083	12	311400
7240	Petro 19	Franklin		MN0021083	10	424900
7241	Minnesota Valley Telephone Company	Franklin		MN0021083	8	517100
7242	Franklin State Bank	Franklin		MN0021083	5	522100
7243	Longbranch Saloon	Franklin		MN0021083	5	722400
7244	Palmrya Mutual Insurance Co.	Franklin		MN0021083	5	524100
7245	Rocker's	Franklin		MN0021083	5	722400
7246	Franklin Post Office	Franklin		MN0021083	4	491100
7247	United Agri Products	Franklin		MN0021083	4	115100
7248	Franklin Locker Service	Franklin	0.17	MN0021083	3	311600
7249	Vicky's Farmsite Cafe	Franklin		MN0021083	3	722100
7250	Franklin Auction & Consignment	Franklin		MN0021083	2	453300
7251	All-Phase Electric	Franklin		MN0021083	1	238200
7252	Randy's Plumbing & Heating	Franklin		MN0021083	1	238200
7253	Wood Treasures	Franklin		MN0021083	1	321900
7258	Target	St. Paul		MN0029815	600	452100
7260	LaMaur	St. Paul		MN0029815	400	423800
7263	Park Construction Co	St. Paul		MN0029815	300	237300
7264	Parsons Electric Co	St. Paul		MN0029815	300	238200
7265	Wal-Mart	St. Paul		MN0029815	262	452100
7266	Holiday Plus	St. Paul		MN0029815	250	452100
7267	Home Depot	St. Paul		MN0029815	150	441300
7268	Menard Cashway Lumber	St. Paul		MN0029815	150	444100
7269	Maple Lawn Nursing Home	Fulda		MN0023507	65	623100
7270	Fulda Public Schools	Fulda		MN0023507	64	611100
7271	New Dawn Inc	Fulda		MN0023507	17	623900
7272	First NB-Fulda	Fulda		MN0023507	16	522100
7273	Interstate Power Co	Fulda		MN0023507	10	221100
7274	Holinka Distributing	Fulda		MN0023507	8	424800
7275	Ramerth Agricultural	Fulda		MN0023507	8	115100
7276	Fulda Electric	Fulda		MN0023507	7	238200
7277	Fulda Free Press	Fulda		MN0023507	7	511100
7278	M.G. Waldbaum	Gaylord	6.76	MN0051209	300	311400
7279	Eastside Ford	Gaylord		MN0051209	144	441100
7280	Sibley, County of	Gaylord	0.16	MN0051209	115	921100
7281	Gaylord Lakeview Home	Gaylord		MN0051209	105	623100
7282	Sibley East Schools	Gaylord		MN0051209	100	611100
7283	Unidoor Corportation	Gaylord		MN0051209	60	321900
7284	Prarie House	Gaylord		MN0051209	28	722100
7285	Citizens St Bk of Gaylord	Gaylord		MN0051209	17	522100
7286	Tri-County Builders	Gaylord		MN0051209	15	236200
7287	Home Quality Foods	Gaylord	0.06	MN0051209	13	445200
7288	RCM	Gaylord		MN0051209	13	541300
7289	Anderson Drug	Gaylord		MN0051209	6	446100
7290	Duebers	Gaylord		MN0051209	6	453900
7291	First National Bank of Gaylord	Gaylord		MN0051209	6	522100
7292	Gibbon Public School-GFW	Hector		MNG580020	50	611100
7293	CJ's Family Restaurant	Hector		MNG580020	25	722100
7294	May-Wes Manufacturing	Hector	0.15	MNG580020	22	332900
7295	Northern Insulation	Hector		MNG580020	14	238300
7296	Ankers, Inc.	Hector		MNG580020	13	325300
7297	Texaco Super Stop and Wash, Inc.	Hector		MNG580020	12	447100
7298	South Central Coop	Hector		MNG580020	9	424900
7299	State Bk of Gibbon	Hector		MNG580020	9	522100
7300	Minnesota Valley Bank	Hector		MNG580020	7	522100
7301	Ag-Land Coop.	Hector		MNG580020	6	454300
7302	Starkey Labs Inc	Glencoe	0.37	MN0022233	476	334500
7303	Glencoe Regional Health Services	Glencoe	0.28	MN0022233	425	622100
7304	Telex Communications Inc	Glencoe		MN0022233	300	334200
7305	Glencoe-Silver Lake Schools Dist #422	Glencoe		MN0022233	270	611100
7308	Coborn's	Glencoe		MN0022233	65	445100
7309	Mark's Economart	Glencoe		MN0022233	63	445100
7310	McLeod County Social Svc Ctr	Glencoe		MN0022233	50	923100
7311	Twin Cities & Western Railroad	Glencoe	0.02	MN0022233	45	482100
7312	Pamida Inc	Glencoe		MN0022233	38	452100
7313	Delta Fabricating Co	Glencoe	0.00	MN0022233	35	332700

Appendix B. Industrial Phosphorus Data Matched to MNPRO Database by NAICS

ID	Facility Name	City	P_kgd	Permit_No	employee_count	NAICS Code
7314	Security Bank & Trust Company	Glencoe		MN0022233	32	522100
7315	Glencoe, City of	Glencoe	0.04	MN0022233	30	921100
7316	First Minnesota Bank NA	Glencoe		MN0022233	21	522100
7317	Supersweet Feed	Glencoe		MN0022233	17	424900
7318	Young America Corp	Glencoe		MN0022233	16	493100
7319	Spectrol	Glencoe		MN0022233	10	238200
7320	Glenwood School Dist #2149			MN0052710	247	611100
7321	Glacial Ridge Hospital		0.12	MN0052710	180	622100
7322	WASP Inc		0.00	MN0052710	170	332700
7323	Glenwood Retirement Village			MN0052710	150	623100
7324	Pope, County of		0.15	MN0052710	110	921100
7325	Dairyland Computer & Consulting Inc			MN0052710	90	541500
7326	Lakeview Care Ctr			MN0052710	80	623100
7327	American Business Forms			MN0052710	75	424100
7328	Clyde Machines Inc			MN0052710	70	423800
7329	Glenwood Bridge			MN0052710	55	237300
7330	MHC Inc			MN0052710	50	333200
7331	CP Rail Systems		0.02	MN0052710	34	482100
7332	Tom's Food Pride			MN0052710	30	445100
7333	Dealers Livestock Equipment Ctr			MN0052710	20	333200
7334	R/C Maching		0.00	MN0052710	20	332700
7335	B&D Rollers Inc			MN0052710	9	811200
7336	Bodeker Machining			MN0052710	8	333200
7337	Mike's Fish & Seafood Inc		3.02	MN0052710	8	445200
7338	H&S Specialties Inc		0.01	MN0052710	7	325200
7339	Jerel Mfg			MN0052710	6	331200
7340	Total Fab Inc		0.03	MN0052710	5	332900
7341	Glyndon Public Schools-ISD #2164	Glyndon		MN0020630	120	611100
7342	Homecare of Minnesota	Glyndon		MN0020630	55	621600
7343	Stamart	Glyndon		MN0020630	21	424900
7344	Glyndon Tastee Freez	Glyndon		MN0020630	12	722100
7345	Cenex Land-O-Lakes	Glyndon		MN0020630	11	424900
7346	Fuchs Sanitation	Glyndon		MN0020630	11	562100
7347	Miguel's	Glyndon		MN0020630	11	722100
7348	Glyndon Highway Host	Glyndon		MN0020630	10	722100
7349	Glyndon, City of	Glyndon	0.01	MN0020630	6	921100
7350	US Post Office	Glyndon		MN0020630	5	491100
7351	Glyndon Self Storage	Glyndon		MN0020630	4	493100
7352	Hill Lounge	Glyndon		MN0020630	4	722400
7353	Eddy & Giny's Garden Ctr	Glyndon		MN0020630	3	444200
7354	O's Bar & Grill	Glyndon		MN0020630	3	722400
7355	Felton Farmers Elevator	Glyndon		MN0020630	2	493100
7356	Glyndon Garage	Glyndon		MN0020630	2	811100
7357	Linda's Cut n Curl	Glyndon	0.01	MN0020630	2	812100
7358	Northwestern St Bk of Ulen - Glyndon	Glyndon		MN0020630	2	522100
7359	Schuman's Shaklee	Glyndon		MN0020630	2	454300
7360	Brownie's Dairy	Glyndon	0.06	MN0020630	1	311500
7363	United Health Care	St. Paul		MN0029815	1100	524100
7364	Tennant Co	St. Paul		MN0029815	650	333300
7365	Courage Center	St. Paul		MN0029815	550	623900
7366	Dahlberg Inc	St. Paul	14.46	MN0029815	500	339100
7367	Red Line Health Care	St. Paul	1.83	MN0029815	350	541700
7368	Jim Lupient Oldsmobile-GMC	St. Paul		MN0029815	270	441100
7369	KARE TV	St. Paul		MN0029815	225	515100
7370	CyberOptics	St. Paul	0.15	MN0029815	198	334500
7372	Alexander & Alexander Inc	St. Paul		MN0029815	160	524100
7373	Grow Biz Intl Inc	St. Paul		MN0029815	150	533100
7374	MA Mortenson Co	St. Paul		MN0029815	140	236200
7375	Northrup King Co	St. Paul	0.14	MN0029815	130	541700
7376	I.S.D. #2311	Gonvick		MN0020541	100	611100
7377	Winsor Products, Inc.	Gonvick		MN0020541	18	311800
7378	Clearwater Veterinary Clinic	Gonvick		MN0020541	15	541900
7379	Richards Publishing, Inc.	Gonvick		MN0020541	15	511100
7380	Northern State Bank	Gonvick		MN0020541	12	522100
7381	Lange Transport, Inc.	Gonvick		MN0020541	10	485500
7382	North Central Feed	Gonvick		MN0020541	4	424900
7383	Cranes Meat Market	Gonvick	0.76	MN0020541	2	445200
7384	EMD & Associates	Winona		MN0030147	850	334400

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ID	Facility Name	City	P_kgd	Permit_No	employee_count	NAICS Code
7385	Knitcraft Corp	Winona		MN0030147	210	313200
7386	Winona Lighting Custom Div	Winona		MN0030147	100	443100
7387	Polymer Composites Inc	Winona	0.06	MN0030147	69	325200
7388	Brad Ragan Inc	Winona		MN0030147	65	326200
7389	Northern States Power Co	Winona		MN0030147	45	221100
7390	Winona Van Norman	Winona	0.09	MN0030147	44	333500
7391	Hiatt Manufacturing Inc	Winona		MN0030147	35	423500
7392	Mississippi Welders Supply Co	Winona		MN0030147	22	423800
7393	Winona Distributing	Winona		MN0030147	21	424800
7394	Zeches Institution Supply	Winona		MN0030147	16	445100
7395	United Building Ctr	Winona		MN0030147	15	444100
7396	Graceville Health Center	Graceville	0.16	MN0023540	120	621100
7397	Carlson Oil Co	Graceville		MN0023540	50	424900
7398	Graceville Public Schools	Graceville		MN0023540	40	611100
7399	Hoffman Implement	Graceville		MN0023540	20	423800
7400	Cook County Public Schools	Grand Marais		MN0020010	134	611100
7401	Cook Co North Shore Hospital	Grand Marais	0.07	MN0020010	111	622100
7402	Cook, County of	Grand Marais	0.15	MN0020010	107	921100
7403	Hedstrom Lumber Co	Grand Marais		MN0020010	100	423300
7404	Grand Marais Hotel Corp	Grand Marais		MN0020010	55	721100
7405	Grand Marais, City of	Grand Marais	0.06	MN0020010	45	921100
7406	US Forestry Dept	Grand Marais		MN0020010	33	115300
7407	Sven & Ole's	Grand Marais		MN0020010	32	722100
7408	East Bay Hotel & Dining Room	Grand Marais		MN0020010	30	722100
7409	IGA Foodliner	Grand Marais		MN0020010	25	445100
7410	Cook County Clinic	Grand Marais	0.03	MN0020010	22	621100
7411	Edwin E Thoreson Inc	Grand Marais		MN0020010	20	237300
7412	Grand Marais St Bk	Grand Marais		MN0020010	15	522100
7413	Johnson's Foods	Grand Marais		MN0020010	13	445100
7414	North Shore Fed CU-Grand Marais	Grand Marais		MN0020010	10	522100
7415	Cook County State Bank	Grand Marais		MN0020010	8	522100
7416	Birch Terrace Supper Club	Grand Marais		MN0020010	5	722100
7417	Grand Meadow School Dist #495	Grand Meadow		MN0023558	80	611100
7418	Meadow Manor Nursing Home	Grand Meadow		MN0023558	60	623100
7419	Valley Transportation Svc	Grand Meadow		MN0023558	36	485200
7420	Grumpy's Restaurant & Lounge	Grand Meadow		MN0023558	22	722100
7421	Featherlite Graphics	Grand Meadow		MN0023558	20	811100
7422	Osmundson Brothers Quarry	Grand Meadow		MN0023558	20	212300
7423	Harvest States	Grand Meadow		MN0023558	11	325300
7424	Home Telephone Co	Grand Meadow		MN0023558	9	517100
7425	First Farmers & Merchants State Bank	Grand Meadow		MN0023558	8	522100
7426	Skjenke Bom Lounge	Grand Meadow		MN0023558	7	722100
7427	Glynn's Motor Mart	Grand Meadow		MN0023558	6	424900
7428	The Meadows (Assisted Living)	Grand Meadow		MN0023558	6	623900
7429	Helena Chemical Co	Grand Meadow		MN0023558	5	325300
7430	RJ Werner CPA	Grand Meadow		MN0023558	5	541200
7431	Stier Grocery	Grand Meadow		MN0023558	5	445100
7432	The Diner	Grand Meadow		MN0023558	5	722100
7433	UPM/Blandin Paper Company	Grand Rapids		MN0022080	900	322100
7434	MN Independent School District #318	Grand Rapids		MN0022080	600	611100
7435	Itasca Medical Ctr	Grand Rapids	0.25	MN0022080	386	622100
7436	Arrowhead Promotion	Grand Rapids		MN0022080	315	561900
7437	Itasca, County of	Grand Rapids	0.44	MN0022080	310	921100
7438	Wal-Mart	Grand Rapids		MN0022080	185	452100
7439	Grand Rapids Medical Assoc	Grand Rapids	0.11	MN0022080	171	622100
7440	Potlatch	Grand Rapids		MN0022080	162	322100
7441	All Season Vehicle	Grand Rapids		MN0022080	120	336900
7442	Itasca County Nursing Home	Grand Rapids		MN0022080	120	623100
7443	Target	Grand Rapids		MN0022080	120	452100
7444	Itasca Community College	Grand Rapids		MN0022080	106	611200
7445	K Mart	Grand Rapids		MN0022080	100	452100
7446	Northprint International Inc	Grand Rapids		MN0022080	100	323100
7447	MN Diversified Industries	Grand Rapids		MN0022080	80	339900
7448	Grand Rapids, City of	Grand Rapids	0.09	MN0022080	65	921100
7449	Itasca Clinic	Grand Rapids	0.09	MN0022080	63	621100
7450	Lake Country Power	Grand Rapids		MN0022080	47	221100
7451	North Homes, Inc	Grand Rapids		MN0022080	45	624200
7452	Herald Review	Grand Rapids		MN0022080	39	511100

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ID	Facility Name	City	P_kgd	Permit_No	employee_count	NAICS Code
7453	Timberline Manufacturing Inc	Grand Rapids		MN0022080	35	337100
7454	Full Circle Image	Grand Rapids		MN0022080	25	339900
7455	United Power Assn	Grand Rapids		MN0022080	19	221100
7456	Mesaba Aviation	Grand Rapids		MN0022080	18	481100
7457	Cole Forest Products Inc	Grand Rapids		MN0022080	15	423300
7458	Grey Owl Foods	Grand Rapids		MN0022080	13	445100
7459	Granite Falls Hospital & Manor	Granite Falls	0.15	MN0021211	235	622100
7460	Yellow Medicine East Schools-#2190	Granite Falls		MN0021211	210	611100
7461	Prairie's Edge Resort and Casino	Granite Falls		MN0021211	180	713200
7462	Fagen Inc	Granite Falls	0.00	MN0021211	85	236210
7463	Yellow Medicine, County of	Granite Falls	0.12	MN0021211	85	921100
7464	MN West Community & Tech College	Granite Falls		MN0021211	65	611500
7465	Project Turnabout Treatment Ctr	Granite Falls		MN0021211	60	621420
7466	Granite Falls, City of	Granite Falls	0.06	MN0021211	45	921100
7467	United Parcel Service	Granite Falls		MN0021211	45	488400
7468	Sunsource	Granite Falls		MN0021211	40	333600
7469	Marr Machines	Granite Falls	0.87	MN0021211	30	339100
7470	Affiliated Comm. Medical Ctr	Granite Falls	0.03	MN0021211	25	621100
7471	Specialty Systems	Granite Falls	0.28	MN0021211	25	333924
7472	Parr Piping	Granite Falls	0.06	MN0021211	24	332996
7473	Granite Fluid Power	Granite Falls	0.35	MN0021211	21	333995
7474	Minnesota Feed Distributors	Granite Falls		MN0021211	20	424900
7475	Grasston Co-op Feed Mill	Grasston		MNG580052	4	493100
7476	Greenbush Nursing Home	Greenbush		MN0044431	95	623100
7477	Greenbush Middle River School	Greenbush		MN0044431	92	611100
7478	Greenbush, City of	Greenbush	0.05	MN0044431	37	921100
7479	Central Boiler	Greenbush		MN0044431	35	332400
7480	Buffalo Bituminous	St. Paul		MN0029882	70	324100
7481	North American Inc	St. Paul		MN0029882	55	445100
7482	Rels Manufacturing	St. Paul		MN0029882	25	441100
7483	EPA Audio Visual	St. Paul		MN0029882	15	443100
7484	Coast to Coast	St. Paul		MN0029882	11	444100
7485	Greenworks Inc	St. Paul		MN0029882	11	561700
7486	Holiday Station	St. Paul		MN0029882	10	447100
7487	Pinnacle Construction Co	St. Paul		MN0029882	10	236100
7488	Rockford Texaco	St. Paul		MN0029882	10	447100
7489	Torgerson Well Co	St. Paul		MN0029882	8	237100
7490	Brinkman Accounting	St. Paul		MN0029882	5	541200
7491	Rockford Cabinet Shop	St. Paul		MN0029882	4	337100
7492	Buffie Chiropractic	St. Paul		MN0029882	3	621300
7493	Coffee Time & More Inc	St. Paul		MN0029882	3	722100
7494	American Hair Design	St. Paul	0.00	MN0029882	1	812100
7495	Country Clipper	St. Paul	0.00	MN0029882	1	812100
7496	Kittson Memorial Hospital	Hallock	0.10	MN0020729	150	622100
7497	Kittson, County of	Hallock	0.13	MN0020729	96	921100
7498	Hallock Public Schools-ISD #2171	Hallock		MN0020729	91	611100
7499	Johnson Oil Co	Hallock		MN0020729	38	424900
7500	Farmers Store of Hallock	Hallock		MN0020729	30	445100
7501	Northwestern St Bk of Hallock	Hallock		MN0020729	25	522100
7502	C&M Ford Sales	Hallock		MN0020729	19	811100
7503	Great Lakes Transmission	Hallock		MN0020729	15	486200
7504	Otter Tail Power Co	Hallock		MN0020729	15	221100
7505	Brink, Sobolik, Severson	Hallock		MN0020729	12	541100
7506	Western Implement	Hallock		MN0020729	12	423800
7507	Viking Gas Transmission	Hallock		MN0020729	7	486200
7508	American Federal Savings Bank	Hallock		MN0020729	6	522100
7509	Majestic Oaks			ISTS	250	713900
7510	Knapp Woodworking Inc			ISTS	190	337100
7511	New Market			ISTS	94	445100
7512	Telar Industries Inc			ISTS	75	332300
7513	Crosstown Masonry			ISTS	70	238100
7514	Oxboro Medical		0.04	ISTS	58	622100
7515	Professional Technologies			ISTS	51	326200
7516	Northwest Dairy Forwarding Co			ISTS	42	488400
7517	Halvorson Concrete Inc			ISTS	40	238100
7518	Electric Forklift Supply			ISTS	36	336900
7519	Blaine Heating Air Cond Inc			ISTS	35	238200
7520	Diamond Metal Products Inc		0.00	ISTS	35	332700

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ID	Facility Name	City	P_kgd	Permit_No	employee_count	NAICS Code
7521	Ham Lake Lanes & Lounge			ISTS	35	713900
7522	Crosstown St Bk of Ham Lake			ISTS	32	522100
7523	Illinois Fixture & Wood			ISTS	30	423300
7524	LaMachine Shop Inc			ISTS	30	333200
7525	Kenco Construction			ISTS	22	236100
7526	Rapid Sports Center			ISTS	20	451100
7527	Dahlquist Machine		0.00	ISTS	19	332700
7528	Safety Speed Cut		0.12	ISTS	18	332900
7529	Mueller & Sons Inc	Hamburg		MN0025585	100	237300
7530	State Bk of Hamburg	Hamburg		MN0025585	5	522100
7531	Waconia Farm Supply	Hamburg		MN0025585	5	424900
7532	Manthy Welding	Hamburg		MN0025585	1	811300
7533	Molded Foam Products	Hamburg		MN0025585	1	424600
7534	Hancock Concrete Products Inc	Hancock		MN0023582	75	327300
7535	Hancock Public Schools-Dist #768	Hancock		MN0023582	45	611100
7536	Hancock, City of	Hancock	0.05	MN0023582	35	921100
7537	Prairie Waivered Community Svcs	Hancock		MN0023582	35	623900
7538	Hancock Co-op Inc	Hancock		MN0023582	13	424900
7539	By-Lo Gas & Groceries	Hancock		MN0023582	8	445100
7540	1st American St Bk of MN	Hancock		MN0023582	6	522100
7541	Owl's Nest Cafe	Hancock		MN0023582	6	722100
7542	Hancock Equipment	Hancock		MN0023582	5	423800
7543	Jeppe's Happy Hour Bar	Hancock		MN0023582	5	445300
7544	US Post Office	Hancock		MN0023582	5	491100
7545	Another Man's Treasure	Hancock		MN0023582	3	453300
7546	Hancock Telephone Co	Hancock		MN0023582	3	517100
7547	Hancock Upholstery	Hancock		MN0023582	3	337100
7548	Riverside Express	Hancock		MN0023582	3	484200
7549	North Metro Landscaping Inc	Waverly		MN0021326	57	541300
7550	Diamond Tool Inc	Waverly	0.00	MN0021326	30	332700
7551	Burschville Construction Inc	Waverly		MN0021326	25	237100
7552	Spraungel Construction Inc	Waverly		MN0021326	23	238100
7553	Mik-Patti's Grill & Bar	Waverly		MN0021326	22	722100
7554	Haugen Lumber Co	Waverly		MN0021326	15	321900
7555	Tom Thumb	Waverly		MN0021326	12	445100
7556	Hilltop Bar	Waverly		MN0021326	11	722100
7557	Mavco Inc	Waverly		MN0021326	11	238900
7558	Miller Trucking & Landscape	Waverly		MN0021326	10	212300
7559	West Air Inc	Waverly		MN0021326	10	238200
7560	Roy C Inc	Waverly		MN0021326	9	443100
7561	CL Paulson & Associates Inc	Waverly		MN0021326	7	711300
7562	Len's Lawn Service	Waverly		MN0021326	5	561700
7563	Rockford State Bank - Hanover	Waverly		MN0021326	5	522100
7564	T&S Trucking Inc	Waverly	0.26	MN0021326	5	484100
7565	Caprice Woodcraft Inc	Waverly		MN0021326	4	444100
7566	Hanover Hardware	Waverly		MN0021326	4	444100
7567	Fillmore Central Schools	Harmony		MN0022322	145	611100
7568	Harmony/Gundersen Lutheran Health Care Facility	Harmony	0.05	MN0022322	70	622100
7569	Harmony Enterprises Inc	Harmony	0.00	MN0022322	50	332700
7570	Minnowa Construction	Harmony		MN0022322	50	237300
7571	Root River Education District	Harmony		MN0022322	24	611500
7572	Harmony Agri Services Inc	Harmony		MN0022322	20	424900
7573	Harmony IGA Store	Harmony		MN0022322	20	445100
7574	City of Harmony	Harmony	0.02	MN0022322	12	921100
7575	Bluff Country Coverings Inc	Harmony		MN0022322	10	314900
7576	Pederson Brothers	Harmony		MN0022322	10	212300
7577	Harmony Telephone Co	Harmony		MN0022322	8	517200
7578	Morem Electric, Inc.	Harmony		MN0022322	5	443100
7579	Dakota, County of	St. Paul		MN0029955	2034	921140
7581	School District 200	St. Paul		MN0029955	650	611110
7584	Wal-Mart	St. Paul		MN0029955	186	452112
7586	Hastings, City of	St. Paul		MN0029955	118	921140
7588	Cub Foods	St. Paul		MN0029955	105	445110
7589	Hayfield Window & Door Co	Hayfield		MN0023612	140	332300
7590	Hayfield Public School District	Hayfield		MN0023612	115	611100
7591	Field Crest Nursing Home	Hayfield		MN0023612	110	623100
7592	Innovative Food Processors, Inc	Hayfield	1.22	MN0023612	54	311400
7593	Huntting Elevator Co	Hayfield	0.23	MN0023612	23	311200

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ID	Facility Name	City	P_kgd	Permit_No	employee_count	NAICS Code
7594	Citizens State Bank	Hayfield		MN0023612	18	522100
7595	Century Plastics	Hayfield	0.02	MN0023612	10	326100
7596	VIVO	Hayfield	0.01	MN0023612	7	334500
7597	Central Co-op	Hayfield		MN0023612	6	424600
7599	Hemenway Ironworks		0.00	ISTS	18	332700
7600	Hayward Machinery			ISTS	10	333200
7601	Farmers Elevator			ISTS	8	493100
7602	Nick's Grocery			ISTS	7	445100
7603	Crop Mate			ISTS	4	325300
7604	Americana Natl Bank			ISTS	2	522100
7605	Suttle Apparatus Corp	Hector		MN0025445	180	334200
7606	Buffalo Lake-Hector Schools	Hector		MN0025445	80	611100
7607	United Grain and Energy - Hector	Hector		MN0025445	54	424900
7608	Loftness Farm Equipment Inc	Hector		MN0025445	40	423800
7609	Olinger Trucking Inc.	Hector	1.29	MN0025445	25	484100
7610	Communications Systems Inc	Hector		MN0025445	20	517100
7611	Ralph-Larson Chevrolet	Hector		MN0025445	20	441100
7612	Prairie View	Hector		MN0025445	18	623300
7613	Interstate Telcom Consulting Inc	Hector		MN0025445	17	517100
7614	United Grain & Energy Convenience Store	Hector		MN0025445	16	447100
7615	Rural American Bank	Hector		MN0025445	9	522100
7616	Cenex/LOL Agronomy	Hector		MN0025445	8	115100
7617	City of Hector	Hector	0.01	MN0025445	8	921100
7618	Hendricks Hospital/Nursing Home	Hendricks	0.10	MN0021121	160	622100
7619	Hendricks Public Schools	Hendricks		MN0021121	40	611100
7620	NB Golf Carts	Hendricks		MN0021121	16	451100
7621	Hendricks Clinic	Hendricks	0.02	MN0021121	14	621100
7622	Kirkvold Oil Co	Hendricks		MN0021121	13	424900
7623	Larson Food	Hendricks		MN0021121	12	445100
7624	Hendricks Assembly Co	Hendricks		MN0021121	7	334400
7625	First Security Bk Hendricks	Hendricks		MN0021121	6	521100
7626	Gilbert Machinery & Salvage Inc	Hendricks		MN0021121	6	424900
7627	Hendricks Farmers Elevator	Hendricks		MN0021121	5	493100
7628	Hendricks Farmers Lumber	Hendricks		MN0021121	5	444100
7629	Norman County West Public Schools	Hendrum		MN0021644	43	611100
7630	Nepstad Oil Co	Hendrum		MN0021644	8	424900
7631	Viking Bk	Hendrum		MN0021644	6	522100
7632	Cenex	Hendrum		MN0021644	3	325300
7633	Hendrum Elevator	Hendrum		MN0021644	3	493100
7634	Hendrum, City of	Hendrum	0.00	MN0021644	3	921100
7635	Immanuel Lutheran Church	Hendrum		MN0021644	3	813100
7636	Schnabel Insurance	Hendrum		MN0021644	3	524100
7637	Simplot	Hendrum		MN0021644	3	325300
7638	Community Pride Publications	Hendrum		MN0021644	2	511100
7639	Hendrum Standard	Hendrum		MN0021644	2	447100
7640	Jyl's Diner	Hendrum		MN0021644	2	722100
7641	Last Chance Saloon	Hendrum		MN0021644	2	722400
7642	US Post Office	Hendrum		MN0021644	2	491100
7643	Hellerud-Larson Law Office	Hendrum		MN0021644	1	541100
7644	Joanne's Hairstyling	Hendrum	0.00	MN0021644	1	812100
7645	Norman Co. Abstracting/Accounting	Hendrum		MN0021644	1	541200
7646	Opheim & Rantala Law Office	Hendrum		MN0021644	1	541100
7647	Rowell Family Chiropractic	Hendrum		MN0021644	1	621300
7648	Henning Health Care	Henning		MN0041131	82	623100
7649	Henning Public School	Henning		MN0041131	60	611100
7650	Henning Hatchery, Jenny-O	Henning		MN0041131	35	112300
7651	First NB of Henning	Henning		MN0041131	22	522100
7652	Earl B Olson	Henning	1.13	MN0041131	20	311600
7653	Future Products	Henning		MN0041131	18	315200
7654	North American Crop Underwriters Inc	Henning		MN0041131	13	524100
7655	Mid-Central Equipment	Henning		MN0041131	11	333200
7656	Pro-Ag Farmers Coop	Henning		MN0041131	8	424900
7657	Cenex	Henning		MN0041131	6	424900
7658	C & C Outfitters	Henning		MN0041131	3	451100
7659	Hermantown Public Schools	Duluth		MN0049786	250	611100
7660	Menards	Duluth		MN0049786	154	444100
7661	Wal-Mart	Duluth		MN0049786	150	452100
7662	Sam's Club	Duluth		MN0049786	142	452100

Appendix B. Industrial Phosphorus Data Matched to MNPRO Database by NAICS

ID	Facility Name	City	P_kgd	Permit_No	employee_count	NAICS Code
7663	Natural Resource & Research Institute	Duluth	75.54	MN0049786	140	541700
7664	Curtis Oil & Tire	Duluth		MN0049786	120	811100
7665	Eggebrecht Chevrolet Geo	Duluth		MN0049786	70	441100
7666	Knox Lumber Co	Duluth		MN0049786	50	444100
7667	Arrowhead Concrete Works Inc	Duluth		MN0049786	25	327300
7668	Duluth Dodge Oldsmobile	Duluth		MN0049786	20	441100
7669	Hibbing Taconite Co	Hibbing		MN0030643	780	212200
7670	Reptron	Hibbing		MN0030643	603	334400
7671	University Regional Medical Ctr - Mesabi	Hibbing	0.35	MN0030643	540	622100
7672	Hibbing Public Schools-ISD #701	Hibbing		MN0030643	425	611100
7673	Hibbing Community College	Hibbing		MN0030643	200	611200
7674	L&M Radiator Inc	Hibbing		MN0030643	186	332300
7675	Leisure Hills	Hibbing		MN0030643	176	623100
7676	SMDC-Duluth Clinic - Hibbing	Hibbing	0.19	MN0030643	140	621100
7677	Fairview - Mesaba Clinic	Hibbing	0.17	MN0030643	125	621100
7678	Golden Crest Nursing Home	Hibbing		MN0030643	118	623100
7679	Intermet Hibbing Foundary	Hibbing		MN0030643	103	333200
7680	Manney's Shopper Inc	Hibbing		MN0030643	100	511100
7681	Hibbing Public Utilities Comm	Hibbing		MN0030643	83	221100
7682	Ameripride	Hibbing		MN0030643	65	812300
7683	Industrial Rubber	Hibbing		MN0030643	60	326200
7684	DMR Electronics	Hibbing		MN0030643	49	334400
7685	Dom-Ex	Hibbing		MN0030643	48	423800
7686	Daily Tribune	Hibbing		MN0030643	42	511100
7687	Barr Engineering	Hibbing		MN0030643	40	541300
7688	Taconite Engineering	Hibbing		MN0030643	36	541300
7690	Grand Casino Inc	Hinckley		MN0023701	1730	713200
7691	Tobie's Restaurant	Hinckley		MN0023701	198	722100
7692	Hinckley-Finlayson Public Schools	Hinckley		MN0023701	165	611100
7693	Cassidy's Restaurant	Hinckley		MN0023701	65	722100
7694	Burger King	Hinckley		MN0023701	47	722100
7695	Daggett's Super Valu	Hinckley		MN0023701	40	445100
7696	Hardee's	Hinckley		MN0023701	30	722100
7697	Brokema Beltway	Hinckley		MN0023701	18	326200
7698	Bernicks Distribution	Hinckley		MN0023701	10	424800
7699	Good Samaritan Center	Hoffman		MN0021199	77	623100
7700	Hoffman Aseptic Packaging Co	Hoffman	1.35	MN0021199	60	311400
7701	Hoffman Co-op Oil Assn	Hoffman		MN0021199	24	424900
7702	Runestone Telephone Assn	Hoffman		MN0021199	19	517100
7703	Grant County DAC	Hoffman		MN0021199	16	624300
7704	Farmers St Bk of Hoffman	Hoffman		MN0021199	10	522100
7705	Arnquist Home Center	Hoffman		MN0021199	9	442100
7706	Hoffman Lumber Company	Hoffman		MN0021199	9	444100
7707	Ron's Supermarket	Hoffman		MN0021199	8	445100
7708	Hoffman Co-op Grain Assn	Hoffman		MN0021199	5	493100
7709	Western Consolidated Cooperative	Appleton	0.14	MN0023728	25	424510
7710	City of Holloway	Appleton		MN0023728	4	921190
7711	Holloway Cafe	Appleton		MN0023728	3	722110
7712	SUPERVALU Minneapolis Div	St. Paul		MN0029815	1540	424410
7713	NAPCO International Inc	St. Paul		MN0029815	900	333600
7714	Thermotech	St. Paul		MN0029815	325	334200
7715	Sungard Financial Systems	St. Paul		MN0029815	150	518200
7716	Magstar Technologies	St. Paul		MN0029815	115	481100
7717	Parts Plus/Kunz Oil	St. Paul		MN0029815	90	211100
7718	Rainbow Foods	St. Paul		MN0029815	78	445100
7719	Edco Products Inc	St. Paul		MN0029815	60	453200
7720	Ace Communications Group	Houston		MN0023736	80	517100
7721	Valley View Nursing Home	Houston		MN0023736	75	623100
7722	Houston Public Schools	Houston		MN0023736	70	611100
7723	Fortress Bank N.A.	Houston		MN0023736	16	522100
7724	Houston, City of	Houston	0.02	MN0023736	14	921100
7725	Root River Market Cooperative	Houston		MN0023736	13	445100
7726	High Plains Cenex	Houston		MN0023736	12	424900
7727	Houston Dental Clinic	Houston		MN0023736	12	621200
7728	Bluff Country Financial Services	Houston		MN0023736	10	541200
7729	Farmers Coop Elevator	Houston		MN0023736	8	493100
7730	Hoskins Electric	Houston		MN0023736	8	238200
7731	Houston County Recycling	Houston		MN0023736	8	562100

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ID	Facility Name	City	P_kgd	Permit_No	employee_count	NAICS Code
7732	Valley Veterinary Clinic	Houston		MN0023736	6	541900
7733	Texaco-Houston Food Mart	Houston		MN0023736	5	447100
7734	Dura Supreme Inc	Howard Lake		MN0051926	300	337100
7735	Gage Letter Shop	Howard Lake		MN0051926	175	561400
7736	Howard Lake School Dist. #880	Howard Lake		MN0051926	130	611100
7737	Howard Lake Care Ctr Inc	Howard Lake		MN0051926	80	623100
7738	Munson Feed Co	Howard Lake		MN0051926	30	424900
7739	Gerry's Super Valu	Howard Lake		MN0051926	25	445100
7740	American Feeds	Howard Lake		MN0051926	20	424900
7741	Innocast Bronze	Howard Lake	0.14	MN0051926	20	332900
7742	Howard Lake, City of	Howard Lake	0.02	MN0051926	14	921100
7743	Stonstegard Foods	Howard Lake		MN0051926	7	424400
7744	Minnesota Power/Syl Laskin	Hoyt Lakes		MN0020206	40	221100
7745	County Inn & Suites	Hoyt Lakes		MN0020206	20	721100
7746	Floe Manufacturing	Hoyt Lakes	0.00	MN0020206	15	332700
7747	Belcorp	Hoyt Lakes		MN0020206	13	238900
7748	Mesabi Drug/Ben Franklin	Hoyt Lakes		MN0020206	13	446100
7749	Hoyt Lakes IGA	Hoyt Lakes		MN0020206	10	445100
7750	Wilson Tool	St. Paul	0.00	MN0029815	520	332700
7751	Schweiters Properties	St. Paul		MN0029815	190	321200
7752	American Structural Metal, Inc.	St. Paul		MN0029815	40	331500
7753	Glamos Wire	St. Paul		MN0029815	40	332600
7754	Granger's, Inc.	St. Paul		MN0029815	30	424900
7756	Industrial Painting	St. Paul		MN0029815	20	325500
7757	Como Lube	St. Paul		MN0029815	15	424700
7760	Hutchinson Area Health Care	Hutchinson	0.43	MN0055832	667	622100
7761	Hutchinson Schools - ISD 423	Hutchinson		MN0055832	423	611100
7762	Wal-Mart	Hutchinson		MN0055832	400	452100
7763	Cash Wise Foods	Hutchinson		MN0055832	240	445100
7764	Hutchinson Utilities Commission	Hutchinson		MN0055832	219	221100
7765	Target	Hutchinson		MN0055832	160	452100
7766	Menards	Hutchinson		MN0055832	147	423700
7767	Hutchinson Medical Ctr	Hutchinson	0.19	MN0055832	140	621100
7768	Goebel Fixture Co	Hutchinson		MN0055832	130	321900
7769	Hutchinson Mfg Sales Inc	Hutchinson	0.00	MN0055832	110	332700
7770	Shopko	Hutchinson		MN0055832	110	452100
7771	City of Hutchinson	Hutchinson	0.14	MN0055832	101	921100
7772	More 4 / Econo Foods	Hutchinson		MN0055832	100	445100
7773	Ag Systems Inc	Hutchinson		MN0055832	75	423800
7774	K Mart	Hutchinson		MN0055832	75	452100
7775	Hutchinson Telephone Co	Hutchinson		MN0055832	70	517100
7776	Applebee's Neighborhood Grill	Hutchinson		MN0055832	63	722100
7777	Burger King	Hutchinson		MN0055832	53	722100
7778	Hutchinson Auto Center	Hutchinson		MN0055832	50	441200
7779	McDonald's	Hutchinson		MN0055832	45	722100
7780	Impressions	Hutchinson		MN0055832	44	339900
7781	Provesta Flavor Ingredients	Hutchinson	2.05	MN0055832	44	311400
7782	Hillyard Floor Care-Supply Company	Hutchinson		MN0055832	43	424600
7783	Hardee's	Hutchinson		MN0055832	40	722100
7784	Haugen Furniture	Hutchinson		MN0055832	40	442100
7785	Lamplighter Lounge	Hutchinson		MN0055832	35	722100
7786	New Dimension Plating	Hutchinson	0.39	MN0055832	35	332800
7787	United States Post Office	Hutchinson		MN0055832	34	491100
7788	Hutchinson Leader	Hutchinson		MN0055832	31	511100
7789	American Energy Systems, Inc.	Hutchinson		MN0055832	30	339900
7790	Richard Larson Builders / ABC Seamless Siding	Hutchinson		MN0055832	30	236200
7791	Crow River Press Inc	Hutchinson		MN0055832	28	511100
7793	International Falls School Dist #361	International Falls		MN0020257	305	611110
7794	United Health Care	International Falls		MN0020257	300	524298
7795	Falls Memorial Hospital	International Falls	0.19	MN0020257	160	622110
7796	Koochiching, County of	International Falls		MN0020257	120	921190
7797	International Bildrite Inc	International Falls	0.30	MN0020257	64	322130
7798	Rainy River Comm College	International Falls	0.62	MN0020257	56	611310
7799	International Falls, City of	International Falls		MN0020257	55	921190
7800	Duluth Clinic - Int' Falls	International Falls		MN0020257	50	621111
7801	Ric Jig Tackle	International Falls		MN0020257	50	339920
7802	Shannon's Plumbing & Heating	International Falls		MN0020257	50	238220
7803	Daily Journal	International Falls	0.05	MN0020257	40	511110

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ID	Facility Name	City	P_kgd	Permit_No	employee_count	NAICS Code
7804	Bergstrom Wood Products Inc	International Falls		MN0020257	25	321920
7805	Wagner Construction Inc	International Falls	0.02	MN0020257	20	238910
7806	Coca Cola Bottling	International Falls	0.46	MN0020257	16	312111
7807	Mannco Trucking	International Falls	0.01	MN0020257	16	238910
7808	Wenberg Transfer	International Falls		MN0020257	13	484121
7809	CHS Cooperatives	St. Paul		MN0029815	900	325300
7810	Inver Grove Hts School District #199	St. Paul		MN0029815	458	611100
7812	Evergreen Industries	St. Paul		MN0029815	300	444100
7813	Inver Hills Community College	St. Paul		MN0029815	300	611300
7814	BFI Waste Services	St. Paul		MN0029815	140	562100
7815	Southview Chevrolet	St. Paul		MN0029815	138	441100
7816	Inver Grove Heights, City of	St. Paul	0.18	MN0029815	130	921100
7817	Inver Grove Ford	St. Paul		MN0029815	100	441100
7818	Lofton Label Inc	St. Paul		MN0029815	100	322100
7819	Kerasotes Theater	St. Paul		MN0029815	90	512100
7820	Outback Steakhouse	St. Paul		MN0029815	81	722100
7821	Damon's of Minnesota	St. Paul		MN0029815	75	722100
7822	Applebee's Neighborhood Grill	St. Paul		MN0029815	60	722100
7823	Bituminous Roadways Inc	St. Paul		MN0029815	40	237300
7824	Divine Providence Community Home	Ivanhoe		MN0023825	152	623300
7825	Lincoln, County of	Ivanhoe	0.09	MN0023825	65	921100
7826	Lincoln HI Public Schools	Ivanhoe		MN0023825	55	611100
7827	USDA- Lincoln County Office	Ivanhoe		MN0023825	15	115100
7828	Lyon County Coop	Ivanhoe		MN0023825	8	424900
7829	AGCO-Ag Chem Division	Jackson		MNG580063	900	423800
7830	Core Source	Jackson		MNG580063	180	524100
7831	Technical Services-Electronics	Jackson		MNG580063	144	425100
7832	Jackson County Central Schools	Jackson		MNG580063	129	611100
7833	Good Samaritan Ctr	Jackson		MNG580063	101	623100
7834	Best Western Country Manor Inn	Jackson		MNG580063	93	721100
7835	Jackson Medical Center	Jackson	0.05	MNG580063	80	622100
7836	New Fashion Pork	Jackson		MNG580063	70	112200
7837	Accent Insurance Recovery Solutions	Jackson		MNG580063	50	524100
7838	Erickson Trucks 'n Parts	Jackson	3.48	MNG580063	46	336200
7839	Kema-Asa Auto Plaza	Jackson		MNG580063	43	441100
7840	Ag Forte, LLC	Jackson		MNG580063	40	112300
7841	Vet's Oil Co	Jackson		MNG580063	40	454300
7842	Livewire Printing Co	Jackson		MNG580063	38	323100
7843	Pioneer HI-Bred Intl	Jackson		MNG580063	33	424900
7844	B&H Manufacturing Inc	Jackson		MNG580063	32	423800
7845	Farmers Co-op Assn	Jackson		MNG580063	28	424900
7846	Janesville-Waldorf-Pemberton Schools	Janesville		MNG580025	100	611110
7847	Janesville Nursing Home	Janesville		MNG580025	60	623110
7848	Southern Valley Co-op/Cenex	Janesville		MNG580025	30	447110
7849	Trinity Lutheran School	Janesville		MNG580025	29	611110
7850	Morton Building Inc	Janesville	0.00	MNG580025	25	236210
7851	Janesville St Bk	Janesville		MNG580025	14	522110
7852	Dill Company	Janesville		MNG580025	11	493130
7853	Janesville Elevator Construction Inc	Janesville		MNG580025	11	493110
7854	Pipestone-Jasper Elementary School	Jasper		MNG580026	30	611100
7855	Jasper Farmers Elevator	Jasper		MNG580026	17	493100
7856	Jasper Mini-Mall	Jasper	0.00	MNG580026	12	445200
7857	Jasper St Bk	Jasper		MNG580026	12	522100
7858	Rodman Welding & Mfg Inc	Jasper	0.06	MNG580026	8	332900
7859	Three Straw Cafe	Jasper		MNG580026	8	722100
7860	Jasper Foods	Jasper		MNG580026	7	445100
7861	Jasper Lanes & Recreation	Jasper		MNG580026	6	713900
7862	Jasper Stone Company	Jasper		MNG580026	5	327900
7863	Pipestone Embroidery	Jasper		MNG580026	5	451100
7864	Hi-Fat Specialities Co Inc	Jasper		MNG580026	3	311100
7865	Jasper, City of	Jasper	0.00	MNG580026	2	921100
7866	Jordan Public School District #717	Jordan		MN0020869	154	611100
7867	Valley Plumbing Inc	Jordan		MN0020869	140	238200
7868	SM Hentges & Sons Inc	Jordan		MN0020869	130	237300
7869	Minnesota Valley Electric Coop	Jordan		MN0020869	97	221100
7870	Dyna-Fab Inc	Jordan	0.00	MN0020869	75	332700
7871	OK Corral Inc	Jordan		MN0020869	72	722100
7872	Theradyne Corp	Jordan	0.05	MN0020869	60	334500

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ID	Facility Name	City	P_kgd	Permit_No	employee_count	NAICS Code
7873	Radermacher Super Valu	Jordan		MN0020869	55	445100
7874	US Transformer Inc	Jordan		MN0020869	50	335300
7875	Wolf Motors Ford	Jordan		MN0020869	50	441100
7876	RBE Electronics Inc	Jordan	0.03	MN0020869	37	334500
7877	Mc Donalds	Jordan		MN0020869	35	722100
7878	Community Bank Minnesota Valley	Jordan		MN0020869	34	522100
7879	Engel Diversified Industries	Jordan	0.00	MN0020869	30	332700
7880	Valleyview Board & Lodge	Jordan		MN0020869	28	721100
7881	Siwek Lumber & Millwork	Jordan		MN0020869	25	444100
7882	Valley Bank MN	Jordan		MN0020869	24	522100
7883	Continental Lift Truck	Jordan		MN0020869	20	336900
7884	Cedar Ridge Arabians	Jordan		MN0020869	15	112900
7885	Burger King	Jordan		MN0020869	14	722100
7886	Jordan Texaco	Jordan		MN0020869	10	447100
7887	Kasson-Mantorville Public Schools	Kasson		MN0050725	200	611100
7888	Erdman Supermarket Inc	Kasson		MN0050725	90	445100
7889	Swenke CO	Kasson		MN0050725	50	238900
7890	Images On Metal	Kasson	0.09	MN0050725	44	333500
7891	Kasson-Mayo Family Practice	Kasson	0.05	MN0050725	35	621100
7892	Kasson, City of	Kasson	0.04	MN0050725	27	921100
7893	Kasson State Bank	Kasson		MN0050725	24	522100
7894	Daniel's Restaurant	Kasson		MN0050725	21	722100
7895	Hiawathaland Tool Inc Plastic	Kasson	0.02	MN0050725	21	325200
7896	Burger King	Kasson		MN0050725	20	722100
7897	Kasson Lumber CO	Kasson		MN0050725	20	444100
7898	Tri-Star Manufacturing	Kasson	0.02	MN0050725	12	333500
7899	Eastwood State Bank	Kasson		MN0050725	6	522100
7900	National Steel Pellet Co	Keewatin	3.26	MN0022012	461	331100
7901	Iron Range Raceway	Keewatin		MN0022012	16	711200
7902	Tackle Tamer Products Inc	Keewatin	0.00	MN0022012	5	325200
7903	Kelliher Public School	Kelliher		MNG580068	55	611100
7904	Kelliher Care Center	Kelliher		MNG580068	40	623100
7905	Erickson Mills	Kelliher		MNG580068	15	321100
7906	Thor's Bar/Bradley's Cafe	Kelliher		MNG580068	14	722400
7907	Village One Stop	Kelliher		MNG580068	13	445100
7908	Citizens St Bank of Kelliher	Kelliher		MNG580068	7	521100
7909	Kelliher, City of	Kelliher	0.01	MNG580068	7	921100
7910	Kelliher Shopping Center	Kelliher		MNG580068	4	445100
7911	Kelliher Auto Sales	Kelliher		MNG580068	3	441100
7912	Skoe Logging	Kelliher		MNG580068	3	113300
7913	Beck Lumber Co	Kelliher		MNG580068	2	444100
7914	Log Cabin Crafts	Kelliher		MNG580068	2	453200
7915	Nelson Car Wash/Laundromat	Kelliher		MNG580068	2	811100
7916	Kelliher Looks	Kelliher	0.00	MNG580068	1	812100
7917	Kittson Central School	Kennedy		MNG580028	35	611100
7918	Urbaniak Implement	Kennedy		MNG580028	22	423800
7919	VFW Post 3828	Kennedy		MNG580028	10	813400
7920	Bowman Industries	Kennedy		MNG580028	8	339900
7921	Harvest States	Kennedy		MNG580028	7	493100
7922	Petersburg Chevrolet	Kennedy		MNG580028	4	441100
7923	Foldcraft-Plymold Co.	Kenyon		MN0021628	200	339900
7924	I.S.D. No. 2172	Kenyon		MN0021628	119	611100
7925	Kenyon Sunest Home	Kenyon		MN0021628	89	623300
7926	City of Kenyon	Kenyon	0.05	MN0021628	38	921100
7927	Peterson FordCo.	Kenyon		MN0021628	29	441200
7928	Security State Bank	Kenyon		MN0021628	24	522100
7929	KMS School Dist. #775	Kerkhoven		MN0020583	79	611110
7930	Carlson Manufacturing	Kerkhoven	0.55	MN0020583	32	332999
7931	Crop Production Service	Kerkhoven		MN0020583	25	115112
7932	Rustad Bus Service	Kerkhoven		MN0020583	20	485510
7933	Glacial Plains Cooperative	Kerkhoven	0.03	MN0020583	5	424510
7934	USC Public Schools	Kiester		MN0039721	41	611100
7935	Kiester Implement	Kiester		MN0039721	14	424900
7936	Kiester Grain & Feed	Kiester		MN0039721	6	493100
7937	Kinbrae Supper Club			ISTS	10	722100
7938	Apple Growers	La Crescent		MN0020621	300	111300
7939	La Crescent School Dist #300	La Crescent		MN0020621	193	611100
7940	Winona Knits	La Crescent		MN0020621	118	315100

Appendix B. Industrial Phosphorus Data Matched to MNPRO Database by NAICS

ID	Facility Name	City	P_kgd	Permit_No	employee_count	NAICS Code
7941	La Crescent Health Care Center	La Crescent		MN0020621	100	623100
7942	Truss Specialists Inc	La Crescent		MN0020621	100	444100
7943	Houston County Group Homes	La Crescent		MN0020621	80	623900
7944	Ready Bus Line Company	La Crescent		MN0020621	55	485500
7945	Hardee's	La Crescent		MN0020621	42	722100
7946	Bauer's Market & Nursery	La Crescent		MN0020621	35	444200
7947	Voss & Sons Construction	La Crescent		MN0020621	23	236100
7948	La Crescent St Bk	La Crescent		MN0020621	19	522100
7949	Corky's Pizza & Ice Cream	La Crescent		MN0020621	15	722100
7950	Wieser Precast/Doric Vaults	La Crescent		MN0020621	12	327300
7951	Subway	La Crescent		MN0020621	11	722100
7952	Franciscan Skemp Healthcare	La Crescent	0.01	MN0020621	8	621100
7953	Lake Benton Public School	Lake Benton		MN0023884	45	611100
7954	Veire's Farm & Home	Lake Benton		MN0023884	20	424900
7955	Country House	Lake Benton		MN0023884	18	722100
7956	Lincoln-Pipestone Rural Water	Lake Benton		MN0023884	11	221300
7957	Presbyterian Family Foundation, Inc.	Lake Benton		MN0023884	11	621400
7958	City of Lake Benton	Lake Benton	0.01	MN0023884	10	921100
7959	Lake Benton Farmers Elevator	Lake Benton		MN0023884	10	424900
7960	Zond Maintenance Corp.	Lake Benton		MN0023884	10	562100
7961	Journal Printing Co.	Lake Benton		MN0023884	7	323100
7962	First Security Bank	Lake Benton		MN0023884	6	522100
7964	Hearth Technologies	Lake City		MN0020664	409	333400
7965	Lake City Medical Center - Mayo Health System	Lake City	0.21	MN0020664	319	622100
7966	Lake City Schools-ISD#813	Lake City		MN0020664	180	611100
7967	Valley Craft Inc	Lake City		MN0020664	150	337200
7968	Lake City, City of	Lake City	0.20	MN0020664	140	921100
7969	Wild Wings Inc	Lake City		MN0020664	100	323100
7970	Fiesta Foods	Lake City		MN0020664	82	445100
7971	J&B Pallet Recycling Inc	Lake City		MN0020664	39	321900
7972	Horizon Milling	Lake City	7.67	MN0020664	37	311200
7973	Ag Partners	Lake City		MN0020664	32	424900
7974	Burger King	Lake City		MN0020664	30	722200
7975	Pepin Mfg Inc	Lake City		MN0020664	27	333200
7976	American Bk Lake City	Lake City		MN0020664	25	522100
7977	Acrotech Inc	Lake City	0.02	MN0020664	22	325200
7978	Pepin Heights Orchard Inc	Lake City		MN0020664	22	111300
7979	Lake City Federal Savings and Loan Association	Lake City		MN0020664	17	522100
7980	Haas Woodworks	Lake City		MN0020664	16	337100
7981	Land O'Lakes Inc	Lake City	0.94	MN0020664	15	311500
7982	Engineering Laboratory Design	Lake City	0.35	MN0020664	12	339100
7983	Automation Services, Inc.	Lake City	0.01	MN0020664	9	335900
7984	Duncan's Inc/Even Par Enterprises Inc	Lake City		MN0020664	2	339900
7985	Sunnyside Nursing Home	Lake Park		MN0023892	89	623100
7987	Colonial Manor Nursing Home	Lakefield		MN0020427	72	621400
7988	Lakefield Public Schools-ISD #325	Lakefield		MN0020427	59	611100
7989	Hussong Manufacturing, Inc.	Lakefield		MN0020427	48	333400
7990	Hage Oil Co	Lakefield		MN0020427	25	424900
7991	Co-op Agriculture Ctr	Lakefield		MN0020427	20	424900
7992	Hi-Lo Club	Lakefield		MN0020427	20	722100
7993	Habilitative Services	Lakefield		MN0020427	16	621400
7994	Mosley Sheet Metal & Plumbing	Lakefield		MN0020427	13	238200
7995	Immanuel Lutheran School	Lakefield		MN0020427	12	611100
7996	Doman-Rose	Lakefield		MN0020427	6	621400
7997	Shiely Company			ISTS	10	212300
7998	Lakeville Public School District #194	St. Paul		MN0030007	1120	611100
8003	Belzer's Chev-Dodge-KIA	St. Paul		MN0030007	160	441100
8004	Rosemount Office Systems Inc	St. Paul		MN0030007	155	337200
8005	Hearth and Home Technologies	St. Paul	1.05	MN0030007	153	332900
8006	Carquest Distribution Ctr	St. Paul		MN0030007	130	336300
8007	National Polymers Inc	St. Paul	0.10	MN0030007	125	325200
8009	Imperial Plastics Inc	St. Paul	0.09	MN0030007	115	325200
8010	Rexam Flexible & Medical Pkg	St. Paul	0.19	MN0030007	113	326100
8011	J&E Mfg CO	St. Paul	0.48	MN0030007	91	541700
8012	New Morning Windows	St. Paul		MN0030007	80	444100
8013	Performance Computer Forms	St. Paul		MN0030007	75	323100
8014	Stampings of Minnesota Inc	St. Paul	0.36	MN0030007	68	541700
8015	Goodwill/Easter Seal	St. Paul		MN0029815	235	453300

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ID	Facility Name	City	P_kgd	Permit_No	employee_count	NAICS Code
8016	Twin City Die Castings Co	St. Paul		MN0029815	200	331500
8017	Luther Seminary	St. Paul		MN0029815	165	611500
8018	Bolger Publications & Printing	St. Paul		MN0029815	110	511100
8019	Univ of MN Academic Computing Ctr	St. Paul		MN0029815	85	611300
8020	Newmech	St. Paul		MN0029815	80	238900
8021	Midwest Editions	St. Paul		MN0029815	50	323100
8022	MG Mc Grath Inc	St. Paul	0.24	MN0029815	35	332900
8023	Children's Home Society	St. Paul		MN0029815	34	624200
8024	International Operating Engineers	St. Paul	0.04	MN0029815	15	813900
8025	JAL Amoco	St. Paul		MN0029815	13	447100
8026	Superamerica	St. Paul		MN0029815	12	447100
8027	Seraphim Communications	St. Paul		MN0029815	8	515200
8028	Lauderdale Hollows	St. Paul		MN0029815	7	531100
8029	City Gables	St. Paul		MN0029815	5	531100
8030	Lauderdale, City of	St. Paul	0.01	MN0029815	5	921100
8031	Twin City Chinese Christian Church	St. Paul		MN0029815	4	813100
8032	Western Remodeling	St. Paul		MN0029815	4	236100
8033	Rapit Printing	St. Paul		MN0029815	3	323100
8034	Rose Hill Investments	St. Paul		MN0029815	2	531100
8036	Central Health Care Inc	Le Center		MN0023931	100	623100
8037	Le Sueur, County of	Le Center	0.14	MN0023931	100	921100
8038	Royal American Foods	Le Center		MN0023931	70	311800
8039	Fiberglass Fabrications	Le Center		MN0023931	47	332300
8040	European Roasterie	Le Center	0.78	MN0023931	40	311900
8041	Armar Corp	Le Center		MN0023931	34	337100
8042	Hwy Ag Services	Le Center		MN0023931	30	115100
8043	Golden Eye Products	Le Center		MN0023931	28	339900
8044	Throlson & Associates	Le Center		MN0023931	12	511100
8045	Camas Inc	Le Center	0.45	MN0023931	8	311600
8046	Rainbow Woodworks	Le Center		MN0023931	8	337100
8047	LeRoy Products Corp.	Le Roy		MN0021041	128	339900
8048	LeRoy-Ostrander Public Schools	Le Roy		MN0021041	75	611100
8049	Watt's on First	Le Roy		MN0021041	25	722100
8050	First State Bank	Le Roy		MN0021041	24	522100
8051	Hanson Tire	Le Roy		MN0021041	23	326200
8052	LeRoy Iron & Metal	Le Roy	0.12	MN0021041	18	332900
8053	LeRoy Cooperative	Le Roy		MN0021041	15	424900
8054	Isenberg Equipment	Le Roy		MN0021041	11	423800
8055	LeRoy Ampride/Coop Oil	Le Roy		MN0021041	11	424900
8056	Amoco Food Shop	Le Roy		MN0021041	10	453900
8057	Agriliance	Le Roy		MN0021041	9	325300
8058	Brownlow's Red Owl	Le Roy		MN0021041	9	445100
8059	Le Sueur Inc	Le Sueur		MN0022152	640	331500
8060	Minnesota Valley Health Ctr	Le Sueur		MN0022152	185	623100
8061	Le Sueur/Henderson Schools	Le Sueur		MN0022152	175	611100
8062	Davisco International, Inc.	Le Sueur	7.49	MN0022152	120	311500
8063	M. G. Waldbaum Inc	Le Sueur		MN0022152	110	112300
8064	Doane Pet Care	Le Sueur		MN0022152	55	311100
8065	Unimin Corp	Le Sueur		MN0022152	50	212300
8066	General Mills Ag Research	Le Sueur	1.39	MN0022152	30	311400
8067	Technipac, Inc	Le Sueur		MN0022152	28	561900
8068	Bimeda, Inc.	Le Sueur		MN0022152	26	325400
8069	It Takes Two	Le Sueur		MN0022152	23	424100
8070	Distel Grain	Le Sueur		MN0022152	21	423800
8071	Le Sueur Publishing	Le Sueur		MN0022152	21	511100
8072	MicroStore	Le Sueur		MN0022152	21	541500
8073	Seaver Companies	Le Sueur		MN0022152	21	446100
8074	Le Sueur Farmers Elevator	Le Sueur		MN0022152	15	424500
8075	Mobilcrete Inc	Le Sueur		MN0022152	15	238100
8076	Johnson Aggregates	Le Sueur		MN0022152	10	212300
8077	Lester Building Systems Div	Lester Prairie		MN0023957	200	321900
8078	Poly Foam Inc	Lester Prairie		MN0023957	75	424600
8079	Lester Prairie Public School Dist #424	Lester Prairie		MN0023957	60	611100
8080	Formative Engineering Corp	Lester Prairie	0.03	MN0023957	35	325200
8081	Riverside Electronics Ltd	Lewiston		MN0023965	360	334400
8082	Herff/Jones	Lewiston		MN0023965	350	812900
8083	Lewiston Public School District #857	Lewiston		MN0023965	135	611100
8084	Lewiston Villa	Lewiston		MN0023965	62	623100

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ID	Facility Name	City	P_kgd	Permit_No	employee_count	NAICS Code
8085	Minnesota Product Innovators	Lewiston	0.02	MN0023965	24	325200
8086	Lewiston Monument Co	Lewiston		MN0023965	22	327900
8087	Lewiston Auto Co	Lewiston		MN0023965	20	441100
8088	Minnesota Drafting & Design	Lewiston		MN0023965	14	541300
8089	Lewiston Feed & Produce	Lewiston		MN0023965	13	424900
8090	Lewiston Implement Inc	Lewiston		MN0023965	12	333200
8091	Benson Farm Service	Lewiston		MN0023965	10	424900
8092	Chisago Lakes School District	Center City		MN0055808	550	611500
8093	Plastic Products Inc	Center City	0.20	MN0055808	255	325200
8094	Bevco Inc	Center City	1.39	MN0055808	30	311400
8095	State of MN Correctional Facility	St. Paul		MN0029815	600	922100
8096	AdGraphics	St. Paul		MN0029815	260	453200
8097	Anoka County Juvenile Center	St. Paul		MN0029815	160	922100
8098	Synovis Interventional Systems	St. Paul	0.12	MN0029815	160	334500
8099	Molin Concrete Products Co	St. Paul		MN0029815	135	327300
8100	Rehbein Transit Inc	St. Paul		MN0029815	130	485400
8101	Summit Fire Protection	St. Paul		MN0029815	100	238200
8102	Nol-Tec Systems Inc	St. Paul		MN0029815	70	333900
8103	Custom Mfg & Engineering	St. Paul	0.05	MN0029815	60	325200
8104	Loosbrock Digging Service	Lismore		MNG580076	20	238900
8105	City of Lismore	Lismore	0.02	MNG580076	14	921100
8106	5 Star Co-op Fertilizer	Lismore		MNG580076	10	325300
8107	B & L Construction	Lismore		MNG580076	10	236100
8108	Heartland Mutual Insurance Co.	Lismore		MNG580076	7	524100
8109	State Bank of Lismore	Lismore		MNG580076	6	522100
8110	Farmers Union Co-op Oil Co.	Lismore		MNG580076	5	424900
8111	Veld Lumber Company	Lismore		MNG580076	5	444100
8112	Adrian Co-op Elevator	Lismore		MNG580076	4	424900
8113	Bob's Locker & Market	Lismore	0.02	MNG580076	4	445200
8114	Electric Motor Center	Lismore		MNG580076	2	335300
8115	Lismore Agency	Lismore		MNG580076	2	524100
8116	Lismore Cellular Inc.	Lismore		MNG580076	2	334200
8117	Jim's Service	Lismore		MNG580076	1	447100
8118	Kemper Trucking	Lismore	0.05	MNG580076	1	484100
8119	Innovex, Inc.	Litchfield		MN0023973	400	425100
8120	Litchfield School District 465	Litchfield		MN0023973	376	611100
8121	Augustana Lutheran Homes	Litchfield		MN0023973	245	623100
8122	Meeker County	Litchfield	0.25	MN0023973	175	921100
8123	First District Association	Litchfield	10.74	MN0023973	172	311500
8124	Meeker County Memorial Hospital	Litchfield	0.10	MN0023973	150	622100
8125	Minnesota Rubber	Litchfield		MN0023973	123	339900
8126	Towmaster Trailers, Inc.	Litchfield	8.10	MN0023973	107	336200
8127	Custom Products of Litchfield	Litchfield		MN0023973	104	332300
8128	Sparboe Companies	Litchfield		MN0023973	90	112300
8129	Anderson Chemical Company	Litchfield		MN0023973	63	424600
8130	Johnson Bros. Corporation	Litchfield		MN0023973	60	237300
8131	Litchfield Garment Company	Litchfield		MN0023973	47	315200
8132	Berk Packaging Solutions	Litchfield		MN0023973	35	561900
8133	Modern Quilters	Litchfield		MN0023973	35	314100
8135	Slumberland	St. Paul		MN0029815	240	442100
8136	Arden Fasteners	St. Paul		MN0029815	130	339900
8137	Frattalone Excavating	St. Paul		MN0029815	110	238900
8138	Bally's US Swim & Fitness	St. Paul		MN0029815	100	713900
8139	Olsen Thielen & Co Ltd	St. Paul		MN0029815	100	541200
8140	Kath Companies	St. Paul		MN0029815	80	441300
8141	Levitz Furniture	St. Paul		MN0029815	77	442100
8142	McKesson Drug	St. Paul		MN0029815	67	424200
8143	Peterson Maintenance	St. Paul		MN0029815	62	561700
8144	CI Title	St. Paul		MN0029815	54	541100
8145	Gopher Electronics Co	St. Paul		MN0029815	47	443100
8146	Larson Boats	Little Falls		MN0020761	935	336600
8147	Unity Family Health Care	Little Falls	0.42	MN0020761	650	622100
8148	Crestliner Inc	Little Falls		MN0020761	376	336600
8149	IWCO	Little Falls		MN0020761	347	541800
8150	Falls Fabricating Inc	Little Falls		MN0020761	117	331200
8151	Lutheran Care Center	Little Falls		MN0020761	105	623100
8152	Minnesota Power	Little Falls		MN0020761	75	221100
8153	Anderson Custom Processing	Little Falls	0.81	MN0020761	42	311900

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ID	Facility Name	City	P_kgd	Permit_No	employee_count	NAICS Code
8154	Pete & Joy's Bakery	Little Falls		MN0020761	40	311800
8155	Little Falls Machine Inc	Little Falls		MN0020761	37	333300
8156	Precision Tool Technologies	Little Falls	0.29	MN0020761	10	339100
8157	Littlefork Medical Ctr	Littlefork		MN0021181	80	621111
8158	Littlefork Public School Dist #362	Littlefork		MN0021181	35	611110
8159	Green Forest Products Inc	Littlefork	0.00	MN0021181	15	321113
8160	Larson Timber Products	Littlefork	0.00	MN0021181	6	321113
8161	Hart Press Inc	Long Prairie		MN0020303	640	511100
8162	Long Prairie Packing Co	Long Prairie	11.00	MN0020303	275	311600
8163	Long Prairie Memorial Hospital	Long Prairie	0.16	MN0020303	250	622100
8164	Todd, County of	Long Prairie	0.35	MN0020303	250	921100
8165	Dan's Prize Inc	Long Prairie	7.52	MN0020303	188	311600
8166	Long Prairie-Grey Eagle Schools	Long Prairie		MN0020303	180	611100
8167	Central Bi-Products Rendering	Long Prairie	4.40	MN0020303	110	311600
8168	Daybreak Foods Inc	Long Prairie		MN0020303	80	112300
8169	Cathedral Press	Long Prairie		MN0020303	30	511100
8170	Lake Country CNC Machinery	Long Prairie	0.03	MN0020303	25	335900
8171	R-Way Trucking	Long Prairie		MN0020303	22	336200
8172	Chassis Liner	Lucan	0.00	MN0031348	36	332700
8173	BrauHaus	Lucan		MN0031348	14	722400
8174	State Bank of Lucan	Lucan		MN0031348	11	522100
8175	Northern States	Lucan		MN0031348	10	221100
8176	Meadowland Cooperative	Lucan		MN0031348	5	424900
8177	Gold'n Plump Poultry	Luverne	6.10	MN0020141	316	311600
8178	Luverne Public Schools	Luverne		MN0020141	250	611300
8179	Luverne Commmunity Hospital	Luverne	0.12	MN0020141	182	622100
8180	Minnesota Veterans Home	Luverne		MN0020141	155	623100
8181	Berkley Information Services	Luverne		MN0020141	130	541500
8182	Mary Jane Brown Home	Luverne		MN0020141	120	623100
8183	Rock, County of	Luverne		MN0020141	105	624200
8184	Continental Western - Tri-State Ins.	Luverne		MN0020141	95	524100
8185	Luverne Medical Center	Luverne	0.06	MN0020141	45	621100
8186	Papik Motors	Luverne		MN0020141	40	453300
8187	Luverne, City of	Luverne	0.05	MN0020141	37	921100
8188	Hills Stainless Steel	Luverne		MN0020141	32	333200
8189	Green Lea Manor Nursing Home	Mabel		MN0020877	85	623100
8190	Mabel/Canton High School	Mabel		MN0020877	36	611100
8191	Community First NB - Mabel	Mabel		MN0020877	10	522100
8192	Mabel Farm Equipment	Mabel		MN0020877	10	333200
8193	Hagen Lumber Co	Mabel		MN0020877	7	444100
8194	Mabel Cooperative Telephone Co	Mabel		MN0020877	7	517100
8195	Mabel, City of	Mabel	0.01	MN0020877	7	921100
8196	Neuman Plumbing	Mabel		MN0020877	5	238200
8197	Nelson Electric	Mabel		MN0020877	4	238200
8198	Tony Downs Foods CO	Madelia	17.00	MN0024040	300	311600
8199	House Of Print	Madelia		MN0024040	150	323100
8200	Luther Memorial Home	Madelia		MN0024040	92	623100
8201	Madelia Community Hospital	Madelia	0.05	MN0024040	70	622100
8202	Feder Plumbing Heating & Ac	Madelia		MN0024040	40	238200
8203	Wolf Etter & Co.	Madelia		MN0024040	26	541200
8204	Madelia Clinic	Madelia	0.03	MN0024040	21	621100
8205	Gopher Concrete	Madelia		MN0024040	18	327300
8206	Preferred Printing	Madelia		MN0024040	10	323100
8207	Ryter Corp	Madelia	5.40	MN0024040	10	541700
8208	Forstner Fire Apparatus	Madelia	0.53	MN0024040	7	336200
8209	Gappa Electric	Madelia		MN0024040	7	238200
8210	Lac qui Parle Health Services	Madison	0.11	MN0051764	175	622100
8211	Lac qui Parle Valley School District 2853	Madison		MN0051764	165	611100
8212	County of Lac Qui Parle	Madison	0.07	MN0051764	50	921100
8213	Municipal Castings Inc	Madison		MN0051764	30	331500
8214	Madison Bottling Co.	Madison	1.89	MN0051764	28	312100
8215	Madison Implement Co.	Madison		MN0051764	20	115100
8216	Jubilee Foods	Madison		MN0051764	19	445100
8217	Klein NB of Madison	Madison		MN0051764	18	522100
8218	City of Madison	Madison	0.02	MN0051764	17	921100
8219	United Prairie Bank of Madison	Madison		MN0051764	12	522100
8220	USDA Service Center	Madison		MN0051764	12	924100
8221	Kuehl Motors Inc	Madison		MN0051764	10	441100

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ID	Facility Name	City	P_kgd	Permit_No	employee_count	NAICS Code
8222	Lund Implement Co.	Madison		MN0051764	10	115100
8223	State Line Farmers/Harvest States Coop	Madison		MN0051764	10	311200
8224	Rice Home Medical Services	Madison		MN0051764	6	621900
8225	Madison Chamber of Commerce	Madison		MN0051764	2	813400
8226	Shooting Star Casino	Mahnomen		MN0024066	873	713200
8227	Mahnomen Hospital/Nursing Home	Mahnomen	0.08	MN0024066	124	622100
8228	Mahnomen Public School	Mahnomen		MN0024066	110	611100
8229	Mahnomen, County of	Mahnomen	0.12	MN0024066	84	921100
8230	Wild Rice Electric Co-op Inc	Mahnomen		MN0024066	41	221100
8231	First NB in Mahnomen	Mahnomen		MN0024066	20	522100
8232	Golden Eagle Bingo Lodge	Mahnomen		MN0024066	19	713900
8233	Stardust Suites	Mahnomen		MN0024066	18	721100
8234	Harvest States Agri-Center	Mahnomen		MN0024066	17	424900
8235	Mahnomen, City of	Mahnomen	0.02	MN0024066	16	921100
8236	Winter Truck Lines	Mahnomen	0.83	MN0024066	16	484100
8237	Mahnomen Concrete Products	Mahnomen		MN0024066	14	327300
8238	White Earth Tribal Community College	Mahnomen		MN0024066	10	611200
8239	Mahtomedi School District #832	St. Paul		MN0029815	254	611100
8240	St Andrews Church	St. Paul		MN0029815	85	813100
8241	Dairy Queen	St. Paul		MN0029815	27	722100
8242	Picadilly Restaurant	St. Paul		MN0029815	27	722100
8243	Jethro's Char-House & Pub	St. Paul		MN0029815	25	722100
8244	St Jude of the Lake	St. Paul		MN0029815	20	611100
8245	Freedom Valu Center	St. Paul		MN0029815	19	424900
8246	3 Seasons Restaurant	St. Paul		MN0029815	16	722100
8247	Mahtomedi, City of	St. Paul	0.02	MN0029815	11	921100
8248	Wildwood Branch Library	St. Paul		MN0029815	11	519100
8249	Carbone's Pizza	St. Paul		MN0029815	10	722100
8250	Lakeside Club Restaurant	St. Paul		MN0029815	9	722100
8251	Auto Edge	St. Paul		MN0029815	6	811100
8252	Wildwood Service	St. Paul		MN0029815	6	811100
8253	Flame Bar	St. Paul		MN0029815	5	722400
8254	Liquor Barrel	St. Paul		MN0029815	5	445300
8255	Zachman's Water Care	St. Paul		MN0029815	5	424600
8256	Immanuel-St Joseph's-Mayo Health System	Mankato	1.00	MN0030171	1540	622100
8257	Minnesota State University at Mankato	Mankato		MN0030171	1400	611300
8258	Mankato Rehabilitation Center Inc	Mankato		MN0030171	1325	624300
8260	Young America Corporation	Mankato		MN0030171	675	561400
8261	The Thro Company	Mankato		MN0030171	644	623100
8262	Blue Earth County	Mankato	0.52	MN0030171	370	921100
8263	HickoryTech	Mankato		MN0030171	363	517100
8264	Midwest Wireless	Mankato		MN0030171	293	517200
8265	Southern Minn. Construction Co.	Mankato		MN0030171	275	236200
8266	City of Mankato	Mankato	0.37	MN0030171	263	921100
8267	Harry Meyering Center	Mankato		MN0030171	255	624100
8268	Cenex/Harvest States	Mankato	0.00	MN0030171	202	311200
8269	Minnesota Elevator Inc	Mankato		MN0030171	200	333300
8270	Schwickert Company	Mankato		MN0030171	200	238100
8271	Johnson Worldwide Associates	Mankato		MN0030171	185	336900
8272	Atlantis Plastics	Mankato	0.31	MN0030171	178	326100
8273	Coughlan Companies	Mankato		MN0030171	160	511100
8274	Crysteel Manufacturing, Inc.	Mankato	12.11	MN0030171	160	336200
8275	E-Travel Experts	Mankato		MN0030171	160	561400
8276	EI Microcircuits	Mankato		MN0030171	158	334400
8277	Hubbard Feeds, Inc.	Mankato		MN0030171	150	311100
8278	Katolight Corporation	Mankato		MN0030171	134	444100
8279	Free Press Co	Mankato		MN0030171	132	511100
8280	AgStar Farm Credit Services	Mankato		MN0030171	130	522100
8281	Perfecseal Mankato	Mankato	3.61	MN0030171	125	339100
8282	Crown Cork & Seal Co	Mankato		MN0030171	122	331300
8283	Tru Serv Corporation	Mankato		MN0030171	120	423700
8284	Vetter Stone Company	Mankato		MN0030171	114	212300
8285	Dotson Co Inc	Mankato	0.77	MN0030171	112	332900
8287	Dodge, County of	Mantorville	0.19	MN0021059	132	921100
8288	Hubbell House	Mantorville		MN0021059	100	722100
8289	Mantorville, City of	Mantorville	0.00	MN0021059	3	921100
8290	Independent School District #279	St. Paul		MN0029815	3000	611110
8291	Scimed Life Systems Inc	St. Paul	2.01	MN0029815	3000	334510

Appendix B. Industrial Phosphorus Data Matched to MNPRO Database by NAICS

ID	Facility Name	City	P_kgd	Permit_No	employee_count	NAICS Code
8292	United Parcel Service	St. Paul		MN0029815	900	492110
8294	Barborossa & Sons	St. Paul		MN0029815	300	238990
8296	Hanson Concrete Products	St. Paul		MN0029815	300	444190
8297	Walmart	St. Paul		MN0029815	300	452112
8299	Cub Foods	St. Paul		MN0029815	270	445110
8300	Mineapolis Auto Auction	St. Paul		MN0029815	250	441229
8301	REO Plastics	St. Paul	1.43	MN0029815	250	325211
8302	Tiller Corporation	St. Paul		MN0029815	250	212399
8303	U.S. West Dex	St. Paul	0.76	MN0029815	230	323119
8304	Champp's Americana	St. Paul		MN0029815	225	722110
8305	Target	St. Paul		MN0029815	225	452111
8306	Data Recognition Corp	St. Paul	0.04	MN0029815	220	518210
8307	St. Jude Medical	St. Paul		MN0029815	200	541720
8308	Maple Lake Public School Dist #881	Hutchinson		MN0024082	125	611100
8309	Bernatello's Pizza	Hutchinson	2.59	MN0024082	115	311400
8310	Hance Cable Testing	Hutchinson		MN0024082	85	221100
8311	Product Technologies Inc	Hutchinson		MN0024082	70	331500
8312	Cedar Lake Engineering	Hutchinson	0.26	MN0024082	50	541700
8313	Sun Patio Inc	Hutchinson		MN0024082	50	336600
8314	Rhino, Inc.	Hutchinson	0.00	MN0024082	28	332700
8315	Maple Lake Lumber Co	Hutchinson		MN0024082	23	444100
8316	Security St Bank of Maple Lake	Hutchinson		MN0024082	20	522100
8317	Wright County Community Action	Hutchinson		MN0024082	19	624200
8318	Dental Resources, Inc.	Hutchinson	0.00	MN0024082	14	339100
8319	Cabinet Design & Distribution, Inc.	Hutchinson		MN0024082	13	321900
8320	Maple Lake Marine, Inc.	Hutchinson		MN0024082	12	441200
8321	C&W Spinning	Hutchinson	0.05	MN0024082	10	541700
8322	H&H Archery Supply	Hutchinson		MN0024082	10	339900
8323	Lohse Transfer	Hutchinson	0.00	MN0024082	9	484100
8324	St. Timothy Catholic School	Hutchinson		MN0024082	9	611100
8325	Wright Aero Inc	Hutchinson		MN0024082	9	481200
8326	City of Maple Lake	Hutchinson	0.01	MN0024082	8	921100
8327	Lake Region Co-op Oil	Hutchinson		MN0024082	8	424900
8328	LDM Electric	Hutchinson		MN0024082	7	238200
8329	Maple Lake Bakery	Hutchinson	0.03	MN0024082	7	445200
8330	Maple Lake Recovery Center	Hutchinson		MN0024082	7	624200
8331	Roger's Amoco, Inc.	Hutchinson		MN0024082	7	447100
8332	Advanced Chairmats, Inc.	Hutchinson		MN0024082	5	339900
8333	Jude Candy & Tobacco Co	Hutchinson		MN0024082	5	454200
8334	Madigan's Bar & Grill	Hutchinson		MN0024082	5	722100
8335	New Designs Hairstyling	Hutchinson	0.01	MN0024082	5	812100
8336	TMS Machining	Hutchinson	0.00	MN0024082	5	332700
8337	A-Meat Shoppe	Hutchinson	0.02	MN0024082	4	445200
8338	Elletson Manufacturing	Hutchinson		MN0024082	4	336900
8339	H&H Sport Shop	Hutchinson		MN0024082	4	451100
8340	Hegle Door	Hutchinson		MN0024082	4	238900
8341	Lake Region Co-op-Fertilizer Plant	Hutchinson		MN0024082	4	115100
8342	Maple Lake Post Office	Hutchinson		MN0024082	4	491100
8343	American Roto Tool	Hutchinson	0.00	MN0024082	3	332700
8344	Black's Linemen Supply	Hutchinson		MN0024082	3	423900
8345	Elletson Bowl & Recreation Center	Hutchinson		MN0024082	3	713900
8346	Kloster Industrial Assets, Inc.	Hutchinson		MN0024082	3	561900
8347	Lady Bug Bookstore	Hutchinson		MN0024082	3	451200
8348	Maple Lake Cafe	Hutchinson		MN0024082	3	722100
8349	Maple Lake Legion #131	Hutchinson		MN0024082	3	813400
8350	Mooney Bus Company	Hutchinson		MN0024082	3	485400
8351	Nabours Novelty, Inc.	Hutchinson		MN0024082	3	713200
8352	Old Times Newsletter	Hutchinson		MN0024082	3	511100
8353	Paumen General Supply	Hutchinson		MN0024082	3	441300
8354	Quinlan Dental	Hutchinson		MN0024082	3	621200
8356	Health East	St. Paul	0.62	MN0029815	950	622100
8357	Dayton's	St. Paul		MN0029815	450	452100
8358	Maplewood School District #622	St. Paul		MN0029815	400	611100
8359	Sears Roebuck	St. Paul		MN0029815	350	452100
8360	Cub Foods East	St. Paul		MN0029815	250	445100
8361	Cub Foods West	St. Paul		MN0029815	250	445100
8362	Mervyn's	St. Paul		MN0029815	200	452100
8363	Volunteers of America	St. Paul		MN0029815	190	623300

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ID	Facility Name	City	P_kgd	Permit_No	employee_count	NAICS Code
8364	Home Depot	St. Paul		MN0029815	185	444100
8365	Menards	St. Paul		MN0029815	180	444100
8366	Kohl's Department Store	St. Paul		MN0029815	160	452100
8367	Health Partners	St. Paul	0.20	MN0029815	150	621100
8368	Rainbow Foods	St. Paul		MN0029815	130	445100
8369	Hermanson Dental Service	St. Paul	3.61	MN0029815	125	339100
8370	Best Western Inn	St. Paul		MN0029815	100	721100
8371	Truck Utilities & Mfg Co	St. Paul		MN0029815	60	441100
8372	Countryside Volkswagen & Saab	St. Paul		MN0029815	50	441100
8374	US Bank Corporation	Marshall		MN0022179	450	532400
8375	Hy-Vee Foods	Marshall		MN0022179	400	445100
8376	Weiner Memorial Medical Ctr	Marshall	0.25	MN0022179	385	622100
8377	Southwest Minnesota State University	Marshall		MN0022179	375	611300
8378	Archer Daniels Midland Company	Marshall	0.00	MN0022179	325	311200
8379	Marshall Public Schools	Marshall		MN0022179	320	611100
8380	REM Service Inc	Marshall		MN0022179	183	623200
8381	BH Electronics Inc	Marshall	0.11	MN0022179	93	335900
8382	Best Western Marshall Inn	Marshall		MN0022179	90	721100
8383	Marshall Independent	Marshall		MN0022179	83	511100
8384	McGregor Public Schools	McGregor		MN0024023	137	611100
8385	Floe Intl & Hoyt McGregor Payroll	McGregor		MN0024023	72	238100
8386	Savamco	McGregor		MN0024023	50	453900
8387	Covenant Pines Bible Camp	McGregor		MN0024023	46	721200
8388	Savanna Pallets	McGregor		MN0024023	30	321900
8389	CMA Camp	McGregor		MN0024023	24	721200
8390	Savanna Golf & Supper Club	McGregor		MN0024023	20	713900
8391	McGregor Clinic	McGregor	0.03	MN0024023	19	621100
8392	Fireside Inn	McGregor		MN0024023	17	722100
8393	Ukura's Big Dollar	McGregor		MN0024023	14	445100
8394	Medford Outlet Center	Medford		MN0024112	350	453900
8395	Medford Furniture Outlet	Medford		MN0024112	75	442100
8396	Medford Public School	Medford		MN0024112	69	611100
8397	Olympic Fire Protection	Medford		MN0024112	50	562100
8398	Fabricated Wood Products	Medford		MN0024112	38	321900
8399	McDonald's	Medford		MN0024112	38	722100
8400	Straight River Enterprises	Medford		MN0024112	33	923100
8401	Triple E Manufacturing	Medford		MN0024112	22	332300
8402	Yule Transport	Medford		MN0024112	18	484100
8403	Poly Pak Plastics	Medford	0.03	MN0024112	15	326100
8404	Americanna Community Bank	Medford		MN0024112	9	522100
8405	Our Place	Medford		MN0024112	7	722100
8406	Bob Anhorn Service Inc.	Medford	0.01	MN0024112	5	335900
8407	Pat Simmons Real Estate	Medford		MN0024112	5	531200
8408	CJ Foods	Medford		MN0024112	4	445100
8410	ISD #740, Melrose	Melrose		MN0020290	183	611100
8411	CentraCare Health Services	Melrose	0.11	MN0020290	175	622100
8413	Central MN Federal Credit Union	Melrose		MN0020290	68	522100
8414	diversiCOM/Melrose Telephone Co	Melrose		MN0020290	64	517100
8415	Stearns Electric Association	Melrose		MN0020290	61	221100
8416	Ernie's Jubilee Foods	Melrose		MN0020290	54	445100
8417	CentraCare Clinic	Melrose	0.05	MN0020290	35	621100
8418	City of Melrose	Melrose	0.04	MN0020290	30	921100
8419	Green Pine Acres Nursing Home	Menahga		MNG580032	120	623100
8420	Menahga Public Schools	Menahga		MNG580032	110	611100
8421	Cooperative Sampo Bulk Dlvry	Menahga		MNG580032	38	424900
8422	Salo Manufacturing	Menahga	0.03	MNG580032	18	325900
8423	First NB of Menahga	Menahga		MNG580032	16	522100
8424	Menahga Concrete Products	Menahga		MNG580032	15	327300
8425	WW Products	Menahga		MNG580032	9	326200
8426	Dairyland Equipment	Menahga		MNG580032	6	424900
8427	Huntersville Wood Products	Menahga		MNG580032	3	423300
8428	Northland Insurance Co	St. Paul		MN0029815	456	524100
8431	Solvay Animal Health Inc	St. Paul		MN0029815	175	424900
8432	General Pump/US	St. Paul		MN0029815	60	333900
8433	Milaca Public Schools - Dist. #912	Milaca		MN0024147	220	611100
8434	Gorecki Manufacturing	Milaca		MN0024147	196	443100
8435	Mille Lacs, County of	Milaca		MN0024147	188	921100
8436	Elim Nursing Home	Milaca		MN0024147	160	623100

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ID	Facility Name	City	P_kgd	Permit_No	employee_count	NAICS Code
8437	Medtronic Inc	Milaca		MN0024147	144	334500
8438	Olson's Super Valu	Milaca		MN0024147	80	445100
8439	Fairview Clinic - Milaca	Milaca	0.06	MN0024147	45	621100
8440	Coin-Tainer Co	Milaca		MN0024147	41	423400
8441	Bremix Concrete Co	Milaca		MN0024147	35	327300
8442	Milaca Mills	Milaca		MN0024147	27	315100
8443	First NB of Milaca	Milaca		MN0024147	24	522100
8444	Milaca, City of	Milaca	0.03	MN0024147	24	921100
8445	East Central Electric Assn - Milaca	Milaca		MN0024147	16	221100
8446	Milaca Building Center	Milaca		MN0024147	12	444100
8447	Princeton Bank - Milaca	Milaca		MN0024147	10	522100
8448	Viking Gas Transmission	Milaca		MN0024147	8	486200
8449	Milan Elementary School	Milan		MN0020753	35	611100
8450	Milan Community Child Care Center	Milan		MN0020753	5	624400
8451	Prairie State Bank	Milan		MN0020753	5	521100
8452	Strand of Milan, Inc	Milan		MN0020753	5	115100
8453	Fragodt Floor Covering II	Milan		MN0020753	4	238300
8454	Glacial Plains Elevator	Milan		MN0020753	4	115100
8455	John's Machine Shop	Milan		MN0020753	4	811300
8456	More Cafe	Milan		MN0020753	4	722100
8457	Milan Legion	Milan		MN0020753	3	722400
8458	Streed Mobil	Milan		MN0020753	3	447100
8459	CNS Creations	Milan		MN0020753	2	453200
8460	Milan Beach Resort	Milan		MN0020753	2	721200
8461	Milan Blacksmith Shop	Milan		MN0020753	2	333900
8462	Milan Post Office	Milan		MN0020753	2	491100
8463	Phoenix Type	Milan		MN0020753	2	511100
8464	Prairie Land Financial Group	Milan		MN0020753	2	524200
8465	Brian's Auto Service & Repair	Milan		MN0020753	1	811100
8466	University of Minnesota	St. Paul		MN0029815	34317	611300
8467	Dayton Hudson Corp	St. Paul		MN0029815	22600	452100
8468	First Bank System Inc	St. Paul		MN0029815	14725	551100
8469	Hennepin, County of	St. Paul	1.50	MN0029815	10472	921100
8470	Norwest Corporation	St. Paul		MN0029815	10250	551100
8471	Grand Metropolitan Inc	St. Paul		MN0029815	7700	424800
8473	Minneapolis, City of	St. Paul	10.54	MN0029815	7500	921100
8474	Northern States Power Co	St. Paul		MN0029815	7362	221100
8476	US Post Office - Main	St. Paul		MN0029815	4000	491100
8478	US West Communications	St. Paul		MN0029815	2100	517100
8479	CP Wainman Pioneers-America	St. Paul		MN0029815	2000	813400
8480	Norwest Bk MN NA	St. Paul		MN0029815	2000	522100
8481	Regional Kidney Disease Center	St. Paul		MN0029815	2000	621400
8482	Target	St. Paul		MN0029815	1900	452100
8483	Minneapolis Children's Med Ctr	St. Paul	1.10	MN0029815	1700	622100
8484	American Express Financial Advisors Inc.	St. Paul		MN0029815	1592	523100
8485	Minnegasco	St. Paul		MN0029815	1377	221200
8486	Minneota Manor Health Care Ctr	Minneota		MNG580033	150	623100
8487	Superior Truss & Components	Minneota		MNG580033	110	444100
8488	Schott Corp	Minneota		MNG580033	103	425100
8489	Minneota Public Schools	Minneota		MNG580033	85	611100
8490	St Edward's School	Minneota		MNG580033	15	611100
8491	Ufkin's	Minneota		MNG580033	10	442100
8492	Cargill	St. Paul		MN0029882	3400	115100
8493	Carlson Companies Inc	St. Paul		MN0029882	3100	561510
8494	Allina Health System	St. Paul		MN0029882	1200	524100
8495	DataCard Corp	St. Paul		MN0029882	1000	453210
8496	Advantek Inc	St. Paul		MN0029882	600	334400
8499	Opportunity Partners	St. Paul		MN0029882	500	624310
8500	Scicom Data Service	St. Paul	0.03	MN0029882	195	518210
8501	Minnetrista School District #277	St. Paul		MN0029882	169	611100
8502	Burl Oaks Golf Club	St. Paul		MN0029882	10	713900
8503	Jennie-O Turkey Store	Montevideo	10.71	MN0020133	325	311615
8504	Montevideo Public Schools	Montevideo		MN0020133	300	611110
8505	SL-Montevideo Technology Inc.	Montevideo	2.05	MN0020133	218	335312
8506	Friendship Homes of Minnesota	Montevideo		MN0020133	200	321991
8507	Luther Haven Nursing Home	Montevideo		MN0020133	193	623110
8508	REM Southwest Services	Montevideo		MN0020133	150	624120
8509	Micro Dynamics Corporation	Montevideo	2.71	MN0020133	140	334419

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ID	Facility Name	City	P_kgd	Permit_No	employee_count	NAICS Code
8510	Chippewa County-Monte Hospital	Montevideo	0.17	MN0020133	138	622110
8511	Chippewa County	Montevideo		MN0020133	135	921110
8512	Wal-Mart	Montevideo		MN0020133	130	452112
8513	Chandler Industries Inc.	Montevideo		MN0020133	110	332710
8514	County Market	Montevideo		MN0020133	80	445110
8516	United Steel Products Co	Montgomery		MN0024210	272	332300
8517	Montgomery Public Schools	Montgomery		MN0024210	150	611100
8518	Knish Construction	Montgomery		MN0024210	37	238100
8519	Fred's IGA Foods	Montgomery		MN0024210	25	445100
8520	Holy Redeemer School	Montgomery		MN0024210	25	611100
8521	Barnett Bros Construction	Montgomery		MN0024210	23	238900
8522	First Natl Bank of Montgomery	Montgomery		MN0024210	23	522100
8523	Paradigm Sports Inc	Montgomery		MN0024210	19	339900
8524	Montgomery, City of	Montgomery	0.02	MN0024210	16	921100
8525	Casey's General Store	Montgomery	0.00	MN0024210	15	445200
8526	HE Westerman Lumber Co	Montgomery		MN0024210	13	444100
8527	Rural American Bank - Montgomery & Lonsdale	Montgomery		MN0024210	13	522100
8528	Skluzacek Amoco	Montgomery		MN0024210	12	447100
8529	MCP	Montgomery		MN0024210	10	333200
8530	Minnesota Valley Ag	Montgomery		MN0024210	9	424900
8531	Cemstone	Montgomery		MN0024210	4	327300
8532	Monticello Public Schools	Monticello		MN0020567	450	611100
8533	Monticello-Big Lake Hospital	Monticello	0.28	MN0020567	432	622100
8535	Fulfillment Systems Inc	Monticello		MN0020567	212	561900
8536	Sunny Fresh Foods Inc	Monticello	10.82	MN0020567	191	311600
8537	Cub Foods	Monticello		MN0020567	156	445100
8538	Big K-Mart	Monticello		MN0020567	111	452100
8539	Maus Foods	Monticello		MN0020567	106	445100
8540	Standard Iron & Wire Works Inc	Monticello	0.00	MN0020567	85	332700
8541	Bondhus Corp	Monticello		MN0020567	81	332200
8542	Fingerhut Corp	Monticello		MN0020567	75	454100
8543	Hoglund Transportation Inc	Monticello		MN0020567	74	485400
8544	Tapper's Inc	Monticello		MN0020567	72	337100
8545	Fay-Mar Tube & Metal Fabricators Inc	Monticello	0.33	MN0020567	48	332900
8546	Aroplax Corp	Monticello	0.03	MN0020567	43	325200
8547	JME of Monticello	Monticello	2.12	MN0020567	41	484100
8548	Hoglund Bus Co	Monticello		MN0020567	38	423800
8549	Electro Industries Inc	Monticello		MN0020567	37	339900
8550	Vector Tool & Mfg Inc	Monticello	0.00	MN0020567	34	332700
8551	Suburban Manufacturing Inc.	Monticello	0.00	MN0020567	31	332700
8552	Dahlheimer Distributing Co. Inc.	Monticello		MN0020567	24	424800
8553	Rainbow Enterprises, Inc.	Monticello	0.03	MN0020567	24	335900
8554	TDS Telecom	Monticello		MN0020567	19	517100
8555	D & D, Inc.	Monticello		MN0020567	18	485400
8556	Tire Service Equipment Mfg. Co.	Monticello		MN0020567	18	336300
8557	AME Group - Monticello Plant	Monticello		MN0020567	16	327300
8558	Groebner & Associates, Inc.	Monticello		MN0020567	16	423900
8559	Lake Tool Inc.	Monticello	0.01	MN0020567	14	325200
8560	Polycast Specialties Inc.	Monticello		MN0020567	14	326200
8561	Clow Stamping Co.	Monticello	0.06	MN0020567	12	541700
8562	Custom Canopy Inc.	Monticello	0.08	MN0020567	12	332900
8563	Jones Manufacturing of Monticello, Inc.	Monticello		MN0020567	12	339900
8564	Willi Hahn Corpation/Wiha Tools	Monticello		MN0020567	10	423700
8565	B & B Metal Stamping	Monticello	0.03	MN0020567	6	541700
8566	Ataboy Manufacturing, Inc.	Monticello	0.03	MN0020567	5	332900
8567	EDMA	Monticello	0.00	MN0020567	3	335900
8568	Eden Electronics	Montrose		MN0024228	25	335300
8569	Best Disposal Services	Montrose		MN0024228	22	562100
8570	Knight Colors & Chemicals	Montrose		MN0024228	15	423800
8571	Citizens State Bank	Montrose		MN0024228	13	522100
8572	Hank's Pattern	Montrose	0.06	MN0024228	8	332900
8573	MN Dept. of Natural Resources	Montrose		MN0024228	8	924100
8574	Fitzsimmons	Montrose		MN0024228	5	541600
8575	US Post Office	Montrose		MN0024228	5	491100
8576	Countryview Realty	Montrose		MN0024228	4	531200
8577	Montrose Dental Office	Montrose		MN0024228	4	621200
8578	Jeff Ex	Montrose		MN0024228	3	811100
8579	All Season Repair	Montrose		MN0024228	2	811100

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ID	Facility Name	City	P_kgd	Permit_No	employee_count	NAICS Code
8580	Green Ink	Montrose		MN0024228	2	323100
8581	Jerry Braegelmann	Montrose		MN0024228	2	453900
8582	Marketons Body Shop	Montrose		MN0024228	2	811100
8583	Montrose Chirporactic	Montrose		MN0024228	2	621300
8584	Brenny Trucking	Montrose	0.05	MN0024228	1	484100
8585	Chantland Classic & Quality	Montrose		MN0024228	1	441200
8586	Scott's Glass & Mirror	Montrose		MN0024228	1	327200
8587	Moorhead Public Schools-ISD #152	Moorhead		MN0049069	815	611100
8588	Minnesota State University Moorhead	Moorhead		MN0049069	800	611300
8589	Concordia College - Moorhead	Moorhead		MN0049069	613	611300
8590	Eventide Lutheran Home	Moorhead		MN0049069	452	623100
8591	American Crystal Sugar Co	Moorhead	0.13	MN0049069	380	311300
8592	Clay, County of	Moorhead	0.51	MN0049069	365	921100
8593	Moorhead, City of	Moorhead	0.36	MN0049069	254	921100
8594	ASP Inc	Moorhead		MN0049069	200	541600
8595	Moorhead Electric Inc	Moorhead		MN0049069	171	238200
8596	Northwest Tech College - Moorhead	Moorhead		MN0049069	163	611300
8597	Camas	Moorhead		MN0049069	150	327300
8598	Sunmart	Moorhead		MN0049069	125	445100
8599	Moorhead Health Care Ctr	Moorhead		MN0049069	115	623100
8600	Herberger's Department Store	Moorhead		MN0049069	94	452100
8601	K Mart	Moorhead		MN0049069	83	452100
8602	Best Western Red River Inn	Moorhead		MN0049069	77	721100
8603	Target	Moorhead		MN0049069	76	452100
8604	Abbott Arne Schwindt	Moorhead		MN0049069	55	237300
8605	Hornbacher's Foods	Moorhead		MN0049069	46	445100
8606	Mercy Hospital and Health Care Center	Moose Lake	0.25	MN0020699	380	622100
8607	Minnesota Correctional Facility-Moose Lake	Moose Lake		MN0020699	338	922100
8608	Moose Lake Public Schools	Moose Lake		MN0020699	78	611100
8609	Lake State Federal Credit Union	Moose Lake		MN0020699	58	522100
8610	Moose Lake Government	Moose Lake	0.07	MN0020699	52	921100
8611	Gateway Family Health Clinic	Moose Lake	0.05	MN0020699	40	621100
8612	First National Bank	Moose Lake		MN0020699	27	522100
8613	Emergency Response Center	Moose Lake	0.04	MN0020699	26	621100
8614	Americinn	Moose Lake		MN0020699	17	721100
8615	Moose Lake-Minnesota Real Estate	Moose Lake		MN0020699	12	531200
8616	Moose Lake Power	Moose Lake		MN0020699	10	238100
8617	Moose Lake Star Gazette	Moose Lake		MN0020699	6	511100
8618	Arrowhead Leader Newspaper	Moose Lake		MN0020699	5	511100
8619	Kanabec County Hospital	Mora	0.16	MN0021156	250	622100
8620	Mora School District	Mora		MN0021156	250	611100
8621	EPC	Mora	0.16	MN0021156	195	325200
8622	Industries, Inc.	Mora	0.10	MN0021156	120	325200
8623	Bluewater	Mora		MN0021156	75	336600
8624	Mora Medical Center	Mora	0.08	MN0021156	62	621100
8625	Pamida	Mora		MN0021156	50	452100
8626	Peoples National Bank	Mora		MN0021156	35	522100
8627	City of Mora	Mora	0.05	MN0021156	33	921100
8628	Kanabec County	Mora	0.04	MN0021156	30	921100
8629	Ingenuity, Inc	Mora	0.00	MN0021156	13	332700
8630	Morgan Public School Dist #636	Morgan		MN0020443	80	611100
8631	Gil-Mor Manor Nursing Home	Morgan		MN0020443	79	623100
8632	Harvest Land Cooperative	Morgan		MN0020443	35	493100
8633	Wayne's	Morgan		MN0020443	24	811300
8634	Morgan Grain & Feed	Morgan		MN0020443	14	493100
8635	Beckers Super Valu	Morgan		MN0020443	12	445100
8636	Dicks Sports Ctr	Morgan		MN0020443	5	451100
8637	MaB'sCafe	Morgan		MN0020443	5	722100
8638	B&L Industries	Morgan		MN0020443	4	425100
8639	Clements Lumber Inc	Morgan		MN0020443	4	444100
8640	Morgan Messenger	Morgan		MN0020443	3	511100
8641	Jeff's Garage	Morgan		MN0020443	1	811100
8642	NRP Plastics	Morgan	0.00	MN0020443	1	325200
8643	University of MN - Morris	Morris		MN0021318	449	611300
8644	Prairie Community Svc	Morris		MN0021318	238	623300
8645	Stevens Community Medical Ctr	Morris	0.14	MN0021318	210	622100
8646	Morris Public Schools	Morris		MN0021318	176	611100
8647	West Wind Village	Morris		MN0021318	162	623100

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ID	Facility Name	City	P_kgd	Permit_No	employee_count	NAICS Code
8648	Riley Bros Paving Inc	Morris		MN0021318	140	237300
8649	Stevens, County of	Morris	0.19	MN0021318	133	921100
8650	Riley Bros. Construction	Morris		MN0021318	130	237300
8651	WesMor Industries	Morris		MN0021318	119	332400
8652	Superior Industries	Morris		MN0021318	75	333100
8653	Willie's Super Valu	Morris		MN0021318	60	445100
8654	Mc Donalds	Morris		MN0021318	50	722100
8655	USDA Soil Lab	Morris		MN0021318	49	924100
8656	Morris, City of	Morris	0.07	MN0021318	47	921100
8657	Prairie Inn	Morris		MN0021318	47	721100
8658	Met Lounge/Diamond Supper Club	Morris		MN0021318	45	722400
8659	West Central Environmental Consulting	Morris		MN0021318	28	541600
8660	Jackpot Junction Casino	Morton		MN0051292	500	713200
8661	Altimate Medical	Morton	0.25	MN0051292	40	339100
8662	Flexor	Morton		MN0051292	30	423900
8663	Redpoll	Morton		MN0051292	10	811400
8664	Sysco Minnesota	St. Paul		MN0029815	615	722300
8667	Midwest Medical Services	St. Paul		MN0029815	192	621600
8668	Mounds View School Dist.	St. Paul		MN0029815	183	611100
8669	Tyson Companies	St. Paul	9.05	MN0029815	175	484100
8670	Vitran Express	St. Paul	7.24	MN0029815	140	484100
8671	Disetronic Medical Systems	St. Paul	0.15	MN0029815	120	541700
8672	Mermaid Supper Club & Banquet Ctr	St. Paul		MN0029815	110	713900
8674	Saturn of St Paul	St. Paul		MN0029815	80	441100
8675	Dell-Comm	St. Paul		MN0029815	74	517100
8677	Jonco Die Company	St. Paul	0.00	MN0029815	52	332700
8678	CG Hill & Sons	St. Paul		MN0029815	40	333200
8679	U.S. Geological Survey	St. Paul	0.06	MN0029815	40	921100
8681	Mountain Iron/Buhl School Dist. #712	Mountain Iron		MN0040835	110	611110
8682	L&M Supply	Mountain Iron		MN0040835	55	444130
8683	Monson Trucking	Mountain Iron		MN0040835	50	484121
8684	GE Industry Sales & Svc	Mountain Iron		MN0040835	45	811310
8685	DW&P Railroad	Mountain Iron	0.49	MN0040835	30	482111
8686	Northeast Service Cooperative	Mountain Iron		MN0040835	30	611710
8687	Arrowhead Library System	Mountain Iron		MN0040835	28	921190
8688	Mountain Iron, City of	Mountain Iron		MN0040835	26	921140
8689	Benchmark Engineering	Mountain Iron	0.00	MN0040835	25	541330
8690	Mtn. Lake Public Schools	Mountain Lake		MNG580035	109	611100
8691	Good Samaritan Village	Mountain Lake		MNG580035	100	623100
8692	Balzer, Inc.	Mountain Lake		MNG580035	64	333100
8693	Bargen Inc	Mountain Lake		MNG580035	50	237300
8694	Eventide Home	Mountain Lake		MNG580035	50	623100
8695	Mtn. Lake Furniture	Mountain Lake		MNG580035	35	337100
8697	Hiebert Greenhouses Inc	Mountain Lake		MNG580035	30	111400
8698	Kennel-Aire Mfg Co	Mountain Lake		MNG580035	30	332600
8699	Fast Distributing	Mountain Lake		MNG580035	25	333100
8700	Mtn.Lake Christian School	Mountain Lake		MNG580035	25	611100
8701	Watonwan Enterprises	Mountain Lake		MNG580035	10	337100
8702	Fast Wings	Mountain Lake	0.03	MNG580035	4	332900
8703	Murdock Elementary School	Murdock		MN0052990	40	611110
8704	Dooley's Petroleum	Murdock		MN0052990	14	424710
8705	Glacial Plains Cooperative	Murdock	0.06	MN0052990	11	424510
8706	Riley Bus Service	Murdock		MN0052990	9	485510
8707	First State Bank of Murdock	Murdock		MN0052990	6	522110
8708	Nashwauk Dairy Queen	Nashwauk		MN0053392	40	722100
8709	Nashwauk Schools-ISD 319	Nashwauk		MN0053392	35	611100
8710	Fred's IGA	Nashwauk		MN0053392	24	445100
8711	Nashwauk, City of	Nashwauk	0.02	MN0053392	13	921100
8712	Latvala Lumber Co	Nashwauk		MN0053392	12	444100
8713	American Bk of Nashwauk	Nashwauk		MN0053392	10	522100
8714	AFSCME Union Hdqtrs	Nashwauk	0.02	MN0053392	7	813900
8715	Data Processing	Nashwauk		MN0053392	5	518200
8716	Blue Goose Restaurant	Alexandria		MN0040738	25	722100
8717	Nelson Creamery	Alexandria	1.06	MN0040738	17	311500
8718	Corral & Crystal Bar	Alexandria		MN0040738	9	722400
8719	Diamond Jim's	Alexandria		MN0040738	4	722400
8720	Medtox Laboratory Inc	St. Paul		MN0029815	450	621511
8721	City of New Brighton	St. Paul		MN0029815	250	921190

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ID	Facility Name	City	P_kgd	Permit_No	employee_count	NAICS Code
8722	Hypro Corp Lear Inc	St. Paul	1.51	MN0029815	250	333911
8723	Extendicare Homes, Inc	St. Paul		MN0029815	175	623312
8724	Next Day Gourmet	St. Paul		MN0029815	175	423490
8725	Print Craft	St. Paul	0.58	MN0029815	175	323110
8726	Sparta Foods	St. Paul		MN0029815	175	311999
8727	Donatelle Plastics	St. Paul		MN0029815	150	326199
8728	Cub Foods	St. Paul		MN0029815	125	445110
8729	Trend Enterprises, Inc	St. Paul		MN0029815	125	562111
8730	Minnesota Masonic Homes North Ridge	St. Paul		MN0029815	1050	623110
8731	Egan Companies	St. Paul		MN0029815	625	238200
8732	Gage In-Store Marketing	St. Paul		MN0029815	350	339900
8733	Intermet	St. Paul		MN0029815	340	331500
8734	Simon Delivers, Inc.	St. Paul		MN0029815	240	454300
8736	St Therese Care Center	St. Paul		MN0029815	200	623100
8739	Paddock Laboratories	St. Paul		MN0029815	165	325400
8740	Ambassador Nursing Home	St. Paul		MN0029815	160	623100
8742	Navarre Corp	St. Paul		MN0029815	150	454100
8743	Gaines & Hanson Printing Co	St. Paul		MN0029815	140	323100
8745	Clariant Corporation	St. Paul	0.10	MN0029815	120	325200
8746	Oildyne Division	St. Paul		MN0029815	120	333900
8747	DisplayMasters Inc	St. Paul		MN0029815	115	711300
8749	Pac One	St. Paul		MN0029815	110	561900
8750	Mello Smello-Internatural Designs Inc	St. Paul		MN0029815	100	541600
8751	New London-Spicer Public Schools	Spicer		MN0052752	240	611100
8752	Glenoaks Care Ctr	Spicer		MN0052752	70	623100
8753	Hillcrest Restaurant	Spicer		MN0052752	42	722100
8754	Cable Spinning Equipment Co Inc	Spicer		MN0052752	40	423600
8755	Peterson Bus Svc	Spicer		MN0052752	35	485500
8756	Berry Test Sets	Spicer		MN0052752	23	423600
8757	Mid-State Telephone	Spicer		MN0052752	22	517100
8758	Big Store Grocery	Spicer		MN0052752	20	445100
8759	Farmers St Bk of New London	Spicer		MN0052752	19	522100
8760	McBroom Construction	Spicer		MN0052752	17	238100
8761	Rambow Inc	Spicer	0.01	MN0052752	17	334500
8762	American Legion Post #537	Spicer		MN0052752	15	813400
8763	Concrete Products	Spicer		MN0052752	15	327300
8764	United Minnesota Bk	Spicer		MN0052752	12	522100
8765	Dahmes Stainless	Spicer		MN0052752	9	423800
8766	New Prague Public Schools	New Prague		MN0020150	375	611110
8767	Chart Industries/MVE	New Prague	0.00	MN0020150	300	332700
8768	Queen Of Peace Hospital	New Prague	0.34	MN0020150	285	622110
8769	Mala Strana Health Care Ctr	New Prague		MN0020150	135	623110
8770	Econofoods	New Prague		MN0020150	77	445110
8771	Scott Equipment	New Prague		MN0020150	70	423800
8772	Con Agra	New Prague	6.88	MN0020150	67	311200
8773	Schumacher's New Prague	New Prague		MN0020150	60	721110
8774	Suel Printing Co.	New Prague		MN0020150	37	323100
8775	MN Valley Ag Coop	New Prague		MN0020150	31	424720
8776	Busch Bro, Machining	New Prague		MN0020150	25	333200
8777	Community Security Bank	New Prague		MN0020150	23	522110
8778	State Bank of New Prague	New Prague		MN0020150	23	522110
8779	RaDon Inc	New Prague	0.06	MN0020150	22	315999
8780	Marquette Bank	New Prague		MN0020150	21	522110
8781	Kratochvil Construction	New Prague		MN0020150	20	236220
8784	New Ulm Medical Center	New Ulm	0.31	MN0030066	480	622100
8785	New Ulm Public Schools-ISD#88	New Ulm		MN0030066	281	611100
8786	J & R Schugal Trucking Inc	New Ulm	11.38	MN0030066	220	484100
8788	Minnesota Valley Testing Laboratories	New Ulm		MN0030066	130	541300
8789	Dittrich Specialties	New Ulm		MN0030066	125	334400
8790	Holm Industries	New Ulm		MN0030066	120	339900
8791	Caterpillar Paving Co	New Ulm		MN0030066	97	333100
8792	PGI Mailers	New Ulm		MN0030066	85	561900
8793	Winding's Inc	New Ulm		MN0030066	84	335300
8794	MTS Automation	New Ulm		MN0030066	75	335300
8795	QMC Technologies	New Ulm		MN0030066	70	335300
8797	D & A Truck Line	New Ulm	2.59	MN0030066	50	484100
8799	Palm Beach Marinecraft	New Ulm		MN0030066	48	336600
8800	Kraft Transports	New Ulm	2.02	MN0030066	39	484100

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ID	Facility Name	City	P_kgd	Permit_No	employee_count	NAICS Code
8801	American Artstone Co	New Ulm		MN0030066	38	327300
8802	Lund Boat CO	New York Mills		MN0054330	372	336600
8803	Telnet Systems Inc	New York Mills		MN0054330	142	561900
8804	Elders Home Inc	New York Mills		MN0054330	124	623100
8805	New York Mills Schools-ISD #553	New York Mills		MN0054330	88	611100
8806	Otter Tail-Wadena CAC	New York Mills		MN0054330	53	624200
8807	Embroidery Studio	New York Mills		MN0054330	26	424300
8808	Modern Assemblies	New York Mills		MN0054330	8	423300
8809	Fritz Co	St. Paul	0.03	MN0029815	100	311300
8810	Northern States Power Co	St. Paul		MN0029815	100	221100
8811	Knox Lumber Co	St. Paul		MN0029815	93	444100
8812	Tinucci's Restaurant & Catering	St. Paul		MN0029815	70	722100
8813	Metro Gravel	St. Paul		MN0029815	39	212300
8814	Diversified Manufacturing Corp	St. Paul	0.04	MN0029815	35	325600
8815	Newport Cold Storage	St. Paul	0.02	MN0029815	35	334113
8816	MidAmerica Bk	St. Paul		MN0029815	21	522100
8817	Hewitt Machine & Mfg Inc	Searles		MNG580037	60	336600
8818	Nicollet Public Schools	Searles		MNG580037	55	611100
8819	Schmidts' Meat Market	Searles	0.16	MNG580037	35	445200
8820	Nicollet Manufacturing	Searles		MNG580037	15	336600
8821	Davisco International	Searles	0.65	MNG580037	14	311400
8822	Nicollet St Bk	Searles		MNG580037	14	522100
8823	Nicollet-New Ulm Vet Clinic	Searles		MNG580037	9	541900
8824	George's City Meats	Searles	0.04	MNG580037	8	445200
8825	Crystal Co-op	Searles		MNG580037	7	424900
8826	Nicollet Plumbing & Heating	Searles		MNG580037	7	238200
8827	North Branch Schools-ISD #138	North Branch		MN0024350	382	611100
8828	Tanger Factory Outlet	North Branch		MN0024350	300	452100
8829	Green Acres Country Care Ctr	North Branch		MN0024350	150	623100
8830	Nelson's Country Market	North Branch		MN0024350	80	445100
8831	Superior Engineering Inc	North Branch	0.00	MN0024350	50	332700
8832	Branch Manufacturing Co	North Branch	0.00	MN0024350	49	332700
8833	Peterson's North Branch Mill	North Branch		MN0024350	47	424900
8834	Swede O Inc	North Branch	1.10	MN0024350	38	339100
8835	Central Chevrolet Chrysler Inc	North Branch		MN0024350	35	441100
8836	Zinpro	North Branch		MN0024350	25	424900
8837	AmericInn Motel & Suites	North Branch		MN0024350	20	721100
8838	Community NB of Branch	North Branch		MN0024350	20	522100
8839	First National Bank of North Branch	North Branch		MN0024350	20	522100
8840	Lamperts Lumber	North Branch		MN0024350	20	444100
8841	Olson Power & Equipment	North Branch		MN0024350	18	424900
8842	Slumberland	North Branch		MN0024350	16	442100
8843	Heatco, Inc	North Branch		MN0024350	15	333400
8844	Jennings DeWan & Anderson	North Branch		MN0024350	14	541100
8845	Anderson Koch Ford	North Branch		MN0024350	13	441100
8846	Realty World Dresel	North Branch		MN0024350	10	531200
8847	Reider Machine	North Branch	0.00	MN0024350	9	332700
8848	Menne Printing & Graphics DBA Kopy Boy	North Branch		MN0024350	5	323100
8849	Product Fabricators Inc	North Branch	0.03	MN0024350	5	332900
8850	Chisago County Household Hazard Waste Facility	North Branch		MN0024350	3	562100
8851	G&K Builders	North Branch		MN0024350	2	236200
8852	Carlson Craft Social		3.63	ISTS	1093	323119
8853	Carlson Craft Commercial		2.17	ISTS	653	323119
8854	Kato Engineering/Reliance Electric			ISTS	476	333611
8855	Precision Press		1.17	ISTS	353	323119
8856	Taylor Corp			ISTS	335	561110
8857	Mico Inc			ISTS	310	336340
8858	Carlson Craft - Catalog Division		0.79	ISTS	237	323119
8859	So Central Tech College - Mankato			ISTS	212	611519
8860	Masterpiece Studios		0.66	ISTS	200	323119
8861	CGI - Commercial		0.52	ISTS	156	323119
8862	Fine Impressions Inc		0.51	ISTS	155	323119
8863	Carlson Craft Specialty Products		0.48	ISTS	144	323119
8864	Wis-Pak Inc		3.92	ISTS	135	312111
8865	Thin Film Technology		2.19	ISTS	130	334613
8866	Great Papers		0.38	ISTS	113	323119
8867	Pepsi-Cola Bottling Co		2.47	ISTS	85	312111
8868	Sween - Division of Coloplast		32.49	ISTS	80	325900

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ID	Facility Name	City	P_kgd	Permit_No	employee_count	NAICS Code
8869	Lindsay Window & Door Co			ISTS	50	327200
8870	Golden Heart Daycare			ISTS	35	624410
8871	Valley Bank			ISTS	35	522110
8872	Interactive Technologies Inc	St. Paul		MN0029815	400	335300
8873	Target	St. Paul		MN0029815	360	452100
8874	Aetrium Inc	St. Paul		MN0029815	150	334400
8875	Lillie Suburban Newspapers Inc	St. Paul		MN0029815	125	511100
8876	Berwald Roofing Inc	St. Paul		MN0029815	80	238100
8877	Delta Engineering Inc	St. Paul		MN0029815	80	541300
8879	Postal Employees Credit Union	St. Paul		MN0029815	67	522100
8880	Ground Round	St. Paul		MN0029815	60	722100
8881	Custom Millwork	St. Paul		MN0029815	50	423300
8882	TA Schifsky & Sons Inc	St. Paul		MN0029815	45	324100
8883	Heritage National Bank	St. Paul		MN0029815	26	522100
8884	St Olaf College	Northfield		MN0024368	840	611300
8885	Malt-O-Meal Co	Northfield	18.00	MN0024368	811	311200
8886	Carleton College	Northfield		MN0024368	678	611300
8887	Sheldahl Inc	Northfield		MN0024368	550	334400
8888	Northfield Public Schools-ISD#659	Northfield		MN0024368	500	611100
8889	Northfield Hospital	Northfield	0.22	MN0024368	332	622100
8890	Northfield, City of	Northfield	0.28	MN0024368	200	921100
8891	Three Links Care Ctr	Northfield		MN0024368	180	623100
8892	Allina Medical Clinic	Northfield		MN0024368	170	623100
8893	Cardinal Insulated Glass	Northfield		MN0024368	140	327200
8894	Frigoscandia Equipment	Northfield		MN0024368	130	333200
8895	Laura Baker School	Northfield		MN0024368	125	611500
8896	Main Stream Publications	Northfield		MN0024368	108	511100
8897	Northfield Retirement Ctr	Northfield		MN0024368	96	623100
8898	College City Beverage	Northfield		MN0024368	67	424800
8899	Northome Healthcare Ctr	Northome		MN0049158	91	623100
8900	Northome School Dist #363	Northome		MN0049158	46	611100
8901	Ellen's Cafe	Northome		MN0049158	10	722100
8902	Northland Community Bank	Northome		MN0049158	8	522100
8903	Northland Medical Center	Northome	0.01	MN0049158	8	621100
8904	Developmental Achievement Ctr	Northome		MN0049158	7	611500
8905	Northome True Value	Northome		MN0049158	7	452900
8906	Northome Grocery	Northome		MN0049158	5	445100
8907	Bongards' Creameries	Norwood Young America	17.17	MN0024392	275	311500
8908	Tino's (Division of SSE Manufacturing)	Norwood Young America	8.60	MN0024392	185	311400
8909	School District #108	Norwood Young America		MN0024392	149	611100
8910	State Bank of Norwood Young America	Norwood Young America		MN0024392	23	522100
8911	Lano's Equipment	Norwood Young America		MN0024392	22	333200
8912	Andersen Window Corporation	St. Paul		MN0029998	300	238100
8913	MCF - Oak Park Heights	St. Paul		MN0029998	280	922100
8914	Stillwater Area High School	St. Paul		MN0029998	215	611100
8915	Routson Motors	St. Paul		MN0029998	160	441100
8916	Rainbow Foods	St. Paul		MN0029998	125	445100
8917	Wal-Mart	St. Paul		MN0029998	125	453900
8918	Stillwater Motors	St. Paul		MN0029998	105	441100
8919	United States Postal Service Carrier Annex	St. Paul		MN0029998	100	491100
8921	Menards	St. Paul		MN0029998	60	423700
8923	MN Dept of Transportation	St. Paul		MN0029815	300	926100
8924	Washington County Human Svcs	St. Paul		MN0029815	176	923100
8925	Ryder Student Transportation	St. Paul		MN0029815	140	485400
8926	Rainbow Foods	St. Paul		MN0029815	135	445100
8927	Menard's	St. Paul		MN0029815	120	444100
8928	Classic Manufacturing	St. Paul	0.00	MN0029815	100	332700
8929	Polar Plastics Inc	St. Paul	0.13	MN0029815	75	326100
8930	Spartan Promotional Group Inc	St. Paul		MN0029815	55	313200
8931	Ogilvie Public Schools	Ogilvie		MN0021997	115	611100
8932	Camco Inc	Ogilvie		MN0021997	35	423800
8933	Tower Bar & Lounge	Ogilvie		MN0021997	10	722400
8934	Bill's Well Drilling	Ogilvie		MN0021997	7	237100
8935	Double J Cafe	Ogilvie		MN0021997	7	722100
8936	Henschel's Thriftway	Ogilvie		MN0021997	7	445100
8937	Co-op Feed Mill	Ogilvie		MN0021997	6	493100
8938	US Post Office	Ogilvie		MN0021997	6	491100
8939	Junnila Dental Office	Ogilvie		MN0021997	5	621200

Appendix B. Industrial Phosphorus Data Matched to MNPRO Database by NAICS

ID	Facility Name	City	P_kgd	Permit_No	employee_count	NAICS Code
8940	Princeton Bank - Ogilvie	Ogilvie		MN0021997	5	522100
8941	Vasko Rubbish Removal	Ogilvie		MN0021997	4	562100
8942	Northpost Inc	Ogilvie	0.00	MN0021997	2	332700
8943	Oklee Public Schools	Oklee		MNG580038	55	611100
8944	Oklee Farmers Elevator	Oklee		MNG580038	9	493100
8945	Security St Bk of Oklee	Oklee		MNG580038	8	522100
8946	Oklee Lumber	Oklee		MNG580038	5	321900
8947	Renville, County of	Olivia	0.27	MN0020907	190	921100
8948	BOLD Schools ISD #2534	Olivia		MN0020907	144	611100
8949	Renville County Hospital	Olivia	0.05	MN0020907	81	622100
8950	Olivia Healthcare Center	Olivia		MN0020907	68	623100
8951	Mycogen Seed Co	Olivia		MN0020907	50	111100
8952	Olivia, City of	Olivia	0.05	MN0020907	34	921100
8953	Prairie Family Practice	Olivia	0.03	MN0020907	24	621100
8954	Sheep Shedde Restaurant	Olivia		MN0020907	22	722100
8955	Terry's Holiday Market	Olivia		MN0020907	22	445100
8956	Elk River Concrete Products	Olivia		MN0020907	16	327100
8957	Sunrise Packaging, Inc.	Olivia		MN0020907	15	323100
8958	Dekalb Genetics Corporation	Olivia		MN0020907	12	111100
8959	Precision Soya of Minnesota LLC	Olivia		MN0020907	12	111100
8960	Ortonville Public School Dist #62	Ortonville		MN0051152	214	611100
8961	Ortonville Area Health Services	Ortonville	0.12	MN0051152	180	622100
8962	Ortonville, City of	Ortonville	0.13	MN0051152	96	921100
8963	Big Stone County	Ortonville	0.09	MN0051152	65	921100
8964	Hasslen Construction Co	Ortonville		MN0051152	60	236100
8965	Pepsi-Cola	Ortonville	2.09	MN0051152	31	312100
8966	Bill's SuperValue Plus	Ortonville		MN0051152	30	445100
8967	Minnwest Bk Ortonville	Ortonville		MN0051152	21	522100
8968	Dallas Hanson Construction	Ortonville		MN0051152	18	236100
8969	Northside Medical Center	Ortonville		MN0051152	17	524100
8970	Econolodge	Ortonville		MN0051152	15	721100
8971	Pizza Ranch	Ortonville		MN0051152	15	722100
8972	Ortonville Stone Company	Ortonville		MN0051152	14	212300
8973	US Post Office	Ortonville		MN0051152	10	491100
8974	CenBank	Ortonville		MN0051152	8	522100
8975	Osakis Public Schools	Osakis		MN0020028	96	611100
8976	Community Memorial Home	Osakis		MN0020028	90	623100
8977	Rollie's Sales & Service	Osakis		MN0020028	38	336900
8978	Just Like Grandma's	Osakis		MN0020028	34	721100
8979	Lind-Rite Precision Engineering Inc	Osakis	0.00	MN0020028	24	332700
8980	Food-N-Fuel	Osakis		MN0020028	17	447100
8981	Hensley Inc	Osakis	0.83	MN0020028	16	484100
8982	First NB of Osakis	Osakis		MN0020028	14	522100
8983	Home Quality Foods	Osakis		MN0020028	13	445100
8984	St Agnes School	Osakis		MN0020028	12	611100
8985	Osakis Clinic	Osakis	0.01	MN0020028	11	621100
8986	Osakis Creamery Assn	Osakis	0.69	MN0020028	11	311500
8987	Osakis, City of	Osakis	0.01	MN0020028	10	921100
8988	Thrifty White Drug	Osakis		MN0020028	9	446100
8989	Mark's Welding, Inc.	Osakis		MN0020028	5	811300
8990	Osakis Silo Co.	Osakis		MN0020028	5	423800
8991	Maus Fabrication, Inc.	Osakis		MN0020028	3	811300
8992	Osseo Public Schools	St. Paul		MN0029815	330	611100
8993	Berkshire Residence	St. Paul		MN0029815	125	623100
8995	Ceramic Industrial Coatings	St. Paul		MN0029815	55	325500
8996	Osseo Maple Grove Press	St. Paul		MN0029815	50	511100
8997	Riverwood Conference Center	Otsego		MN0064190	85	721100
8998	Otsego Elementary School	Otsego		MN0064190	75	611100
8999	Long Haul Trucking	Otsego		MN0064190	35	488400
9000	Rainbow Daycare & Preschool	Otsego		MN0064190	19	624400
9001	F&F Food Mart	Otsego		MN0064190	18	445100
9002	Bank of Elk River at Otsego	Otsego		MN0064190	15	522100
9003	Darkenwald Inc	Otsego		MN0064190	14	531200
9004	Fun City	Otsego		MN0064190	12	713900
9005	Tom Thumb	Otsego		MN0064190	10	445100
9006	Lef Co Farm Inc	Otsego		MN0064190	7	111900
9007	Elk River Box Factory	Otsego		MN0064190	6	444100
9008	Apex Business Center	Otsego		MN0064190	5	493100

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ID	Facility Name	City	P_kgd	Permit_No	employee_count	NAICS Code
9009	Riverbend Park	Otsego		MN0064190	5	721200
9010	Marquette Bank of Otsego	Otsego		MN0064190	4	522100
9011	Riverview Liquorette	Otsego		MN0064190	4	445300
9012	Viracon/Curvlite Inc	Owatonna		MN0051284	1650	327200
9013	Federated Insurance Co	Owatonna		MN0051284	1475	524100
9014	Truth Hardware	Owatonna	1.75	MN0051284	901	333500
9015	Spx Corp-Otc Div	Owatonna	0.92	MN0051284	800	335900
9016	Owatonna Public School District 761	Owatonna		MN0051284	750	611100
9017	Wenger Corp	Owatonna		MN0051284	460	339900
9018	Jostens	Owatonna		MN0051284	376	323100
9019	Cybex Corp	Owatonna		MN0051284	358	339900
9020	Cabela's	Owatonna		MN0051284	353	451100
9021	Spx Corp-Power Team Div	Owatonna		MN0051284	350	333900
9022	Steele County	Owatonna	0.45	MN0051284	317	921100
9023	Owatonna Hospital	Owatonna	0.14	MN0051284	215	622100
9024	Chiquita Processed Foods	Owatonna	9.90	MN0051284	213	311400
9025	Mustang Manufacturing Co	Owatonna		MN0051284	200	423800
9026	National Computer Systems	Owatonna		MN0051284	180	323100
9028	Owatonna Clinic	Owatonna	0.20	MN0051284	145	621100
9029	Blount Inc	Owatonna	0.00	MN0051284	137	332700
9030	Qwest	Owatonna		MN0051284	130	517100
9031	Wal-Mart	Owatonna		MN0051284	123	452100
9032	Hy-Vee Food Store	Owatonna		MN0051284	122	445100
9033	Target	Owatonna		MN0051284	122	452100
9034	Case Wise Foods	Owatonna		MN0051284	120	445100
9035	City of Owatonna	Owatonna	0.16	MN0051284	115	921100
9036	Slidell, Inc.	Owatonna		MN0051284	108	333900
9037	McQuay International	Owatonna		MN0051284	103	333400
9038	Lamb-Weston/RDO Frozen		25.57	MN0056332	550	311400
9039	St. Joseph's Area Health Services		0.19	MN0056332	300	622100
9040	Independent School District #309			MN0056332	270	611100
9041	Straight River Manufacturing			MN0056332	211	333600
9042	J&B Foods			MN0056332	175	445100
9043	Heritage Living Center			MN0056332	170	623100
9044	Hubbard County		0.23	MN0056332	164	921100
9045	North Star Orthodontics			MN0056332	96	339100
9046	Dakota Clinic		0.08	MN0056332	56	621100
9047	Citizens Bank			MN0056332	43	522100
9048	Northwoods Bank			MN0056332	43	522100
9049	L&M Fleet Suppy			MN0056332	40	452100
9050	Wonewok Conference Center (3M)			MN0056332	34	721100
9051	City of Park Rapids		0.04	MN0056332	32	921100
9052	Candle Enterprises			MN0056332	28	339900
9053	State Bank of Park Rapids			MN0056332	27	522100
9054	Itasca-Mantrap Electric Co-op			MN0056332	25	221100
9055	Thielen Motors, Inc.			MN0056332	24	441200
9056	Darchuk's Fabrication		0.00	MN0056332	20	332700
9057	Americinn of Park Rapids			MN0056332	17	721100
9058	Straight River Real Estate			MN0056332	16	531200
9059	MN DNR-Forestry			MN0056332	11	924100
9060	St William's Nursing Home				110	623100
9061	Parkers Prairie Schools-ISD #547				78	611100
9062	Kennys Candy Co		0.02		66	311300
9063	Daniels Food Equipment Inc		0.21		30	332900
9064	Carlson Trucking Inc		1.03		20	484100
9065	Dick's Standard Service				17	447100
9066	Midwest Telephone Co				14	517100
9067	Parkers Bus Co Inc				14	485400
9068	Nibblers Inn				13	722100
9069	Midwest Bank, NA				12	522100
9070	Parkers Prairie, City of		0.02		12	921100
9071	Madison's Food Store Inc				11	445100
9072	Parkers Trumm Drug				10	446100
9073	US Post Office				10	491100
9074	Prairie Implement Inc				9	423800
9075	Paynesville Community Hospital	Paynesville	0.12	MN0020168	190	622100
9076	Paynesville School Dist 741	Paynesville		MN0020168	148	611100
9077	Assoc Milk Producers Inc	Paynesville	5.37	MN0020168	86	311500

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ID	Facility Name	City	P_kgd	Permit_No	employee_count	NAICS Code
9078	Stearns Manufacturing Co	Paynesville		MN0020168	60	423900
9079	Good Samaritan Care Ctr	Paynesville		MN0020168	48	623100
9080	Master Mark Plastic Products	Paynesville	0.03	MN0020168	40	325200
9081	Quality Checked Plastics	Paynesville	0.03	MN0020168	40	325200
9082	United Parcel Svc	Paynesville		MN0020168	34	492100
9083	Jerry's Jack & Jill	Paynesville		MN0020168	28	445100
9084	Wally's G & T Foods	Paynesville		MN0020168	22	445100
9085	Louis Industries Inc	Paynesville		MN0020168	20	237900
9086	Paynesville, City of	Paynesville	0.03	MN0020168	19	921100
9087	Farmer's Union	Paynesville		MN0020168	17	324100
9088	West Central Turkeys Inc	Pelican Rapids	2.25	MN0022225	750	311600
9089	Pelican Rapids Schools-ISD 548	Pelican Rapids		MN0022225	153	611100
9090	Good Samaritan Center	Pelican Rapids		MN0022225	96	623100
9091	Meritcare Pelican Rapids	Pelican Rapids	0.12	MN0022225	92	621100
9092	Lake Region Co-op Electrical	Pelican Rapids		MN0022225	72	221100
9093	Gerald N Evenson Inc	Pelican Rapids	0.00	MN0022225	70	484100
9094	Attachments International Inc.	Pelican Rapids	0.17	MN0022225	25	332900
9095	Blue Water Restaurant & Sports Bar	Pelican Rapids		MN0022225	50	722100
9096	Bridges Bistro & Tavern	Pelican Rapids		MN0022225	50	722100
9097	BTD Manufacturing Inc.	Pelican Rapids		MN0022225	50	333900
9098	Card Brokers of America	Pelican Rapids		MN0022225	50	424100
9099	City of Pelican Rapids	Pelican Rapids	0.07	MN0022225	50	921100
9100	Larry's Supermarket	Pelican Rapids		MN0022225	50	445100
9101	Minn-Dak Transport Inc.	Pelican Rapids	0.00	MN0022225	50	484100
9102	Pelican Drug	Pelican Rapids		MN0022225	50	446100
9103	Pelican Super Valu	Pelican Rapids		MN0022225	50	445100
9104	Southtown Citgo	Pelican Rapids		MN0022225	50	447100
9105	KLN Enterprises Inc.	Perham	10.02	MN0024473	517	311900
9106	Perham Memorial Hospital & Home	Perham	0.19	MN0024473	295	622100
9107	Perham Public School	Perham		MN0024473	260	611100
9108	Arvig Communication Systems	Perham		MN0024473	238	517100
9109	Royal Resources	Perham		MN0024473	107	561300
9110	Tuffy's Pet Foods	Perham		MN0024473	80	311100
9111	Grocery Stores	Perham		MN0024473	70	445100
9112	Perham Co-op Creamery	Perham	3.75	MN0024473	60	311500
9113	Primera Foods	Perham		MN0024473	60	112300
9114	Hammers Construction	Perham		MN0024473	50	236100
9115	United Community Bank	Perham		MN0024473	46	522100
9116	Land O'Lakes	Perham	2.75	MN0024473	44	311500
9117	Bauck Busing	Perham		MN0024473	32	485400
9118	City of Perham	Perham	0.04	MN0024473	31	921100
9119	CC&I Engineering	Perham		MN0024473	30	541300
9120	RD Offutt Co.	Perham		MN0024473	30	111900
9121	Manion Lumber	Pillager		MN0048909	75	423300
9122	Pillager Public School- ISD116	Pillager		MN0048909	64	611110
9123	Lakes Employment Opportunities	Pillager		MN0048909	6	623210
9124	School District 578	Pine City		MN0021784	205	611100
9125	Imation	Pine City		MN0021784	200	339900
9126	Pine Technical college	Pine City		MN0021784	150	611300
9127	Lakeside Medical Center, Inc.	Pine City	0.09	MN0021784	135	622100
9128	Pine County	Pine City	0.19	MN0021784	135	921100
9129	Product Fabrication	Pine City	0.79	MN0021784	115	332900
9130	Atscott Manufacturing	Pine City	0.19	MN0021784	100	333500
9131	Shafer electronic	Pine City		MN0021784	40	425100
9132	Hunt Bus Service	Pine City		MN0021784	35	485400
9133	DAKA	Pine City		MN0021784	25	332300
9134	DS Manufacturing Inc	Pine Island	1.89	MN0024511	170	332800
9135	Pine Haven Care Ctr	Pine Island		MN0024511	150	623100
9136	Land O'Lakes Inc	Pine Island	0.65	MN0024511	130	445200
9137	Pine Island Public Schools	Pine Island		MN0024511	123	611100
9138	Progressive Tool & Mfg Co	Pine Island	0.00	MN0024511	59	332700
9139	Pine Island Farmer's Elevator	Pine Island		MN0024511	36	424500
9140	Whispering Pines Good Samaritan	Pine River		MN0046388	170	623100
9141	Pine River Public Schools	Pine River		MN0046388	165	611100
9142	Houston Ford Inc	Pine River		MN0046388	46	441100
9143	Jerry's Super Valu	Pine River		MN0046388	20	445100
9144	US Marine	Pipestone		MN0054801	340	336600
9145	Pipestone Systems	Pipestone		MN0054801	300	112200

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ID	Facility Name	City	P_kgd	Permit_No	employee_count	NAICS Code
9146	Pipestone/Jasper School Dist.	Pipestone		MN0054801	250	611100
9147	Pipestone County Medical Ctr	Pipestone	0.11	MN0054801	175	622100
9148	Good Samaritan Village	Pipestone		MN0054801	170	623100
9149	Ellison Meat Co	Pipestone	8.50	MN0054801	150	311600
9150	Hank's Foods	Pipestone		MN0054801	50	445100
9151	First NB of Pipestone	Pipestone		MN0054801	43	522100
9152	Juba's Inc	Pipestone		MN0054801	36	445100
9153	Pipestone Publishing Co	Pipestone		MN0054801	35	511100
9154	Pamida Discount Ctr	Pipestone		MN0054801	32	452100
9155	M&M Distributing Co	Pipestone		MN0054801	26	424900
9156	Pipestone Veterinary Clinic	Pipestone		MN0054801	25	541900
9157	Pepsi-Cola Bottling Co	Pipestone	1.55	MN0054801	23	312100
9159	Plainview Community Schools	Plainview		MN0055361	155	611100
9160	Hillcrest Community Care Center	Plainview		MN0055361	100	623100
9161	Plato Woodwork			ISTS	120	444100
9162	Plato Home Center			ISTS	14	444100
9163	Carlson	St. Paul		MN0029815	2225	561510
9164	Prudential Insurance Co	St. Paul		MN0029815	1600	524113
9165	US West Communications	St. Paul		MN0029815	700	517110
9166	Boston Scientific	St. Paul	0.40	MN0029815	600	334510
9168	Select Comfort Corp	St. Paul		MN0029815	475	442110
9170	US Food Service	St. Paul		MN0029815	400	722330
9171	Fortis Health	St. Paul		MN0029815	390	524114
9172	Deltak Corp	St. Paul		MN0029815	370	332410
9173	Turck Inc	St. Paul		MN0029815	322	335999
9174	Wagner Spray Tech Inc	St. Paul	0.53	MN0029815	265	325510
9175	Banner Engineering Corp	St. Paul		MN0029815	260	335999
9176	Nu-Aire Inc	St. Paul	0.27	MN0029815	250	339111
9178	West Health	St. Paul		MN0029815	220	621498
9179	LSI Corp of America	St. Paul	5.94	MN0029815	215	337127
9181	McQuay Intl	St. Paul	0.67	MN0029815	190	333415
9182	Olympic Steel Co	St. Paul		MN0029815	190	423510
9183	Scoville Press Inc	St. Paul	0.58	MN0029815	175	323119
9184	Fillmore, County of	Preston	0.28	MN0020745	200	921100
9185	Good Samaritan Nursing Home	Preston		MN0020745	105	623100
9186	Fillmore Central School District #2198	Preston		MN0020745	90	611100
9187	Root River Hardwoods	Preston		MN0020745	65	337100
9188	Foremost Farms USA	Preston		MN0020745	32	311800
9189	Pro-Corn Ethanol	Preston		MN0020745	29	339900
9190	Dahl's IGA	Preston		MN0020745	23	445100
9191	F&M Community Bk	Preston		MN0020745	20	522100
9192	Fillmore County DAC	Preston		MN0020745	20	624300
9193	Byrne & Company Ltd	Preston		MN0020745	18	541200
9194	Country Hearth Inn	Preston		MN0020745	12	721100
9195	Fillmore County Journal	Preston		MN0020745	12	511100
9196	Crystal Cabinet Works Inc			MN0024538	600	337100
9197	Princeton Public School Dist #477			MN0024538	450	611100
9198	Fairview Northland Reg Hosp		0.27	MN0024538	413	622100
9199	Plastics Products		0.28	MN0024538	350	325200
9200	Westling Mfg Inc			MN0024538	329	336300
9201	Elim Retirement & Nursing Home			MN0024538	190	623100
9202	United States Distilled Prods		10.12	MN0024538	150	312100
9203	ECM Publishers Inc			MN0024538	142	511100
9204	Coborns, Inc.			MN0024538	120	445100
9205	Smith System Mfg Co			MN0024538	85	332300
9206	Automated Flight Svc Station			MN0024538	76	481100
9207	Sladek's Food Pride			MN0024538	64	445100
9208	Pamida Inc			MN0024538	59	452100
9209	Bremer Bank			MN0024538	45	522100
9210	Princeton Auto Center			MN0024538	30	441100
9211	Prior Lake Ind School Dist #719	St. Paul		MN0029882	549	611100
9212	County Market	St. Paul		MN0029882	155	445100
9213	Prior Lake, City of	St. Paul	0.09	MN0029882	65	921100
9214	Prior Lake State Bank	St. Paul		MN0029882	40	522100
9216	ISD $704	Duluth		MN0049786	300	611100
9217	Blackwood's Bar and Grill	Duluth		MN0049786	88	722100
9218	McDonald's	Duluth		MN0049786	42	722100
9219	Country Kitchen	Duluth		MN0049786	30	722100

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ID	Facility Name	City	P_kgd	Permit_No	employee_count	NAICS Code
9220	Country Inn & Suites	Duluth		MN0049786	25	721100
9221	Lamar Advertising	Duluth		MN0049786	25	541800
9222	AmericInn Hotel	Duluth		MN0049786	23	721100
9223	Carlson Bros/ Electric Constructors	Duluth		MN0049786	21	811200
9224	Spirit Mountain Lodge	Duluth		MN0049786	20	721100
9225	Proctor Federal Credit Union	Duluth		MN0049786	19	522100
9226	First National Bank	Duluth		MN0049786	17	522100
9227	Proctor Medical Center	Duluth	0.01	MN0049786	11	621100
9228	Jerry Waldholm Excavating	Duluth		MN0049786	10	238900
9229	Vision Ease			ISTS	400	334600
9230	Connexus Energy			ISTS	230	221100
9232	Anderson & Dahlen		0.31	ISTS	160	333500
9233	ALTRON, Inc			ISTS	104	334100
9234	Command Tooling		0.00	ISTS	84	332700
9235	ACE Solid Waste			ISTS	80	562100
9236	Zero Zone Refrigeration			ISTS	59	333400
9238	Heritage Millwork			ISTS	45	444100
9239	Grosslein Beverage Inc.		2.90	ISTS	43	312100
9240	Airgas North Central			ISTS	42	211100
9241	RJM / General Paper Products			ISTS	40	322200
9242	Artistic Marble	Randall		MN0024562	10	327900
9243	Bernel's Shoe Store	Randall		MN0024562	10	448200
9244	Gosch's Meat Market	Randall	0.04	MN0024562	10	445200
9245	Petro Plus	Randall		MN0024562	10	447100
9246	Homark Co	Red Lake Falls		MN0020613	120	321900
9247	Red Lake Falls Public Schools	Red Lake Falls		MN0020613	95	611100
9248	Red Lake, County of	Red Lake Falls	0.10	MN0020613	68	921100
9249	Hillcrest Nursing Home	Red Lake Falls		MN0020613	55	623100
9250	Red Lake Electric Coop	Red Lake Falls		MN0020613	23	221100
9251	Red Lake County St Bank	Red Lake Falls		MN0020613	22	522100
9252	Tailored Wear	Red Lake Falls		MN0020613	14	448100
9253	Northwest Mfg	Red Lake Falls		MN0020613	10	333400
9254	Treasure Island Casino	Red Wing		MN0024571	1875	713200
9255	Red Wing Shoe Co	Red Wing		MN0024571	1200	316200
9257	Fairview Red Wing Medical Center	Red Wing	0.29	MN0024571	450	622100
9258	Norwood	Red Wing		MN0024571	349	339900
9259	SB Foot Tanning Co	Red Wing		MN0024571	266	316100
9260	Jostens Diploma Division	Red Wing		MN0024571	253	323100
9261	DB Industries Inc	Red Wing		MN0024571	228	315900
9262	Express Services	Red Wing		MN0024571	226	561300
9263	DAYCO PTI Inc	Red Wing		MN0024571	167	326200
9264	St James Hotel	Red Wing		MN0024571	150	721100
9265	Fairview Seminary Home	Red Wing		MN0024571	120	623100
9266	Riedell Shoes Inc	Red Wing		MN0024571	86	339900
9267	Schwan's Technology	Red Wing		MN0024571	77	541500
9268	Goodhue Public Health	Red Wing		MN0024571	72	621600
9269	Artesyn Technologies	Redwood Falls		MN0020401	320	334100
9270	Redwood Falls Schools-ISD #2897	Redwood Falls		MN0020401	225	611100
9271	Schult Homes Corp	Redwood Falls		MN0020401	195	321900
9272	Redwood, County of	Redwood Falls	0.26	MN0020401	183	921100
9273	Redwood Area Municipal Hospital	Redwood Falls	0.07	MN0020401	112	622100
9275	Affilliated Area Medical Center	Redwood Falls	0.08	MN0020401	58	621100
9276	Minnesota Valley Bank	Redwood Falls		MN0020401	56	522100
9277	Service Enterprises	Redwood Falls		MN0020401	55	624300
9278	Redwood Falls, City of	Redwood Falls	0.08	MN0020401	54	921100
9279	Activeaid Inc	Redwood Falls	0.25	MN0020401	40	339100
9280	Warrior Manufacturing Co	Redwood Falls		MN0020401	29	423800
9281	Larry Schefus Trucking Inc	Redwood Falls	1.09	MN0020401	21	484100
9282	Heartland Wood Products	Redwood Falls		MN0020401	20	444100
9283	Redwood Metal Works	Redwood Falls	0.00	MN0020401	14	332700
9284	Monsanto	Redwood Falls	0.04	MN0020401	8	541700
9285	Pioneer Hi-Bred Intl Inc	Redwood Falls	0.03	MN0020401	6	541700
9286	Southern Minnesota Beet Sugar	Renville	0.13	MN0020737	380	311300
9287	Renville County West School District # 2890.	Renville		MN0020737	118	611100
9288	Ren Villa Nursing Home	Renville		MN0020737	110	623100
9289	Golden Oval Egg	Renville		MN0020737	70	112300
9290	ValAdCo	Renville		MN0020737	55	112200
9291	Coop Farmers Elevator	Renville		MN0020737	40	424900

Appendix B. Industrial Phosphorus Data Matched to MNPRO Database by NAICS

ID	Facility Name	City	P_kgd	Permit_No	employee_count	NAICS Code
9292	Farmer's Coop Oil	Renville		MN0020737	31	424900
9293	K&M Mfg & Repair Co	Renville		MN0020737	27	423800
9294	H&L Motors	Renville		MN0020737	21	441100
9295	Renville, City of	Renville	0.02	MN0020737	15	921100
9296	Wacker Implement	Renville		MN0020737	14	423800
9297	Community Electric	Renville		MN0020737	9	238200
9298	Varpness Implement	Renville		MN0020737	9	423800
9299	TransDistribution Inc	Renville		MN0020737	8	485500
9300	Multifoods Specialty Distribution	Rice		MN0056481	350	445100
9301	Ferche Millwork Inc	Rice		MN0056481	200	321900
9302	Rice Elementary School	Rice		MN0056481	65	611100
9303	Lake State Industries	Rice		MN0056481	25	333200
9304	Prairie Farm Company	Rice		MN0056481	25	424400
9305	Central Marble	Rice		MN0056481	22	327900
9306	Aura Lens Products Inc	Rice	0.58	MN0056481	20	339100
9307	Gopher State Contractors Inc	Rice		MN0056481	20	236100
9308	Classic Craft Woodworking	Rice		MN0056481	15	337100
9309	Rice Farm Supply	Rice		MN0056481	15	493100
9310	Wollak's Hardware & Equipment	Rice		MN0056481	13	444100
9311	Benton Cooperative Telephone Co	Rice		MN0056481	11	517100
9312	Richfield Public Schools-ISD #280	St. Paul		MN0029815	588	611100
9313	Richfield, City of	St. Paul	0.77	MN0029815	550	921100
9314	Copy Duplicating Products	St. Paul		MN0029815	450	453200
9315	M & I Bank	St. Paul		MN0029815	237	522100
9316	Rainbow Foods	St. Paul		MN0029815	200	445100
9317	Metro Sales	St. Paul		MN0029815	185	453200
9318	Richfield Health Ctr	St. Paul		MN0029815	120	623100
9319	Chi Chi's Mexican Restaurant	St. Paul		MN0029815	118	722100
9320	Champps	St. Paul		MN0029815	115	722100
9321	K Mart	St. Paul		MN0029815	115	452100
9322	Best Buy	St. Paul		MN0029815	100	443100
9323	Menards	St. Paul		MN0029815	100	444100
9324	Jerry's	Richmond		MN0024597	30	722400
9325	Richmond Bus Service	Richmond		MN0024597	25	485400
9326	Plantenberg Market & Meats	Richmond		MN0024597	22	445100
9327	State Bk of Richmond	Richmond		MN0024597	14	522100
9328	Nick Keller Masonry	Richmond		MN0024597	12	238100
9329	Richmond Marine & Sports	Richmond		MN0024597	10	441200
9330	Riverside Coliseum	Richmond		MN0024597	10	713900
9331	Torah Cafe	Richmond		MN0024597	10	722100
9332	Casey's General Store	Richmond	0.00	MN0024597	9	445200
9333	Meierhofer Real Estate	Richmond		MN0024597	8	531200
9334	Wenner Plumbing & Heating	Richmond		MN0024597	8	238200
9335	Granite City Concrete	Richmond		MN0024597	7	327300
9336	Richmond Body Shop	Richmond		MN0024597	7	811100
9337	Richmond Concrete Products	Richmond		MN0024597	7	327300
9338	Janssen Masonry	Richmond		MN0024597	6	238100
9339	Jennings Well Drilling	Richmond		MN0024597	6	237100
9340	Richmond Area Medical Clinic	Richmond	0.01	MN0024597	6	621100
9341	Jill's Cafe	Richmond		MN0024597	5	722100
9342	Richmond Mobil	Richmond		MN0024597	5	447100
9343	Wenner Hardware	Richmond		MN0024597	5	444100
9345	Robbinsdale Schools-ISD #281	St. Paul		MN0029815	2080	611100
9346	Rainbow Foods	St. Paul		MN0029815	175	445100
9347	Robbinsdale, City of	St. Paul	0.10	MN0029815	74	921100
9348	Twin City Federal Bank	St. Paul		MN0029815	60	522100
9349	US Bank - Robbinsdale	St. Paul		MN0029815	42	522100
9350	Robbinsdale Farm & Garden	St. Paul		MN0029815	40	444200
9351	Burmeister Electric Co	St. Paul		MN0029815	25	238200
9352	American Legion Post #251	St. Paul		MN0029815	21	813400
9353	Citizens Independent Bank	St. Paul		MN0029815	17	522100
9354	Mayo Medical Ctr	Rochester	16.71	MN0024619	25736	622100
9355	IBM Corp	Rochester		MN0024619	4600	334400
9356	Rochester Public Schools	Rochester		MN0024619	2150	611100
9357	Olmsted, County of	Rochester	1.67	MN0024619	1189	921100
9358	HyVee Store	Rochester		MN0024619	1050	445100
9359	Olmsted Medical Center	Rochester	0.60	MN0024619	925	622100
9360	Rochester, City of	Rochester	1.12	MN0024619	800	921100

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ID	Facility Name	City	P_kgd	Permit_No	employee_count	NAICS Code
9361	Sunstone Hotel Properties	Rochester		MN0024619	800	721100
9362	Pemstar Inc	Rochester		MN0024619	680	335300
9365	Rochester Community and Technical College	Rochester		MN0024619	550	611300
9368	Rochester Meats Inc	Rochester	12.75	MN0024619	225	311600
9369	IBM Credit Union	Rochester		MN0024619	213	522100
9370	HIMEC Inc	Rochester	1.34	MN0024619	194	332900
9371	JDS Uniphase	Rochester		MN0024619	125	519100
9372	Gauthier Industries Inc	Rochester	0.46	MN0024619	88	541700
9373	Crossroads Cafe			ISTS	7	722100
9374	Heineman's L & G Products			ISTS	5	238900
9375	Anderson Relics & Antiques			ISTS	4	453900
9376	Tim's 66 & Cafe			ISTS	3	447100
9377	Rockford Public Schools-ISD #883	Rockford		MN0024627	205	611100
9378	Wright-Hennepin Coop Electric Assn	Rockford		MN0024627	180	221100
9379	Byerly's Bakery	Rockford		MN0024627	90	311800
9380	DiversiFoam Products	Rockford		MN0024627	80	424600
9381	Domino's Pizza	Rockford		MN0024627	15	722100
9382	Rockford State Bank	Rockford		MN0024627	15	522100
9383	Rollingstone Schools-ISD #861	Rollingstone		MNG580078	10	611100
9384	Eastwood Bank	Rollingstone		MNG580078	8	522100
9385	Rollingstone Co-op	Rollingstone		MNG580078	8	424900
9386	Rollingstone Lumber	Rollingstone		MNG580078	7	321900
9387	H&M Plumbing	Rollingstone		MNG580078	5	238200
9388	Rollingstone Feed & Grain	Rollingstone		MNG580078	5	424900
9389	Bonnie Rae's Cafe & Grocery	Rollingstone		MNG580078	4	722100
9390	Ginny's Supper Club	Rollingstone		MNG580078	4	722100
9391	Stoos Electric	Rollingstone		MNG580078	4	238200
9392	Southland Elementary School	Rose Creek		MNG580072	30	611100
9393	JD Driver Construction	Rose Creek		MNG580072	17	236100
9394	Huntting Elevator	Rose Creek		MNG580072	9	493100
9395	Woody's	Rose Creek		MNG580072	9	722400
9396	Stroup Distributing	Rose Creek		MNG580072	6	424900
9397	Dave's Plumbing & Heating	Rose Creek		MNG580072	5	238200
9398	Brenda's Market	Rose Creek		MNG580072	4	445100
9399	Rose Creek, City of	Rose Creek	0.01	MNG580072	4	921100
9400	Farmers St Bk of Adams at Rose Creek	Rose Creek		MNG580072	3	522100
9401	Southland Oil	Rose Creek		MNG580072	3	424900
9402	Tradexpos	Rose Creek		MNG580072	3	711300
9403	Ulven Hardware	Rose Creek		MNG580072	3	444100
9404	Rose Creek Equipment	Rose Creek		MNG580072	1	423800
9405	Polaris Industries	Roseau		MNG580039	2100	336900
9406	Roseau Public Schools	Roseau		MNG580039	190	611100
9407	Roseau Area Hospital	Roseau	0.11	MNG580039	165	622100
9408	Roseau, County of	Roseau	0.14	MNG580039	101	921100
9409	Woodland Container Corp	Roseau		MNG580039	60	321900
9410	REM-Roseau	Roseau		MNG580039	50	621400
9411	Wally's Supermarket	Roseau		MNG580039	47	445100
9412	Citizens St Bk of Roseau	Roseau		MNG580039	45	522100
9413	Farmer's Union Oil Co	Roseau		MNG580039	40	444100
9414	Pamida Discount Ctr	Roseau		MNG580039	35	452100
9415	Roseau Clinic	Roseau	0.04	MNG580039	29	621100
9416	Roseau Electric Co-op Inc	Roseau		MNG580039	26	221100
9417	Roseau, City of	Roseau	0.04	MNG580039	25	921100
9418	Occupational Development Ctr	Roseau		MNG580039	23	624300
9419	Rosemount School District #196	St. Paul		MN0025488	2900	611100
9421	Dakota County Technical College	St. Paul		MN0025488	775	611500
9423	Spectro Alloys Corp	St. Paul		MN0025488	110	331200
9424	Reese Enterprises Inc	St. Paul	0.08	MN0025488	100	325200
9425	Genz-Ryan	St. Paul		MN0025488	90	238200
9426	Dakota County HRA	St. Paul	0.08	MN0025488	60	921100
9427	Knutson Services Inc	St. Paul		MN0025488	60	562100
9428	Rosemount, City of	St. Paul	0.08	MN0025488	60	921100
9429	CF Industries	St. Paul		MN0025488	46	424900
9430	Cub Foods	St. Paul		MN0025488	40	445100
9431	Peoples Natural Gas	St. Paul		MN0025488	40	221200
9432	Carlson Tractor & Equipment Co	St. Paul		MN0025488	35	333100
9434	Von Hanson's Meat Market	St. Paul	0.13	MN0025488	30	445200
9435	MN Dept, of Transportation	St. Paul		MN0029815	1500	926120

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ID	Facility Name	City	P_kgd	Permit_No	employee_count	NAICS Code
9436	Beltmann Group	St. Paul		MN0029815	956	484210
9437	Unisys	St. Paul		MN0029815	900	541519
9438	HealthSpan Home Care & Hospice	St. Paul		MN0029815	800	621610
9439	McGough Construction	St. Paul		MN0029815	800	236220
9440	Marshall Fields	St. Paul		MN0029815	700	452111
9441	MN Dept. of Education	St. Paul		MN0029815	500	923110
9442	Sara Lee Baking Co	St. Paul	1.92	MN0029815	500	311813
9443	JC Penney	St. Paul		MN0029815	400	452111
9444	Veritas	St. Paul		MN0029815	400	541512
9445	Byerly's	St. Paul		MN0029815	300	445110
9446	Heartland Home Health & Hospice	St. Paul		MN0029815	300	621610
9447	City of Roseville	St. Paul		MN0029815	281	921190
9449	Bonestroo Rosene Anderlik & Associates	St. Paul	0.00	MN0029815	270	541330
9450	Kraft - Sather Trucking	Round Lake	0.00	MN0051713	350	484100
9451	Round Lake Public School	Round Lake		MN0051713	30	611100
9452	Round Lake Farmer's Co-op	Round Lake		MN0051713	10	424900
9453	City of Round Lake	Round Lake	0.01	MN0051713	6	921100
9454	Round Lake Pit Stop	Round Lake		MN0051713	6	722100
9455	United Prairie Bank	Round Lake		MN0051713	6	522100
9456	Metalcrafters of Round Lake	Round Lake	0.03	MN0051713	4	332900
9457	Hatt Trick Lounge	Round Lake		MN0051713	3	722400
9458	Heath Auto Sales	Round Lake		MN0051713	3	811100
9459	United Prairie Insurance	Round Lake		MN0051713	3	524100
9460	Farmers Insurance Agency	Round Lake		MN0051713	2	524100
9461	Spessard Repair	Round Lake		MN0051713	2	332200
9462	Doeden Plumbing & Heating	Round Lake		MN0051713	1	238200
9463	Head Over Heals Hair Studio	Round Lake	0.00	MN0051713	1	812100
9464	Head Quarters	Round Lake	0.00	MN0051713	1	812100
9465	Royalton Public School District #485	Royalton		MNG580040	102	611100
9466	Newmans' Manufacturing Inc	Royalton	0.00	MNG580040	30	332700
9467	EZ Stop Store	Royalton		MNG580040	19	445100
9468	Majaski Machine Shop	Royalton	0.00	MNG580040	10	332700
9469	Royalton Lumber & Hardware	Royalton		MNG580040	8	444100
9470	Bea's Cafe	Royalton		MNG580040	6	722100
9471	Royal Ag Service	Royalton		MNG580040	2	424900
9472	TRW Electronics	Rushford		MN0024678	450	425100
9473	Good Shepherd Home	Rushford		MN0024678	100	623100
9474	Riverside Electronics Ltd	Rushford		MN0024678	100	425100
9475	Rushford-Peterson Public Schools	Rushford		MN0024678	75	611100
9476	Farmer's Cooperative Elevator	Rushford		MN0024678	25	111100
9477	SEMCAC	Rushford		MN0024678	25	624200
9478	Rushford IGA	Rushford		MN0024678	22	445100
9479	Dahl's Autoworks	Rushford		MN0024678	15	441200
9480	Carlson's Ready Mix	Rushford		MN0024678	12	327300
9481	Jim Norstad Construction	Rushford		MN0024678	12	236100
9482	Rushford State Bank	Rushford		MN0024678	12	522100
9483	City of Rushford	Rushford	0.02	MN0024678	11	921100
9484	Norman's Electric	Rushford		MN0024678	10	238200
9485	SEMDC	Rushford		MN0024678	10	541600
9486	M&M Lawn & Leisure	Rushford		MN0024678	9	423800
9487	National Bank of Rushford	Rushford		MN0024678	9	522100
9488	Woxland's Plumbing and Heating	Rushford		MN0024678	8	238200
9489	Tri-County Record	Rushford		MN0024678	7	511100
9490	J&L Wood Products	Rushford		MN0024678	5	444100
9491	Lutz Printing, Inc	Rushford		MN0024678	5	323100
9492	Rushford TV & Repairs	Rushford		MN0024678	4	443100
9493	Ken's Farm Equip. Builders & Repair			ISTS	10	423800
9494	Norman's Electric Service Inc			ISTS	9	237100
9495	Norse Products Inc			ISTS	8	444100
9496	Cenex/Land O'Lakes			ISTS	6	424900
9497	Jim's Building Center			ISTS	6	444100
9498	Peterson State Fish Hatchery			ISTS	6	112500
9499	Brown's Tire & Battery Inc			ISTS	5	326200
9500	Hi Tec Rebuilders			ISTS	5	441100
9501	Norstad Construction			ISTS	5	236100
9502	DM Construction			ISTS	3	236100
9503	United FArmer's Co-op	Rushmore		MN0025836	12	424900
9504	Gary's Electric	Rushmore		MN0025836	8	238200

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ID	Facility Name	City	P_kgd	Permit_No	employee_count	NAICS Code
9505	Daryl's Service	Rushmore		MN0025836	5	811100
9506	First State Bank of Rushmore	Rushmore		MN0025836	4	522100
9507	City of Rushmore	Rushmore	0.00	MN0025836	3	921100
9508	Petersen Car Service	Rushmore		MN0025836	3	811100
9509	Rushmore Gas Service Co.	Rushmore		MN0025836	3	424900
9510	Rushmore Head Start Center	Rushmore		MN0025836	3	624400
9511	Rushmore Post Office	Rushmore		MN0025836	3	491100
9512	Buss Construction	Rushmore		MN0025836	2	321900
9513	Prin's Trucking	Rushmore	0.10	MN0025836	2	484100
9514	Rushmore Cafe	Rushmore		MN0025836	2	722100
9515	Albert's Trucking	Rushmore	0.05	MN0025836	1	484100
9516	Don's Plumbing & Heating	Rushmore		MN0025836	1	238200
9517	Harlan's Auto Repair	Rushmore		MN0025836	1	811100
9518	Deutschland Meats	Sanborn	0.00	MN0024805	16	311600
9519	Farmers Golf & Health Club	Sanborn		MN0024805	12	713900
9520	Sanborn Farmers Elevator	Sanborn		MN0024805	10	111100
9521	Central Publications	Sanborn		MN0024805	8	511100
9522	Meadowland Coop	Sanborn		MN0024805	8	115100
9523	Rope & Spurr Ballroom	Sanborn		MN0024805	8	713900
9524	Kircher Construction	Sanborn		MN0024805	5	238300
9525	Tom & Jerry's Corner Bar	Sanborn		MN0024805	5	722400
9526	First Security Bank	Sanborn		MN0024805	4	522100
9527	Gramstad Lumber	Sanborn		MN0024805	4	444100
9528	Swede's Surplus	Sanborn		MN0024805	4	444100
9529	Hogen Construction	Sanborn		MN0024805	2	238300
9530	Federal Correctional Institution	Sandstone		MN0056910	273	922100
9531	Sandstone Public Schools-ISD #2580	Sandstone		MN0056910	212	611100
9532	Pine Medical Center	Sandstone	0.12	MN0056910	190	622100
9533	Chris' Fairway	Sandstone		MN0056910	60	445100
9534	Pine County	Sandstone	0.04	MN0056910	28	921100
9535	St Croix Boys Camp	Sandstone		MN0056910	28	922100
9536	Arrowhead Rotor & Stator	Sandstone		MN0056910	23	811200
9537	First NB of the North	Sandstone		MN0056910	20	522100
9538	Jan & Gary's Restaurant	Sandstone		MN0056910	18	722100
9539	Conoco- Sandstone	Sandstone		MN0056910	16	447100
9540	United Parcel Service	Sandstone		MN0056910	15	492100
9541	Amoco- Sandstone	Sandstone		MN0056910	11	445100
9542	Duluth Clinic- Sandstone	Sandstone	0.01	MN0056910	11	621100
9543	Moose Lake Federal CU- Sandstone	Sandstone		MN0056910	10	522100
9544	Minnesota Power	Sandstone		MN0056910	8	221100
9545	Gateway Family Health Center	Sandstone	0.01	MN0056910	7	621100
9546	Total Service Station- Sandstone	Sandstone		MN0056910	6	447100
9547	International Paper	St. Cloud		MN0040878	547	322100
9548	Independent School Distric #748t	St. Cloud		MN0040878	384	611100
9549	De Zurik	St. Cloud	2.41	MN0040878	350	332900
9550	Country Manor Health Care	St. Cloud		MN0040878	248	623100
9551	Care Call	St. Cloud		MN0040878	241	561900
9552	Coborn's	St. Cloud		MN0040878	113	445100
9553	McDonald's	St. Cloud		MN0040878	83	722300
9554	Merrill Corporation	St. Cloud		MN0040878	65	323100
9555	St. Francis Xavier	St. Cloud		MN0040878	50	611600
9556	Payne Lynch and Associates	St. Cloud		MN0040878	36	488900
9557	City of Sartell	St. Cloud	0.05	MN0040878	35	921100
9558	Sauk Centre ISD # 743	Sauk Centre		MN0024821	178	611100
9559	St. Michaels Hospital & Nursing Home	Sauk Centre		MN0024821	172	623100
9560	Standard Iron & Wire Works, Inc.	Sauk Centre		MN0024821	60	331500
9561	Holy Family School	Sauk Centre		MN0024821	47	611500
9562	Truckers Inn - Fuel & Restaurant	Sauk Centre		MN0024821	40	447100
9563	Independant Bankers Assoc. of America	Sauk Centre		MN0024821	35	522100
9564	Kane Transport	Sauk Centre	0.00	MN0024821	31	484100
9565	Sauk Centre Welding & Machine Works	Sauk Centre	0.00	MN0024821	30	336200
9566	Cabinet Components	Sauk Centre		MN0024821	25	337100
9567	O.C.I.	Sauk Centre		MN0024821	25	335300
9568	Central Minnesota Finishing	Sauk Centre		MN0024821	23	238300
9569	Engle Fabrication	Sauk Centre		MN0024821	21	325500
9570	Sauk Centre, City of	Sauk Centre	0.03	MN0024821	21	921100
9571	Sauk Centre Fleet Supply	Sauk Centre		MN0024821	20	333200
9572	Vocational Biographies	Sauk Centre		MN0024821	20	511100

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ID	Facility Name	City	P_kgd	Permit_No	employee_count	NAICS Code
9573	Kohorst Trucking	Sauk Centre	0.00	MN0024821	18	484100
9574	D.H.I.A.	Sauk Centre	1.06	MN0024821	17	311500
9575	Beuning Ag Service	Sauk Centre		MN0024821	16	333200
9576	Schwan's Ice Cream	Sauk Centre	0.94	MN0024821	15	311500
9577	Sauk Centre Coop Creamery	Sauk Centre	0.75	MN0024821	12	311500
9578	Bauerly Brothers	St. Cloud		MN0040878	721	237300
9579	Sauk Rapids Schools-ISD #47	St. Cloud		MN0040878	425	611100
9580	Stearns Manufacturing Co	St. Cloud		MN0040878	331	451100
9581	Komo Machine Inc	St. Cloud	0.00	MN0040878	197	332700
9582	X-Cel Optical Co	St. Cloud		MN0040878	186	333300
9583	Custom Eyes	St. Cloud		MN0040878	142	333300
9584	Trimpac Inc	St. Cloud		MN0040878	110	321900
9585	CSI Ltd	St. Cloud		MN0040878	97	451100
9586	Crystal Cabinet Works Inc.	St. Cloud		MN0040878	96	337100
9587	Huisken Meats	St. Cloud	4.08	MN0040878	72	311600
9588	C&L Distributing Inc	St. Cloud		MN0040878	53	424800
9589	Custom Caseworks Inc	St. Cloud		MN0040878	32	238300
9590	WF Scarince Inc	St. Cloud		MN0040878	29	811300
9591	Ron's Cabinets Inc	St. Cloud		MN0040878	28	337100
9593	Heat N Glo Fireplace Products	St. Paul		MN0030007	261	327300
9594	Fabcon Inc	St. Paul		MN0030007	250	327300
9596	Waste Management Inc	St. Paul		MN0030007	150	562100
9597	Northern Inc	St. Paul		MN0030007	105	454100
9598	Continental Hydraulics Div	St. Paul		MN0030007	100	333900
9599	Master Electric Co Inc	St. Paul		MN0030007	100	238200
9600	Cargill Inc	St. Paul		MN0030007	78	424900
9601	Road Machinery & Supplies Co	St. Paul		MN0030007	75	336900
9602	Hennepin Transfer Inc	St. Paul		MN0030007	65	562100
9603	Burnsville Heating & Air Conditioning	St. Paul		MN0030007	50	238200
9604	Metal Products Inc	St. Paul	0.34	MN0030007	49	332900
9605	Hot-Shot Products Co	St. Paul		MN0030007	40	335300
9606	Pomp's Tire Service	St. Paul		MN0030007	40	326200
9607	BFI Tire Recyclers	St. Paul		MN0030007	30	326200
9608	Continental Grain Co	St. Paul		MN0030007	30	493100
9609	Dustcoating	St. Paul		MN0030007	30	238100
9611	Richards Asphalt Co	St. Paul		MN0030007	20	324100
9612	Sebeka Public Schools	Sebeka		MN0024856	102	611100
9613	Caring Hands Inc	Sebeka		MN0024856	25	621600
9614	Sebeka DAC	Sebeka		MN0024856	20	624200
9615	Anderson Homes	Sebeka		MN0024856	15	453900
9616	Sebeka, City of	Sebeka	0.02	MN0024856	14	921100
9617	Ma's Country Cafe	Sebeka		MN0024856	13	722100
9618	Security St Bk of Sebeka	Sebeka		MN0024856	12	522100
9619	West Central Telephone Assn	Sebeka		MN0024856	12	517100
9620	Shafer Contracting Co	Shafer		MN0030848	250	237300
9621	Shafer Electronics Co	Shafer		MN0030848	105	425100
9622	F&M Plastics Inc	Shafer		MN0030848	20	424600
9623	Choice Deli	Shafer	0.04	MN0030848	10	445200
9624	Bernie's Cafe	Shafer		MN0030848	6	722100
9625	Shafer 1 Stop	Shafer		MN0030848	5	447100
9626	Shafer Automotive & Truck Repair	Shafer		MN0030848	5	811100
9627	Bargainquest	Shafer		MN0030848	4	452100
9628	Crossroads Tavern	Shafer		MN0030848	4	722400
9629	US Post Office	Shafer		MN0030848	4	491100
9631	Valleyfair Amusement Park	St. Paul		MN0029882	1200	713100
9633	Scott, County of	St. Paul	0.70	MN0029882	495	921100
9634	K Mart Distribution Ctr	St. Paul		MN0029882	424	452100
9636	Shakopee School District #720	St. Paul		MN0029882	390	611100
9638	Certain Teed Corp	St. Paul		MN0029882	300	324100
9641	Northstar Auto Auction	St. Paul		MN0029882	220	453300
9645	Empak	St. Paul	0.08	MN0029882	100	325200
9647	Belae Brands	St. Paul		MN0029882	80	424900
9648	Mid-America Plastics Inc	St. Paul	0.06	MN0029882	80	325200
9649	Martin County West Schools	Sherburn		MN0024872	160	611100
9650	Community Options & Resources	Sherburn		MN0024872	110	621400
9651	Alliant	Sherburn		MN0024872	30	221100
9652	Cenex	Sherburn		MN0024872	15	424900
9653	Schwager Trucking	Sherburn	0.00	MN0024872	15	484100

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ID	Facility Name	City	P_kgd	Permit_No	employee_count	NAICS Code
9654	Cargo Carriers Inc.	Sherburn		MN0024872	10	488400
9655	Farmers St Bk of Sherburn	Sherburn		MN0024872	8	522100
9656	Jamboree Foods	Sherburn		MN0024872	8	445100
9657	Nu-Way Co-op	Sherburn		MN0024872	8	424900
9658	Country Cafe	Sherburn		MN0024872	6	722100
9659	Cup and Saucer	Sherburn		MN0024872	6	722100
9660	Sherburn, City of	Sherburn	0.01	MN0024872	6	921100
9661	Dorschner Refrigeration, Oil & Tire	Sherburn		MN0024872	4	443100
9662	Land Services	Sherburn		MN0024872	4	531200
9663	Sherburn Nursery & Floral	Sherburn		MN0024872	4	444200
9664	State Farm Ins	Sherburn		MN0024872	4	524100
9665	Watonwan Farm Service	Sherburn		MN0024872	3	111100
9668	Super Target	St. Paul		MN0029815	312	452100
9669	EMPI	St. Paul	8.67	MN0029815	300	339100
9670	TSI Inc	St. Paul		MN0029815	300	339900
9671	Rainbow Foods	St. Paul		MN0029815	225	445100
9672	Curtis 1000	St. Paul		MN0029815	180	323100
9673	Kozlak's Royal Oak Restaurant	St. Paul		MN0029815	100	722100
9674	PAR Systems	St. Paul		MN0029815	100	423700
9675	Shoreview, City of	St. Paul	0.11	MN0029815	75	921100
9676	Dynamark Inc	St. Paul		MN0029815	60	518200
9677	Hampton Inn	St. Paul		MN0029815	40	721100
9678	Nardini Fire Equipment Co	St. Paul		MN0029815	34	339900
9679	Minuteman International Inc.	St. Paul	0.03	MN0029815	23	325600
9681	Northern States Power Co	St. Paul		MN0029882	90	221100
9682	Minnetonka Country Club	St. Paul		MN0029882	50	713900
9684	Minnesota Veterans Home	Silver Bay		MN0024899	115	923100
9685	Silver Bay Public Schools	Silver Bay		MN0024899	60	611100
9686	Zups Big Dollar	Silver Bay		MN0024899	26	445100
9687	Bay Area Health Ctr	Silver Bay	0.03	MN0024899	21	621100
9688	Van House Construction	Silver Bay		MN0024899	20	236100
9689	Silver Bay, City of	Silver Bay	0.03	MN0024899	18	921100
9690	North Shore Oil & Propane	Silver Bay		MN0024899	16	454300
9691	Northwoods Cafe	Silver Bay		MN0024899	16	722100
9692	North Shore Fed CU-Silver Bay	Silver Bay		MN0024899	13	522100
9693	Julie's Variety & Hardware	Silver Bay		MN0024899	8	452900
9694	Ye Old Store	Silver Bay		MN0024899	8	445100
9695	John's Sanitary Removal	Silver Bay		MN0024899	7	562100
9696	Commercial St Bank-Silver Bay	Silver Bay		MN0024899	6	522100
9697	Bay Side Shopper & Printing	Silver Bay		MN0024899	5	511100
9698	Silver Lake, City of	Silver Lake	0.06	MN0024902	46	921100
9699	Glencoe-Silver Lake Schools	Silver Lake		MN0024902	41	611100
9700	American Selected Products	Silver Lake		MN0024902	30	112300
9701	First Community Bank Silver Lake	Silver Lake		MN0024902	8	522100
9702	Murray County Public Schools	Slayton		MN0024911	160	611100
9703	Murray County Hospital	Slayton	0.06	MN0024911	88	622100
9704	Slayton Manor Care Center	Slayton		MN0024911	80	623100
9705	Murray County Courthouse	Slayton		MN0024911	79	922100
9706	Finley Engineering	Slayton		MN0024911	60	541300
9708	Murray County Developmental Achieve	Slayton		MN0024911	45	624200
9709	Murray County St Bk	Slayton		MN0024911	30	522100
9710	United Parcel Service	Slayton		MN0024911	29	492100
9711	Center For Regional Development	Slayton		MN0024911	23	926100
9712	Page 1 Printers	Slayton		MN0024911	21	323100
9713	Prairie View	Slayton		MN0024911	21	621400
9714	Sam's Super Value	Slayton		MN0024911	19	445100
9715	United Prairie Bk Slayton	Slayton		MN0024911	18	522100
9716	Norwood Promotional Products	Sleepy Eye		MNG580041	556	323100
9717	Christensen Farms	Sleepy Eye		MNG580041	350	112200
9718	Mathiowetz Construction Company	Sleepy Eye		MNG580041	150	238900
9719	Sleepy Eye Care Ctr	Sleepy Eye		MNG580041	140	623100
9720	Sleepy Eye Schools-ISD #84	Sleepy Eye		MNG580041	125	611100
9721	Divine Providence Community Home	Sleepy Eye		MNG580041	83	623100
9722	St Mary's School	Sleepy Eye		MNG580041	75	611100
9723	Farmers Elevator Company	Sleepy Eye		MNG580041	73	424900
9724	Sleepy Eye Municipal Hospital	Sleepy Eye	0.05	MNG580041	71	622100
9725	Orchid Inn & Motor Lodge	Sleepy Eye		MNG580041	65	722100
9727	Jubilee Foods - Sleepy Eye	Sleepy Eye		MNG580041	55	445100

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ID	Facility Name	City	P_kgd	Permit_No	employee_count	NAICS Code
9728	Hardee's - Sleepy Eye	Sleepy Eye		MNG580041	39	722100
9729	Miller Sellner Implement Inc	Sleepy Eye		MNG580041	35	423800
9730	Haala Industries	Sleepy Eye	0.00	MNG580041	34	332700
9731	Anderson Custom Processing Inc	Sleepy Eye		MNG580041	32	424400
9732	Stimpert Enterprises Inc	Sleepy Eye		MNG580041	14	321900
9733	Sportsman's Guide	St. Paul		MN0029815	800	454100
9734	South St Paul School District #6	St. Paul		MN0029815	540	611100
9737	HealthEast Care Center	St. Paul		MN0029815	205	623300
9739	American Bottling	St. Paul	10.12	MN0029815	150	312100
9740	Allstate Sales Corp	St. Paul		MN0029815	107	441200
9741	South Saint Paul, City of	St. Paul	0.14	MN0029815	100	921100
9743	Bremer Bank	St. Paul		MN0029815	50	522100
9744	Cherokee Manufacturing	St. Paul		MN0029815	50	111400
9745	Twin City Bagels	St. Paul		MN0029815	50	311800
9746	Jennie-O Turkey Store	Spicer		MN0052752	71	112330
9747	Marketing Concepts, Inc.	Spicer		MN0052752	68	541511
9748	Melvins on the Lake	Spicer		MN0052752	65	722410
9749	Jahnke Foods	Spicer		MN0052752	45	445110
9750	G. Michaels Bar & Grill	Spicer		MN0052752	42	722110
9751	Green Lake Nursery	Spicer		MN0052752	18	111421
9752	United Prairie Bank	Spicer		MN0052752	16	522110
9753	Northern Engraving Co	Spring Grove		MN0021440	210	511120
9754	Tweeten/Lutheran Health Care Ctr	Spring Grove		MN0021440	126	623100
9755	Spring Grove Public Schools	Spring Grove		MN0021440	63	611100
9756	Roverud Construction Inc	Spring Grove		MN0021440	60	236200
9757	Sodko, Inc./Shooting Star Native Seeds	Spring Grove		MN0021440	28	236200
9758	Red's IGA	Spring Grove		MN0021440	25	445100
9759	Solie Services, Inc	Spring Grove		MN0021440	25	447100
9760	Houston County Group Homes	Spring Grove		MN0021440	20	623900
9761	Jennings State Bank	Spring Grove		MN0021440	20	522100
9762	La Crosse Clock Company & Cabinetry	Spring Grove		MN0021440	20	561700
9763	Spring Grove, City of	Spring Grove	0.02	MN0021440	16	921100
9764	Thompson Inc	Spring Grove		MN0021440	15	484200
9765	About the Horse	Spring Grove		MN0021440	8	316900
9766	Kwik Trip Inc	Spring Grove		MN0021440	7	447100
9767	Spring Grove Coop Telephone Co	Spring Grove		MN0021440	7	517300
9768	Kraus Oil Co Inc	Spring Grove		MN0021440	6	454300
9769	Sani-Blast/Sani-Brush Co	Spring Grove		MN0021440	6	561700
9770	Ladsten Auto Body & Sales	Spring Grove		MN0021440	5	811100
9771	Booman Chiropractic Clinic	Spring Grove		MN0021440	4	621300
9772	Marv's Body Shop & Camper Sales	Spring Grove		MN0021440	4	441200
9773	Spring Grove Bottling Works Inc	Spring Grove	0.27	MN0021440	4	312100
9774	Health Partners	St. Paul	0.22	MN0029815	160	621100
9776	Spring Lake Park Lumber Co	St. Paul		MN0029815	20	444100
9777	Presbyterian Homes	St. Paul		MN0029882	400	623100
9778	Lord Fletcher's Of The Lake	St. Paul		MN0029882	150	722100
9779	Minnetonka Mist	St. Paul		MN0029882	65	722100
9780	Meisel Hardware	St. Paul		MN0029882	50	454100
9781	Burnet	St. Paul		MN0029882	30	531200
9782	Lehmann Farms	St. Paul	1.16	MN0029882	25	311400
9783	Rockvam Boat Yards Inc	St. Paul		MN0029882	20	483200
9784	Ace Hardware	St. Paul		MN0029882	10	444100
9785	All Stars	St. Paul		MN0029882	10	722100
9786	Spring Valley Public Schools	Spring Valley		MN0051934	108	611100
9787	Spring Valley Specialties	Spring Valley		MN0051934	34	493100
9788	Spring Valley, City of	Spring Valley	0.04	MN0051934	32	921100
9789	Kappers Fabricating Inc	Spring Valley	0.00	MN0051934	30	332700
9790	Spring Valley Cheese Inc	Spring Valley	1.87	MN0051934	30	311500
9791	Coleman Powermate, Inc.	Springfield		MN0024953	275	333900
9792	St John Lutheran Home	Springfield		MN0024953	235	623100
9793	Springfield Public Schools	Springfield		MN0024953	100	611100
9794	Ochs Brick & Tile Co	Springfield		MN0024953	80	327100
9795	Springfield Medical Center/Mayo Health System	Springfield	0.05	MN0024953	80	622100
9796	Barron Fabrications Inc	Springfield		MN0024953	50	423800
9797	L & S Electric	Springfield		MN0024953	50	238200
9798	Salonek Construction	Springfield		MN0024953	30	236200
9799	Genuine Woodcraft	Springfield		MN0024953	6	337100
9800	Norwesco Inc	St. Paul	0.03	MN0029882	40	325200

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ID	Facility Name	City	P_kgd	Permit_No	employee_count	NAICS Code
9801	Identi-Graphics	St. Paul		MN0029882	25	339900
9802	Holiday	St. Paul		MN0029882	20	447100
9804	Wolf Sales	St. Paul		MN0029882	15	337100
9805	Thurk Bros Chevrolet	St. Paul		MN0029882	13	441100
9806	Suburban Mold	St. Paul	0.01	MN0029882	10	325200
9807	Cunningham Advertising Inc	St. Paul		MN0029882	9	541800
9808	Tonka Mills/Nylac	St. Paul	0.01	MN0029882	9	325600
9809	St Boni Ford	St. Paul		MN0029882	8	441100
9811	St Charles Schools-ISD #858	St. Charles		MN0046868	115	611100
9812	Whitewater Healthcare Ctr	St. Charles		MN0046868	93	623100
9813	Excel Manufacturing Inc	St. Charles		MN0046868	49	333900
9814	Mike's Food Center	St. Charles		MN0046868	31	445100
9815	St Charles Equipment	St. Charles		MN0046868	13	333200
9816	Subway	St. Charles		MN0046868	11	722100
9817	US Post Office	St. Charles		MN0046868	11	491100
9818	Kwik Trip	St. Charles		MN0046868	10	447100
9819	Merchants Bank - St Charles	St. Charles		MN0046868	10	522100
9820	Twin Valley Ag	St. Charles		MN0046868	9	325300
9821	Ag Specialists	St. Charles		MN0046868	8	325300
9822	Brownell Drug	St. Charles		MN0046868	8	446100
9823	Eastwood Bk	St. Charles		MN0046868	8	522100
9824	Wolter & Raak Ltd	St. Charles		MN0046868	8	541200
9825	St Cloud Hospital / Centra Care Health Systems	St. Cloud	1.88	MN0040878	2899	622100
9826	Minnesota, State of	St. Cloud	2.90	MN0040878	2062	921100
9827	Frigidaire Co Freezer Products	St. Cloud		MN0040878	1755	443100
9828	Fingerhut Corp	St. Cloud		MN0040878	1089	454100
9829	St Cloud Public School Dist #742	St. Cloud		MN0040878	973	611100
9830	Veterans Adm Medical Ctr	St. Cloud	0.53	MN0040878	821	622100
9831	Bankers Systems Inc	St. Cloud		MN0040878	728	453200
9832	Stearns, County of	St. Cloud	0.90	MN0040878	639	921100
9833	Nahan Printing	St. Cloud		MN0040878	527	323100
9834	Merrill May Inc	St. Cloud		MN0040878	486	323100
9836	Antioch Compay / Creative Memories	St. Cloud		MN0040878	450	323100
9837	St. Cloud, City of	St. Cloud	0.57	MN0040878	407	921100
9838	Woodcraft Industries Inc	St. Cloud		MN0040878	406	321900
9840	Swift-Eckrich, Inc.	St. James	22.47	MN0024759	550	311600
9841	St James Automotive	St. James		MN0024759	200	336300
9842	St. James Public Schools	St. James		MN0024759	194	611100
9843	S-T Industries	St. James	0.00	MN0024759	120	332700
9844	Watonwan Farm Services	St. James		MN0024759	60	424900
9845	Tony Downs Foods CO	St. James	2.56	MN0024759	55	311400
9846	Runge Trucking	St. James	2.07	MN0024759	40	484100
9847	St. James, City of	St. James	0.05	MN0024759	36	921100
9848	United Parcel Service	St. James		MN0024759	35	492100
9849	St. James Publishing Company	St. James		MN0024759	19	511100
9850	Olson Industries	St. James	0.16	MN0024759	14	332800
9851	Dynamic Tool & Engineering	St. James	0.00	MN0024759	10	332700
9852	Nelson Truck Hoods	St. James		MN0024759	8	336300
9853	A+ Designs	St. James		MN0024759	7	313200
9854	Parts Supply & Machine	St. James		MN0024759	6	333200
9855	Don Ling's Printers	St. James		MN0024759	5	323100
9856	St. James Concrete	St. James		MN0024759	5	327300
9857	College of St Benedict's	St. Cloud		MN0040878	450	611300
9859	Convent of St Benedict	St. Cloud		MN0040878	102	813100
9860	W Gohman Construction Co	St. Cloud		MN0040878	45	236200
9861	MCO Lens Crafting	St. Cloud	0.90	MN0040878	31	339100
9862	St Joseph Parish/School	St. Cloud		MN0040878	23	813100
9863	SuperAmerica	St. Cloud		MN0040878	21	447100
9864	Vic West Steel	St. Cloud		MN0040878	20	332300
9865	St. Joseph, City of	St. Cloud	0.03	MN0040878	19	921100
9866	First St Bk of St Joseph	St. Cloud		MN0040878	18	522100
9867	La Playette Bar & Restaurant	St. Cloud		MN0040878	18	722400
9868	Accu Serv	St. Cloud		MN0040878	16	518200
9869	Scherer & Sons Trucking	St. Cloud	0.78	MN0040878	15	484100
9870	Metro Plumbing & Heating	St. Cloud		MN0040878	13	238200
9871	St Joe Gas & Bait	St. Cloud		MN0040878	13	447100
9872	Sunset Manufacturing	St. Cloud	0.07	MN0040878	10	332900
9873	Park Nicollet Health Services	St. Paul		MN0029815	4500	621111

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ID	Facility Name	City	P_kgd	Permit_No	employee_count	NAICS Code
9875	St Louis Park Public Schools	St. Paul		MN0029815	762	611110
9877	TravelersExpress/MoneyGram	St. Paul		MN0029815	450	522320
9878	St. Louis Park, City of	St. Paul		MN0029815	252	921110
9879	Midwest Plastic Components	St. Paul	1.14	MN0029815	200	325211
9880	Onvoy	St. Paul		MN0029815	200	517110
9881	Benilde-St. Margaret's High School	St. Paul		MN0029815	140	611110
9883	Quadion Minnesota Rubber	St. Paul		MN0029815	103	326299
9884	Walser Automotive Group	St. Paul		MN0029815	95	441110
9885	As Soon As Possible, Inc.	St. Paul	0.27	MN0029815	80	323115
9887	General Office Products	St. Paul		MN0029815	75	532420
9888	Appliance Recycling Centers of America, Inc.	St. Paul		MN0029815	70	453310
9889	Groves Academy	St. Paul		MN0029815	65	611110
9891	william j. Business Interiors	St. Paul		MN0029815	61	532420
9892	Commercial Furniture Services/Brokers	St. Paul		MN0029815	60	532420
9893	Adolfson & Peterson Construction	St. Paul	0.00	MN0029815	50	236210
9894	J & B Wholesale and Distribution	St. Michael	0.00	MN0020222	400	311400
9895	Builder's Carpet	St. Michael		MN0020222	100	238300
9896	Jet Edge	St. Michael	0.16	MN0020222	85	333500
9897	Marksman Metals	St. Michael	0.15	MN0020222	75	333500
9898	B & D Plumbing, Heating and Air Conditioning	St. Michael		MN0020222	50	238200
9899	Russell's Of Course	St. Michael		MN0020222	45	722100
9900	Progressive Contractors Inc. (PCI)	St. Michael		MN0020222	40	238100
9902	State of Minnesota	St. Paul	1.50	MN0029815	13671	921100
9903	St Paul Public Schools	St. Paul		MN0029815	6567	611100
9904	Health East Care System/ St. Joesph's Hospital	St. Paul	3.30	MN0029815	5080	622100
9905	Marsden Building Maintenance	St. Paul		MN0029815	4000	561700
9907	Ramsey, County of	St. Paul	5.30	MN0029815	3770	921100
9908	St. Paul, City of	St. Paul	4.78	MN0029815	3400	921100
9910	US Post Office	St. Paul		MN0029815	3200	491100
9912	St Paul Ramsey Med Ctr-Health Partners	St. Paul	1.95	MN0029815	3000	622100
9913	St Paul Companies Inc	St. Paul		MN0029815	2650	524100
9914	Minnesota Mutual Life Ins Co	St. Paul		MN0029815	2400	524100
9916	Control Data Systems Inc	St. Paul		MN0029815	1800	541500
9917	Cardiac Pacemakers Export Inc	St. Paul	1.16	MN0029815	1500	334500
9919	Conseco Finance Corp.	St. Paul		MN0029815	1142	522100
9920	Lawson Software	St. Paul		MN0029815	1000	541500
9921	Ashland Petroleum Co	St. Paul		MN0029815	215	324100
9922	Super Mom's Kitchen	St. Paul		MN0029815	140	311800
9923	Garelick Manufacturing Co	St. Paul		MN0029815	105	339900
9924	St Peter Regional Treatment	St. Peter		MN0022535	830	622200
9925	Gustavus Adolphus College	St. Peter		MN0022535	628	611300
9926	St. Peter Public Schools	St. Peter		MN0022535	283	611100
9927	St. Peter Community Hospital	St. Peter	0.17	MN0022535	262	622100
9928	Nicollet, County of	St. Peter	0.35	MN0022535	250	921100
9929	Alumacraft Boat Co	St. Peter		MN0022535	150	336600
9930	Citizens Scholarship Fnd. of America	St. Peter		MN0022535	150	611500
9931	Econofoods	St. Peter		MN0022535	100	445100
9932	Taytronics Inc	St. Peter		MN0022535	100	334400
9933	St. Peter, City of	St. Peter	0.12	MN0022535	85	921100
9934	St. Peter Clinic	St. Peter	0.05	MN0022535	35	621100
9935	Royal Concrete Pipe Inc	Stacy		MN0024970	70	327300
9936	Sub-Tronics Inc	Stacy		MN0024970	70	334400
9937	Wyoming Machine Inc	Stacy	0.00	MN0024970	65	332700
9938	Promotional Mailings	Stacy		MN0024970	50	711300
9939	Pretty Bird Intl	Stacy		MN0024970	20	424900
9940	Lakewood Health System	Staples	0.29	MN0024988	450	622100
9941	Staples Motley School District	Staples		MN0024988	230	611100
9942	Stern Rubber & Company	Staples		MN0024988	140	326200
9943	Central Lakes Tech College - Staples	Staples		MN0024988	81	611300
9944	McKechnie Tooling & Engineer	Staples	0.00	MN0024988	66	332700
9946	First Integrity Bank	Staples		MN0024988	49	522100
9947	Twin City Optical	Staples		MN0024988	41	333300
9948	Ultra Color Inc	Staples		MN0024988	33	812900
9949	Precision Polishing	Staples	0.17	MN0024988	15	332800
9950	Douglas Corporation	Staples	0.03	MN0024988	13	333500
9951	Staples Precision Metalcraft	Staples	0.05	MN0024988	7	332900
9952	Starbuck School Dist #6046-42	Starbuck		MN0021415	95	611100
9953	Minnewaska Lutheran Home	Starbuck		MN0021415	80	623100

Appendix B. Industrial Phosphorus Data Matched to MNPRO Database by NAICS

ID	Facility Name	City	P_kgd	Permit_No	employee_count	NAICS Code
9954	Minnewaska District Hospital	Starbuck	0.04	MN0021415	56	622100
9955	Dy Cast Specialties Corp	Starbuck		MN0021415	40	331500
9956	Starbuck Creamery	Starbuck	1.50	MN0021415	24	311500
9957	Farmers Union Oil Co	Starbuck		MN0021415	15	424900
9958	First NB of Starbuck	Starbuck		MN0021415	15	522100
9959	Glacial Wood Products	Starbuck		MN0021415	12	423300
9960	Tom's Food Pride	Starbuck		MN0021415	12	445100
9961	Starbuck Cement Products	Starbuck		MN0021415	5	327300
9962	Form a Feed Inc	Stewart		MNG580077	60	112900
9963	McLeod West	Stewart		MNG580077	40	517100
9964	McCormick Implement	Stewart		MNG580077	18	423800
9965	Farmer's Cooperative Elevator	Stewart		MNG580077	9	424500
9966	Stewart Energy Products	Stewart	0.04	MNG580077	7	541700
9967	Stewartville Public Schools	Stewartville		MN0020681	196	611100
9968	Halcon Corp	Stewartville		MN0020681	180	337200
9969	Rochester Medical Corp	Stewartville	1.08	MN0020681	170	339100
9970	Stewartville Care Center	Stewartville		MN0020681	120	623100
9971	Geotek Inc.	Stewartville	0.46	MN0020681	41	332800
9972	All American Co-op	Stewartville		MN0020681	30	424900
9973	Stewartville, City of	Stewartville	0.03	MN0020681	20	921100
9974	Jimmy's Dressing	Stewartville	0.38	MN0020681	17	311400
9975	Rochester Petroleum Equipment, Inc.	Stewartville		MN0020681	15	561900
9976	Washington, County of	St. Paul	1.36	MN0029998	970	921100
9977	Stillwater Public Schools-ISD #834	St. Paul		MN0029998	920	611100
9978	UFE Inc	St. Paul	0.64	MN0029998	800	325200
9979	Cub Foods	St. Paul		MN0029998	550	445100
9981	Design Fabricated Parts Inc	St. Paul		MN0029998	330	336300
9982	DiaSorin	St. Paul	1.31	MN0029998	250	541700
9983	Target	St. Paul		MN0029998	197	452100
9984	WR Medical Electronics	St. Paul	0.04	MN0029998	50	334500
9985	Lonnie Lovness	St. Paul		MN0029998	24	339900
9986	Stillwater Gazette Inc	St. Paul		MN0029998	24	511100
9987	Ideal Tool & Machine	St. Paul	0.00	MN0029998	18	332700
9988	Copy Cat Digital Imaging Ctr	St. Paul		MN0029998	15	323100
9989	K-Sun Corp	St. Paul		MN0029998	15	323100
9990	Heritage Embroidery & Design	St. Paul		MN0029998	14	424300
9991	Minnesota Wine Growers Co-op	St. Paul	0.67	MN0029998	10	312100
9992	Aiple Marine Co Inc	St. Paul		MN0029998	9	483200
9993	Ammerman Co Inc	St. Paul		MN0029998	8	423700
9994	Sherburne Gold & Gems Jewelry	St. Paul		MN0029998	5	339900
9995	H&I Wood Specialties	St. Paul		MN0029998	1	337100
9996	Muller Boat Co	Taylors Falls		MN0053309	150	713900
9997	Adventure Mini Golf	Taylors Falls		MN0053309	20	713900
9998	Jericho Trucking	Taylors Falls		MN0053309	15	488400
9999	CJ's Conoco	Taylors Falls		MN0053309	10	447100
10000	Croix Management	Taylors Falls		MN0053309	10	561100
10001	Springs Inn	Taylors Falls		MN0053309	10	721100
10002	Chisago House	Taylors Falls		MN0053309	9	722100
10003	Merit Machine	Taylors Falls	0.00	MN0053309	9	332700
10004	Border Bar & Grill	Taylors Falls		MN0053309	8	722400
10005	General Store	Taylors Falls		MN0053309	7	445100
10006	Hanson & Holt	Taylors Falls		MN0053309	7	541200
10007	Log Jam Restaurant	Taylors Falls		MN0053309	7	722100
10008	Wild River Electric	Taylors Falls		MN0053309	7	238200
10009	Bench Street Antiques	Taylors Falls		MN0053309	6	453300
10010	Camp Waub O Jeeg	Taylors Falls		MN0053309	6	721200
10011	Romaynes Restaurant & Bar	Taylors Falls		MN0053309	6	722100
10012	Barb's Hair Care	Taylors Falls	0.01	MN0053309	5	812100
10013	Pines Motel & Apartments	Taylors Falls		MN0053309	5	721100
10014	Schooney Ice Cream	Taylors Falls	0.02	MN0053309	5	445200
10015	Dr Frank Crain	Taylors Falls		MN0053309	4	621200
10016	Arctic Cat , Incorporated	Thief River Falls		MN0021431	1500	336900
10017	Digi-Key Corporation	Thief River Falls		MN0021431	1170	423600
10018	Northwest Medical Center	Thief River Falls	0.30	MN0021431	457	622100
10019	Seven Clans Casino Hotel & Indoor Waterpark	Thief River Falls		MN0021431	400	721100
10020	Thief River Falls Schools-Dist. 564	Thief River Falls		MN0021431	340	611100
10021	Pennington, County of	Thief River Falls	0.33	MN0021431	235	921100
10022	Northern Pride, Inc.	Thief River Falls	9.19	MN0021431	225	311600

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ID	Facility Name	City	P_kgd	Permit_No	employee_count	NAICS Code
10023	Dakota Clinic	Thief River Falls	0.24	MN0021431	175	621100
10024	Northland Comm & Technical College	Thief River Falls		MN0021431	175	611300
10025	Thief River Falls, City of	Thief River Falls	0.16	MN0021431	115	921100
10026	CP Rail (Soo Line)	Thief River Falls	0.04	MN0021431	100	482100
10027	Dean Foods/Land O'Lakes	Thief River Falls	6.24	MN0021431	100	311500
10028	Hugo's	Thief River Falls		MN0021431	95	445100
10029	Best Western Inn	Thief River Falls		MN0021431	90	721100
10030	K Mart	Thief River Falls		MN0021431	88	452100
10031	Independent Machine Service	Thief River Falls		MN0021431	55	322100
10032	School District	Tracy		MN0021725	135	611500
10033	Tracy Medical Services	Tracy	0.07	MN0021725	53	621100
10034	City of Tracy	Tracy	0.06	MN0021725	40	921100
10035	Tracy Food Pride	Tracy		MN0021725	37	445100
10036	North Star Homes	Tracy		MN0021725	24	339900
10037	Tracy State Bank	Tracy		MN0021725	23	522100
10038	Harvest States	Tracy		MN0021725	19	111100
10039	Tracy Minntronix	Tracy		MN0021725	12	238200
10040	Lutheran Retirement Home	Truman		MN0021652	115	623100
10041	Truman Farmers Elevator Co	Truman		MN0021652	80	493100
10042	Truman Public Schools	Truman		MN0021652	54	611100
10043	Taylor's Restaurant	Truman		MN0021652	20	722100
10044	Bosshart Co	Truman		MN0021652	15	327300
10045	Peoples St Bk of Truman	Truman		MN0021652	15	522100
10046	Tennyson Construction	Truman		MN0021652	15	236100
10047	Schwan's Sales	Truman	0.87	MN0021652	14	311500
10048	Mel Carlson Chevrolet	Truman		MN0021652	13	441100
10049	Truman Bus Service	Truman		MN0021652	12	485400
10050	Larry Baarts Trucking	Truman		MN0021652	10	484100
10051	Truman Food Ctr	Truman		MN0021652	10	445100
10052	Olson's Furniture	Truman		MN0021652	8	442100
10053	Prairieland Compost Facility	Truman		MN0021652	8	562100
10054	Truman Plumbing & Heating	Truman		MN0021652	8	238200
10055	Upton Ford	Truman		MN0021652	8	441100
10056	Melmar Fabrication	Truman	0.04	MN0021652	6	332900
10057	G&D Electric	Truman		MN0021652	5	238200
10058	Leimar Construction	Truman		MN0021652	5	236100
10059	Rode Mfg	Truman	0.03	MN0021652	5	332900
10060	Lake Superior School Dist.#381	Two Harbors		MN0022250	375	611100
10061	First Plan	Two Harbors		MN0022250	230	524100
10062	Community Health Ctr Inc	Two Harbors	0.24	MN0022250	180	621100
10063	Lakeview Memorial Hospital	Two Harbors	0.10	MN0022250	152	622100
10064	Louisiana-Pacific Corp	Two Harbors		MN0022250	138	321200
10065	Stanley Works (La Bounty)	Two Harbors		MN0022250	100	333100
10066	Two Harbors Machine Shop	Two Harbors		MN0022250	100	333200
10067	API	Two Harbors		MN0022250	50	541200
10068	Northshore Manufacturing Inc	Two Harbors		MN0022250	30	333200
10070	Hahn Machinery Inc	Two Harbors		MN0022250	12	333200
10071	I-C System Inc	St. Paul		MN0029815	600	561400
10073	SEH Engineering	St. Paul		MN0029815	250	541300
10074	Imation	St. Paul	0.12	MN0029815	150	325200
10075	Medical Graphics Corp	St. Paul	0.12	MN0029815	150	334500
10076	RPM Mfg	St. Paul		MN0029815	135	336300
10077	Buerkle Buick Honda	St. Paul		MN0029815	130	441100
10079	Dynamic Air Inc	St. Paul		MN0029815	125	333900
10080	S&T Office Products Inc	St. Paul		MN0029815	125	453200
10081	Gephart Electric Co	St. Paul		MN0029815	110	238200
10082	Com-Tal Machine & Engineering	St. Paul		MN0029815	100	333200
10083	Keebler Co	St. Paul		MN0029815	100	311800
10084	Wal-Mart	St. Paul		MN0029815	100	452100
10085	White Bear Lincoln Mercury	St. Paul		MN0029815	85	441100
10087	White Bear Dodge	St. Paul		MN0029815	80	441100
10088	RTI Plastics	St. Paul	0.06	MN0029815	70	325200
10089	Ruberto's Restaurant & Banquet	St. Paul		MN0029815	70	722100
10090	State Farm Insurance	St. Paul		MN0029815	70	524100
10091	Verndale Public School Dist #818			ISTS	70	611100
10092	Verndale Custom Homes			ISTS	35	236100
10093	Verndale Truss Inc			ISTS	30	444100
10094	Vesta Farmers Elevator	Vesta		MNG580043	12	493100

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ID	Facility Name	City	P_kgd	Permit_No	employee_count	NAICS Code
10095	United Southwest Bk	Vesta		MNG580043	6	522100
10096	HEI Inc	St. Paul	0.15	MN0029882	130	335900
10097	Community Living	St. Paul		MN0029882	100	621400
10098	Deer Run Golf Club	St. Paul		MN0029882	60	713900
10099	Victoria House	St. Paul		MN0029882	33	722100
10100	Carver Park Reserve	St. Paul		MN0029882	32	924100
10101	Victoria State Bank	St. Paul		MN0029882	19	522100
10102	Hartman Tree Farm	St. Paul		MN0029882	15	561700
10103	Minnesota Victoria Oil Co/Cenex	St. Paul		MN0029882	14	424900
10104	CH Carpenter Lumber Co	St. Paul		MN0029882	12	423300
10105	Timberwall Landscape Products	St. Paul		MN0029882	9	561700
10106	Hi-5 Liquors	St. Paul		MN0029882	7	445300
10107	Victoria, City of	St. Paul	0.01	MN0029882	7	921100
10108	Food N Fuel	St. Paul		MN0029882	6	445100
10109	Serv-A-Dock	St. Paul		MN0029882	6	339900
10110	Narkie Heating & Air Conditioning Inc	St. Paul		MN0029882	5	238200
10111	SIDCO 4x4	St. Paul		MN0029882	5	336300
10112	Main Street Hair Co & Tanning Salon	St. Paul	0.01	MN0029882	4	812100
10113	Leo's Bar	St. Paul		MN0029882	3	722400
10114	USX	Virginia		MN0030163	1600	213100
10115	Virginia Regional Medical Center	Virginia	0.42	MN0030163	650	622100
10116	St Louis County	Virginia	0.68	MN0030163	486	921100
10118	Arrowhead Economic Opportunity Agency	Virginia		MN0030163	340	624300
10119	Virginia Public Schools	Virginia		MN0030163	320	611100
10120	Sykes Enterprises	Virginia		MN0030163	300	541500
10121	Duluth Clinic - Virginia	Virginia	0.32	MN0030163	240	621100
10122	Target	Virginia		MN0030163	150	452100
10123	Arrowhead Health Care Center - Virginia	Virginia		MN0030163	134	623300
10124	Virginia, City of	Virginia	0.15	MN0030163	109	921100
10125	Mesabi Range Community College - Virginia Campus	Virginia		MN0030163	84	611300
10126	Mesabi Daily News	Virginia		MN0030163	70	511100
10127	Department of Public Utilities	Virginia		MN0030163	67	221100
10128	St Elizabeth Hospital	Wabasha	0.21	MN0025143	320	622100
10129	Uni Patch Inc	Wabasha	0.19	MN0025143	240	334500
10130	Wabasha, County of	Wabasha	0.21	MN0025143	150	921100
10131	Wabasha-Kellogg Public Schools	Wabasha		MN0025143	105	611100
10132	Thomas Industries	Wabasha	0.41	MN0025143	60	332900
10133	Great River Homes	Wabasha		MN0025143	58	621400
10134	Wabasha Clinic	Wabasha	0.07	MN0025143	55	621100
10135	Valley Publications	Wabasha		MN0025143	30	511100
10136	Wabasha Holding Company	Wabasha		MN0025143	23	522100
10137	Boelter Industries Inc	Wabasha		MN0025143	20	322200
10138	Wabasha Sand, Gravel and Ready Mix	Wabasha		MN0025143	13	327300
10139	Loon Lake Decoy	Wabasha		MN0025143	11	339900
10141	Medallion Kitchens	St. Paul		MN0029882	280	337100
10142	Good Samaritan Center	St. Paul		MN0029882	205	623100
10143	Fitness Master Inc	St. Paul		MN0029882	200	339900
10144	Milltronics	St. Paul	0.39	MN0029882	200	333500
10145	Waconia Public Schools	St. Paul		MN0029882	200	611100
10146	Lakeview Clinic Ltd	St. Paul	0.24	MN0029882	174	621100
10149	Waconia Farm & Home Supply	St. Paul		MN0029882	42	424900
10151	Twin City Mold Engineering	St. Paul	0.01	MN0029882	15	325200
10152	Auburn West	St. Paul		MN0029882	12	623100
10153	Northern Lights Casino			MN0041157	350	713200
10154	Ah Gwah Ching Center			MN0041157	320	623100
10155	Cass, County of		0.33	MN0041157	232	921100
10156	Walker School District 119			MN0041157	212	611100
10157	Woodrest Healthcare Center			MN0041157	75	623100
10158	First National Bank of Walker			MN0041157	51	522100
10159	Cochran's Marine			MN0041157	32	483200
10160	Moondance Ranch			MN0041157	32	713900
10161	Bieloh's Family Foods			MN0041157	25	445100
10162	Orton Oil Company			MN0041157	25	454300
10163	East Otter Tail Telephone Co			MN0041157	20	221100
10164	Walnut Grove School	Walnut Grove		MN0021776	28	611100
10165	Wanamingo Schools-ISD #2172	Wanamingo		MN0022209	130	611100
10166	Ag Partners	Wanamingo		MN0022209	90	424900
10167	Maple Island Inc	Wanamingo		MN0022209	50	311500

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ID	Facility Name	City	P_kgd	Permit_No	employee_count	NAICS Code
10168	Riverview Manor	Wanamingo		MN0022209	45	623900
10169	Farmers Co-op Oil	Wanamingo		MN0022209	44	447100
10170	Security St Bk of Wanamingo	Wanamingo		MN0022209	15	522100
10171	Budget Mart Oil	Wanamingo		MN0022209	9	447100
10172	Haller Chevrolet	Wanamingo		MN0022209	9	441100
10173	Wanda Country Steak and Drink	Wanda		MN0020524	25	722100
10174	Wanda State Bank	Wanda		MN0020524	12	521100
10175	North Valley Health Ctr	Warren	0.08	MNG580073	57	621100
10176	Nordic Fiberglass Inc	Warren		MNG580073	35	444100
10177	PKM Electric Cooperative Assn	Warren		MNG580073	20	221100
10178	Strata Concrete	Warren		MNG580073	11	327300
10179	Northwest Regional Dev. Commission	Warren		MNG580073	8	926100
10180	Farm Credit Services	Warren		MNG580073	7	522100
10181	Harvest States Co-op	Warren		MNG580073	7	325300
10182	Warren Tire Service	Warren		MNG580073	7	326200
10183	Great Companions Ltd	Warren		MNG580073	6	424900
10184	Mischel Grain & Seed	Warren		MNG580073	6	493100
10185	Evergreen Implement	Warren		MNG580073	5	423800
10187	Independent School District #690	Warroad		MN0025194	250	611100
10188	Lake of the Woods Casino	Warroad		MN0025194	160	713200
10189	Warroad Care Center	Warroad		MN0025194	64	623100
10190	Doug's Supermarket	Warroad		MN0025194	57	445100
10191	City of Warroad	Warroad	0.05	MN0025194	39	921100
10192	Heatmor	Warroad	0.24	MN0025194	35	332900
10193	ALCO	Warroad		MN0025194	25	452900
10194	Holiday Station Store	Warroad		MN0025194	22	447110
10195	The Patch Restaurant	Warroad		MN0025194	22	722100
10196	Farmers Union Oil Co.	Warroad		MN0025194	21	447110
10197	Super America	Warroad		MN0025194	21	447110
10198	Security State Bank	Warroad		MN0025194	20	522100
10199	Altru Health Clinic	Warroad	0.02	MN0025194	17	621100
10200	Lake Country Chevrolet	Warroad		MN0025194	16	441100
10201	Time Out Pizza	Warroad		MN0025194	15	722100
10202	Brown Printing Co	Waseca		MN0020796	1300	323100
10203	Itron Inc	Waseca		MN0020796	360	334400
10204	Waseca Public Schools	Waseca		MN0020796	350	611100
10205	EF Johnson Co	Waseca		MN0020796	243	334200
10206	Johnson Components	Waseca		MN0020796	210	425100
10207	Federal Correctional Inst-Waseca	Waseca		MN0020796	180	922100
10208	Dean Foods/Bird's Eye Div.	Waseca	7.20	MN0020796	155	311400
10209	ELM Homes Inc	Waseca		MN0020796	130	623900
10210	Waseca, County of	Waseca	0.18	MN0020796	130	921100
10211	Waseca Area Medical Center	Waseca	0.08	MN0020796	125	622100
10212	Winegar Brothers Inc	Waseca		MN0020796	90	333200
10213	Corchran Inc	Waseca		MN0020796	85	332300
10214	DM&E Railroad	Waseca	0.04	MN0020796	80	482100
10215	Waseca Mutual Insurance Co	Waseca		MN0020796	60	524100
10216	Waseca, City of	Waseca	0.08	MN0020796	55	921100
10217	Watertown School District #111	Watertown		MN0020940	225	611100
10218	Elim Nursing Home	Watertown		MN0020940	85	623100
10219	Don's Food Pride	Watertown		MN0020940	50	445100
10220	D'Vinci's Restaurant	Watertown		MN0020940	32	722100
10221	Watertown, City of	Watertown	0.03	MN0020940	20	921100
10222	Subway	Watertown		MN0020940	14	722100
10223	CentraSota	Watertown		MN0020940	12	424900
10224	First American Bk Metro - Watertown	Watertown		MN0020940	11	522100
10225	Lakeview Clinic Ltd	Watertown	0.01	MN0020940	10	621100
10226	Derson Tank	Watertown	0.01	MN0020940	9	321911
10227	Carver County News	Watertown		MN0020940	4	511100
10228	NAPA - Watertown Parts Center	Watertown		MN0020940	4	441100
10229	Hooked on Classics	Watertown		MN0020940	3	453300
10230	Hun-Gree Bear Restaurant	Watertown		MN0020940	2	722100
10231	Hilltop Good Samaritan Ctr			ISTS	70	623100
10232	Mies Equipment Inc			ISTS	30	423800
10233	Terra International Inc			ISTS	25	424900
10234	Randy Kramer Excavating			ISTS	22	238900
10235	Arnold Chevrolet			ISTS	12	441100
10236	Farmers St Bk of Watkins			ISTS	10	522100

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ID	Facility Name	City	P_kgd	Permit_No	employee_count	NAICS Code
10237	Barrier Technology			ISTS	9	444100
10238	Mies Motors			ISTS	8	441100
10239	Stein's Thriftway Foods			ISTS	7	445100
10240	Faber Building & Supply Inc			ISTS	6	444100
10241	Wayzata Public Schools-ISD #284	St. Paul		MN0029882	850	611100
10242	Wayzata Auto Center	St. Paul		MN0029882	165	441100
10243	Burnet Realty Inc	St. Paul		MN0029882	110	531200
10244	Foursome Inc	St. Paul		MN0029882	100	448100
10245	Wayzata Country Club	St. Paul		MN0029882	90	713900
10246	Wayzata, City of	St. Paul	0.11	MN0029882	77	921100
10247	Edina Realty Inc	St. Paul		MN0029882	70	531200
10248	Norwest Bank	St. Paul		MN0029882	63	522100
10249	BORN Information Svc	St. Paul		MN0029882	60	518200
10250	Sunsets on Wayzata Bay	St. Paul		MN0029882	55	722100
10251	Roger Fazendin Realtors	St. Paul		MN0029882	53	531200
10252	Copeland Buhl & Co	St. Paul		MN0029882	50	541200
10253	Montgomery Watson	St. Paul		MN0029882	50	541300
10254	Anchor Bk NA	St. Paul		MN0029882	46	522100
10255	Martin County West Schools-Dist #459	Welcome		MN0021296	82	611100
10256	Eagle Engineering & Mfg Inc	Welcome		MN0021296	78	423700
10257	Timothy's of Welcome	Welcome		MN0021296	11	445300
10258	Cenex	Welcome		MN0021296	10	447100
10259	Watonwan Farm Services	Welcome		MN0021296	8	424900
10260	Welcome Legion Club	Welcome		MN0021296	8	813400
10261	Welcome St Bk	Welcome		MN0021296	6	522100
10262	Crop Builders Inc	Welcome		MN0021296	5	325300
10263	Les Ringnell Insurance	Welcome		MN0021296	5	524100
10264	Gerhardt Corner Grocery	Welcome		MN0021296	4	445100
10265	Northern Natural Gas Co	Welcome		MN0021296	4	486200
10266	NuWay Cooperative	Welcome		MN0021296	4	424900
10267	Federated Rural Electric Assn	Welcome		MN0021296	3	221100
10268	Kramer Funeral Chapel	Welcome		MN0021296	3	812200
10269	Weiss Milling Inc	Welcome		MN0021296	3	493100
10270	Welcome Cafe	Welcome		MN0021296	3	722100
10271	US Post Office	Welcome		MN0021296	2	491100
10272	Welcome Hardware	Welcome		MN0021296	2	444100
10273	Welcome Oil Co	Welcome		MN0021296	2	454300
10274	Welcome TV Sales & Service Inc	Welcome		MN0021296	2	443100
10275	Wells Concrete Products, Inc.	Wells		MN0025224	250	238100
10276	ConAgra Foods	Wells	5.18	MN0025224	230	311400
10277	United South Central High School	Wells		MN0025224	175	611100
10278	Naeve Parkview Home	Wells		MN0025224	76	623100
10279	Wells Super Valu	Wells		MN0025224	40	445100
10280	Herman Manufacturing	Wells	0.00	MN0025224	35	332700
10281	Wells Federal Bank	Wells		MN0025224	34	522100
10282	South Central Veterinary Clinic	Wells		MN0025224	31	541900
10283	A Home of Your Own	Wells		MN0025224	30	236100
10284	Wells Truss Manufacturing	Wells		MN0025224	29	444100
10285	Wells, City of	Wells	0.04	MN0025224	25	921100
10286	Watonwan Farm Services	Wells		MN0025224	15	115100
10287	Wells Concrete Ready Mix	Wells		MN0025224	14	327300
10288	Paragon Bank	Wells		MN0025224	12	522100
10289	Peoples State Bank	Wells		MN0025224	9	522100
10290	S & H Deisel	Wells		MN0025224	9	811100
10291	Blue Earth Valley Telephone Co	Wells		MN0025224	6	517100
10292	Dakota Co	St. Paul		MN0029815	300	923100
10293	Southview Acres Health Care	St. Paul		MN0029815	300	623100
10294	Target	St. Paul		MN0029815	300	452100
10296	Cub Foods	St. Paul		MN0029815	200	445100
10297	Rainbow Foods	St. Paul		MN0029815	160	445100
10299	K Mart	St. Paul		MN0029815	150	452100
10301	City of West St. Paul	St. Paul	0.14	MN0029815	100	921100
10302	Langer Construction Co	St. Paul		MN0029815	100	236100
10303	Tru-Part Mfg Corp	St. Paul		MN0029815	95	333200
10304	Wheaton Community Hospital	Wheaton	0.06	MNG580044	85	622100
10305	Wheaton Public School Dist #803	Wheaton		MNG580044	78	611100
10306	Polytec	Wheaton	0.03	MNG580044	35	325200
10307	Larson Implement Inc	Wheaton		MNG580044	27	333200

Appendix B. Industrial Phosphorus Data Matched to MNPRO Database by NAICS

ID	Facility Name	City	P_kgd	Permit_No	employee_count	NAICS Code
10308	Wheaton Plastics	Wheaton	0.02	MNG580044	20	325200
10309	Gazette Publishing & Printing	Wheaton		MNG580044	18	511100
10310	Spectrum Aeromed	Wheaton	0.01	MNG580044	16	334500
10311	Lundquist Seed	Wheaton		MNG580044	15	424900
10312	Runestone Manufacturing	Wheaton		MNG580044	15	335300
10313	Wheaton Dumont Coop Elevator	Wheaton		MNG580044	15	424900
10314	EZ Loader Boat Trailers	Wheaton		MNG580044	5	453900
10315	White Bear Area Auto Dealers	St. Paul		MN0029815	1100	441100
10316	Taymark Corporation	St. Paul		MN0029815	290	454100
10317	White Bear Care Center	St. Paul		MN0029815	225	623900
10318	Trane Company	St. Paul		MN0029815	207	333400
10319	Sam's Club	St. Paul		MN0029815	160	452100
10321	Smarte Carte	St. Paul	0.00	MN0029815	125	332700
10322	K Mart	St. Paul		MN0029815	100	452100
10323	Renewal by ANDERSON	St. Paul		MN0029815	100	238100
10324	Kohler Mix Specialties	St. Paul		MN0029815	91	424400
10325	Marprint	St. Paul		MN0029815	80	323100
10326	Press Publications	St. Paul		MN0029815	75	511100
10328	Specialty Manufacturing	St. Paul	0.34	MN0029815	50	332900
10329	SpectraCom	St. Paul		MN0029815	33	333300
10330	Aspen Research Corporation	St. Paul	0.15	MN0029815	30	541700
10331	Magnepan, Inc.	St. Paul		MN0029815	30	443100
10332	Grubb Equipment Sales	St. Paul		MN0029815	29	335200
10333	Aquacide Company, Inc.	St. Paul	2.16	MN0029815	4	541700
10334	B & G Products Company	St. Paul		MN0029815	4	454100
10335	Das Designs	St. Paul		MN0029815	3	323100
10336	Jennie-O Turkey Store	Willmar	75.25	MN0025259	1328	311600
10337	Willmar Public Schools	Willmar		MN0025259	819	611100
10338	Rice Memorial Hospital	Willmar	0.44	MN0025259	684	622100
10339	Willmar Regional Treatment Ctr	Willmar		MN0025259	530	621400
10340	Affiliated Medical Ctr	Willmar	0.60	MN0025259	447	621100
10341	Kandiyohi, County of	Willmar	0.61	MN0025259	433	921100
10342	Bethesda Homes	Willmar		MN0025259	350	623100
10343	Ridgewater College - Willmar	Willmar		MN0025259	235	611300
10344	Minnesota Dept. of Transportation	Willmar		MN0025259	225	926100
10345	Willmar Poultry Co	Willmar		MN0025259	225	112300
10346	Burlington Northern Railroad	Willmar	0.10	MN0025259	215	482100
10347	Wal-Mart	Willmar		MN0025259	165	452100
10348	Molenaar Inc	Willmar	0.13	MN0025259	160	325200
10349	West Central Steel/Central MN Fabricating	Willmar	1.03	MN0025259	150	332900
10350	Infinia of Willmar	Willmar		MN0025259	110	623100
10351	Heartland Community Action Agency	Willmar		MN0025259	98	624200
10352	Mills Auto Center	Willmar		MN0025259	94	441100
10353	Holiday Inn & Willmar Conference Center	Willmar		MN0025259	90	721100
10354	Herberger's	Willmar		MN0025259	86	452100
10355	Woodland Centers	Willmar		MN0025259	86	621400
10356	Wilmont Farmers Elevator	Wilmont		MN0025852	12	424900
10357	United Prairie Bank	Wilmont		MN0025852	7	522100
10358	Loosbrock Construction	Wilmont		MN0025852	6	236200
10359	T & C Truking	Wilmont	0.00	MN0025852	6	484100
10360	B & L Construction	Wilmont		MN0025852	5	236200
10361	City Liquor Store	Wilmont		MN0025852	5	722400
10362	Wilmont Family Recreation Center	Wilmont		MN0025852	5	713900
10363	Jueneman OK Hardware	Wilmont		MN0025852	4	444100
10364	Larry's Body Shop	Wilmont		MN0025852	4	811100
10365	Tri City Gas Inc.	Wilmont		MN0025852	4	811100
10366	Balster construction	Wilmont		MN0025852	3	236200
10367	Frenchies Wild WEst	Wilmont		MN0025852	3	339900
10368	Lynch Digmann Funeral Home	Wilmont		MN0025852	3	812200
10369	PSI Cleaning & Assoc.	Wilmont		MN0025852	3	333300
10370	Al Plumbing & Heating	Wilmont		MN0025852	2	238200
10371	Toro Co	Windom		MN0022217	604	423800
10372	Windom Public Schools-ISD #177	Windom		MN0022217	200	611100
10373	Caldwell Packing Co	Windom	10.20	MN0022217	180	311600
10374	Sogge Memorial Good Samaritan	Windom		MN0022217	135	623100
10375	Windom Area Hospital	Windom	0.05	MN0022217	83	622100
10376	Fortune Transportation	Windom	3.62	MN0022217	70	484100
10377	Gordy's Foods	Windom		MN0022217	62	445100

Appendix B. Industrial Phosphorus Data Matched to MNPRO Database by NAICS

ID	Facility Name	City	P_kgd	Permit_No	employee_count	NAICS Code
10378	MN Dept of Transportation	Windom		MN0022217	59	926100
10379	Mc Donalds	Windom		MN0022217	55	722100
10380	Pamida Discount Ctr	Windom		MN0022217	46	452100
10381	Hy-Vee Food Stores	Windom		MN0022217	42	445100
10382	Windom, City of	Windom	0.05	MN0022217	39	921100
10383	US Post Office	Windom		MN0022217	29	491100
10384	Cottonwood County DAC	Windom		MN0022217	28	624200
10385	Windom Coop Assn - Cenex	Windom		MN0022217	26	424900
10386	Cottonwood-Jackson Health Svc	Windom		MN0022217	25	923100
10387	Towler Town Motor Co	Windom		MN0022217	25	441100
10388	Citizen Publishing Co	Windom		MN0022217	21	511100
10389	Parker Oaks Nursing Home	Winnebago		MN0025267	110	623100
10390	JM Manufacturing	Winnebago	0.05	MN0025267	60	325200
10391	Loveall Construction Co	Winnebago		MN0025267	60	238100
10392	Corn Plus, Inc.	Winnebago	0.21	MN0025267	40	541700
10393	Crown Fixtures Inc	Winnebago		MN0025267	35	423700
10394	Minnesota Electric Technology	Winnebago		MN0025267	30	335300
10395	Windings Inc	Winnebago		MN0025267	30	335300
10396	Meter Man Inc	Winnebago		MN0025267	25	111900
10397	Weerts Companies	Winnebago	1.03	MN0025267	20	484100
10398	Winnebago School Dist #2148	Winnebago		MN0025267	20	611100
10399	TRW Automotive Electronics	Winona		MN0030147	980	333200
10400	Fastenal Co	Winona		MN0030147	900	423700
10401	Winona Health	Winona	0.53	MN0030147	820	622100
10402	Winona State University	Winona		MN0030147	750	611300
10403	Winona Public Schools-Dist #861	Winona		MN0030147	610	611100
10404	Watlow Controls	Winona	0.32	MN0030147	417	334500
10406	Watkins Inc	Winona		MN0030147	375	424900
10407	St. Mary's University	Winona		MN0030147	361	611300
10408	Wincraft	Winona		MN0030147	330	315900
10410	Winona County	Winona	0.41	MN0030147	289	921100
10411	Sprint	Winona		MN0030147	260	517100
10412	Winona Knitting Mills Inc	Winona		MN0030147	230	315100
10413	Hal Leonard Publishing	Winona		MN0030147	185	511100
10414	Fiberite Inc	Winona	0.14	MN0030147	175	325200
10416	Boelter Industries	Winona		MN0030147	125	322200
10417	Brock Candy Co.	Winona	0.04	MN0030147	121	311300
10418	Sterner Lighting Systems Inc	Winsted		MN0021571	250	335100
10419	Quast Transfer Inc	Winsted	0.00	MN0021571	185	484100
10420	Millerbernd Manufacturing Co	Winsted		MN0021571	160	332300
10421	Scherping Systems	Winsted		MN0021571	130	333200
10422	St Mary's Care Center	Winsted		MN0021571	120	623100
10423	Littfin Lumber Co	Winsted		MN0021571	100	444100
10424	Mid-America Dairymen Inc	Winsted	1.50	MN0021571	100	311500
10425	Waste Management	Winsted		MN0021571	90	562100
10426	SJF Enterprises	Winsted		MN0021571	80	333900
10427	Niro Sterner Inc	Winsted		MN0021571	65	237900
10428	EDCO of Winsted Products Inc	Winsted		MN0021571	60	314900
10429	Holy Trinity School	Winsted		MN0021571	60	611100
10430	Ram Builders Inc.	Winsted		MN0021571	39	238100
10431	Blue Note Bar & Ballroom	Winsted		MN0021571	20	722100
10432	Hands Inc	Winthrop		MN0051098	280	488900
10433	Winthrop Good Samaritan Ctr	Winthrop		MN0051098	67	623100
10434	Winthrop Public Schools-GFW	Winthrop		MN0051098	67	611100
10435	Dairy Farmers of America Inc	Winthrop		MN0051098	54	311500
10436	GuideCraft USA	Winthrop	0.36	MN0051098	52	332900
10438	JB Lures	Winthrop		MN0051098	25	339900
10439	Bartels Truck Line Inc	Winthrop		MN0051098	23	484100
10440	Lyle's Cafe	Winthrop		MN0051098	22	722100
10441	B&R Plumbing and Heating	Winthrop		MN0051098	15	238200
10442	Tim's Super Valu	Winthrop		MN0051098	15	445100
10443	Jolly Tundra	Winthrop		MN0051098	11	315200
10444	Jackson Electric	Winthrop		MN0051098	10	238200
10445	Winthrop St Bk	Winthrop		MN0051098	10	522100
10446	Winthrop Wood Products	Winthrop		MN0051098	9	321900
10447	Winthrop News	Winthrop		MN0051098	8	511100
10448	Z Trailer Sales	Winthrop		MN0051098	8	336200
10449	State Farm Insurance	St. Paul		MN0029815	1420	524210

Appendix B. Industrial Phosphorus Data Matched to MNPRO Database by NAICS

ID	Facility Name	City	P_kgd	Permit_No	employee_count	NAICS Code
10450	South Washington County Schools	St. Paul		MN0029815	809	611110
10451	The Hartford	St. Paul		MN0029815	796	524210
10452	EFunds	St. Paul	0.07	MN0029815	400	518210
10454	Ecowater Systems	St. Paul	0.98	MN0029815	371	333319
10455	Fortis	St. Paul	0.06	MN0029815	361	518210
10456	target.direct	St. Paul		MN0029815	300	454113
10457	Home Depot	St. Paul		MN0029815	250	444110
10458	Woodbury Senior Living Campus	St. Paul		MN0029815	247	623311
10461	City of Woodbury	St. Paul		MN0029815	174	921140
10462	New Life Academy	St. Paul		MN0029815	120	611110
10463	Vogel Mfg Co	St. Paul	0.03	MN0029815	120	332116
10464	Medical Concepts Development	St. Paul	0.11	MN0029815	86	339112
10465	Heritage Exhibits	St. Paul		MN0029815	85	541850
10466	Swift & Co	Worthington	61.29	MN0031186	1500	311600
10467	Worthington Regional Hospital	Worthington	0.17	MN0031186	261	622100
10468	Highland Manufacturing	Worthington		MN0031186	170	321900
10469	Bedford Industries Inc	Worthington	0.26	MN0031186	153	326100
10470	Intervet, Inc.	Worthington		MN0031186	140	325400
10471	Worthington Specialty Clinics	Worthington	0.14	MN0031186	102	621100
10472	Daily Globe	Worthington		MN0031186	85	511100
10473	Fullerton Building Systems Inc	Worthington		MN0031186	40	236200
10474	New Vision Co-op	Worthington		MN0031186	38	493100
10475	Schaap Sanitation	Worthington		MN0031186	25	562100
10476	Worthington Tractor Parts	Worthington		MN0031186	25	333200
10477	Wrenshall Public Schools-ISD#100	Duluth		MN0049786	60	611100
10478	Northern Natural Gas Co	Duluth		MN0049786	25	486200
10479	Conoco Pipeline	Duluth		MN0049786	2	486200
10480	City of Zimmerman	Zimmerman	0.07	MN0042331	50	921100
10481	DaRan, INC.	Zimmerman	2.59	MN0042331	50	484100
10482	Fairview Clinic	Zimmerman		MN0042331	50	621400
10483	ISD #728	Zimmerman		MN0042331	50	611100
10484	Nelson Nursery	Zimmerman		MN0042331	50	111400
10486	Zumbrota Health Care	Zumbrota	0.11	MN0025330	175	622100
10487	Zumbrota-Mazeppa Public Schools	Zumbrota		MN0025330	160	611100
10488	Zumbrota Livestock Auction Mkt	Zumbrota		MN0025330	60	424500
10489	Custom Iron Inc	Zumbrota		MN0025330	49	332300
10490	Bank of Zumbrota	Zumbrota		MN0025330	43	522100
10491	Covered Bridge Restaurant & Lounge	Zumbrota		MN0025330	35	722100
10492	Hub Food Center	Zumbrota		MN0025330	35	445100
10493	Three River Action Inc	Zumbrota		MN0025330	34	624200
10494	Coolstor Warehouse Services	Zumbrota	0.01	MN0025330	30	334113
10495	Concast Inc	Zumbrota		MN0025330	25	444100
10496	Casey's General Store	Zumbrota		MN0025330	23	424900
10497	Best Way Products	Zumbrota		MN0025330	22	332600
10498	Goodhue County Coop Electric Assn	Zumbrota		MN0025330	21	221100
10499	Grimsrud Publishing	Zumbrota		MN0025330	18	511100

Appendix C

MCES Industrial Users Database

Appendix C. MCES Industrial Users Database

ID	Facility Name	City	Average P (mg/L)	Average Flow (MG)	P_kgd	SIC_No	Permit_No	employee_count	NAICS Code
1	General Mills Inc (JFBTC)	St. Paul	9.36	48.73	4.73	2041	MN0029815	1000	311211
2	Burlington Northern Santa Fe Railway	St. Paul	45.90	11.56	5.50	4011	MN0029815	300	482111
3	Ecolab Inc	St. Paul	393.12	9.93	40.50	2841	MN0030007	111	325611
4	Electronic Industries Inc	St. Paul	3.63	1.64	0.06	3679	MN0029815	28	334418
5	Electro-Plating Eng Co	St. Paul	0.31	13.19	0.04	3471	MN0029815	50	332813
6	H D Hudson Mfg Co	St. Paul	15.83	2.25	0.37	3523	MN0029955	100	332323
7	M - Foods Dairy LLC	St. Paul	58.91	37.23	22.74	2024	MN0029815	120	311520
8	Upper River Services Inc	St. Paul	8.34	2.05	0.18	4789	MN0029815	36	488210
9	Packaging Corp of America	St. Paul	14.10	6.13	0.90	2653	MN0029815	102	322211
10	Lakeview Memorial Hospital	St. Paul	5.17	10.20	0.55	8062	MN0029998	400	622110
11	AbelConn LLC	St. Paul	9.00	5.25	0.49	3643	MN0029815	100	335931
12	Tiro Industries LLC	St. Paul	2.61	20.56	0.56	2844	MN0029815	527	325620
13	Rexam Beverage Can	St. Paul	0.32	29.62	0.10	3411	MN0029815	91	332431
14	Caterpillar Paving Products Inc	St. Paul	220.51	2.43	5.56	3537	MN0029815	492	333924
15	Metal-Matic Inc	St. Paul	8.56	6.11	0.54	3317	MN0029815	398	331210
16	General Mills Inc - Purity Oats	St. Paul	5.14	1.44	0.08	2041	MN0029815	27	311211
17	Rahr Malting Co	St. Paul	196.44	98.03	199.72	2083	MN0029882	68	311213
18	Supra Color Labs Inc	St. Paul	2.47	1.72	0.04	7395	MN0029815	45	540000
19	Weyerhaeuser Co	St. Paul	8.41	6.19	0.54	2653	MN0029815	137	322211
20	Hiawatha Metalcraft Inc (Plant #3)	St. Paul	0.23	36.79	0.09	3471	MN0029815	19	332813
21	Ameripride Services	St. Paul	2.43	60.18	1.52	7218	MN0029815	270	812332
22	Smyth Companies Inc	St. Paul	11.90	1.35	0.17	2751	MN0029815	184	310000
23	Honeywell Advanced Circuits Inc	St. Paul	1.08	26.56	0.30	3679	MN0029815	50	334418
24	States Electric Mfg Co	St. Paul	125.50	0.36	0.46	2542	MN0029815	39	337215
25	Twin City Hide Inc	St. Paul	132.82	11.09	15.27	5159	MN0029815	76	444220
26	Northwest Airlines Inc (OB)	St. Paul	16.00	17.63	2.92	4582	MN0029815	3600	481000
27	Lifetouch Inc (NSS Division)	St. Paul	9.75	4.84	0.49	7221	MN0030007	413	541921
28	AaCron Inc	St. Paul	4.05	53.35	2.24	3471	MN0029815	50	332813
29	Hastings Coop Creamery	St. Paul	29.00	8.95	2.69	2026	MN0029955	37	311511
30	Northern Star Co	St. Paul	156.13	146.52	237.24	2037	MN0029815	223	311411
31	Intermet Co	St. Paul	1.30	9.77	0.13	3361	MN0029815	285	332000
32	MacKay Envelope Co	St. Paul	12.54	0.97	0.13	2751	MN0029815	215	310000
33	Marigold Foods LLC	St. Paul	52.32	62.76	34.05	2023	MN0045845	118	311514
34	Honeywell Inc	St. Paul	3.05	29.14	0.92	3674	MN0029815	583	334413
35	Stylmark	St. Paul	35.70	12.95	4.80	3429	MN0029815	150	332999
36	Packaging Corp of America	St. Paul	5.28	2.49	0.14	2653	MN0029815	76	322211
37	E A Sween Co	St. Paul	20.50	5.22	1.11	2099	MN0029882	237	311830
38	H B Fuller Co	St. Paul	1.90	1.98	0.04	2891	MN0029815	50	325520
39	United Defense, L.P	St. Paul	12.06	28.73	3.59	3489	MN0029815	1630	332995
40	Etchit	St. Paul	1.08	0.62	0.01	3471	MN0029815	8	332813
41	Diamond Products Co	St. Paul	2.22	22.65	0.52	2844	MN0029815	223	325620
42	Hard Chrome Inc	St. Paul	7.64	20.39	1.61	3471	MN0029815	34	332813
43	West Group	St. Paul	5.48	14.96	0.85	2731	MN0030007	1358	516110
44	Buckbee-Mears St Paul	St. Paul	5.18	35.49	1.91	3471	MN0029815	56	332813
45	Culligan Soft Water Service Co	St. Paul	2.90	16.35	0.49	3589	MN0029882	85	333319
46	Americraft Carton Inc	St. Paul	10.80	0.49	0.05	2651	MN0029815	82	322000
47	Rosemount Inc	St. Paul	2.65	20.27	0.56	3811	MN0029882	500	334500
48	Rosemount Aerospace Inc	St. Paul	2.50	1.54	0.04	3471	MN0030007	256	332813
49	Rosemount Aerospace Inc	St. Paul	87.55	6.47	5.87	3471	MN0030007	855	332813
50	Univar USA Inc	St. Paul	5.39	0.83	0.05	5161	MN0029815	37	424000
51	Pioneer Metal Finishing	St. Paul	8.60	93.43	8.33	3471	MN0029815	135	332813
52	Menasha Corp	St. Paul	7.19	3.31	0.25	2653	MN0045845	179	322211
53	United Sugars Corp	St. Paul	14.28	1.97	0.29	2063	MN0029882	26	311313
54	Old Dutch Foods Inc	St. Paul	28.68	34.66	10.31	2065	MN0029815	198	311000
55	Joyner's Silver & Electroplating	St. Paul	0.50	4.34	0.02	3471	MN0029815	101	332813
56	iFlex Inc	St. Paul	0.98	49.96	0.51	3679	MN0029882	60	334418
57	Honeywell Advanced Circuits Inc	St. Paul	11.92	39.06	4.83	3679	MN0029882	50	334418
58	Honeywell Electronic Materials Inc	St. Paul	3.47	87.13	3.14	3679	MN0029815	10	334418
59	St Paul Electroplating Co Inc	St. Paul	0.08	0.22	0.00	3471	MN0029815	4	332813
60	Micro Parts Inc	St. Paul	2.96	1.43	0.04	3599	MN0030007	20	336399
61	Century Circuits & Electronics	St. Paul	6.09	6.88	0.43	3672	MN0029815	70	334412
62	Plating Inc	St. Paul	1.97	10.04	0.21	3471	MN0029815	20	332813
63	Micom Corp	St. Paul	0.83	31.48	0.27	3679	MN0029815	50	334418
64	Honeywell Inc	St. Paul	4.03	26.27	1.10	3471	MN0029815	1362	332813
65	Co-Operative Plating	St. Paul	12.95	24.28	3.26	3471	MN0029815	69	332813
66	Superior Plating Inc	St. Paul	4.37	67.30	3.05	3471	MN0029815	95	332813
67	Circuit Science Inc	St. Paul	0.74	28.17	0.22	3679	MN0029815	100	334418
68	Wolkerstorfer Co Inc	St. Paul	3.92	10.92	0.44	3471	MN0029815	35	332813
69	Douglas Corp - Plating Div	St. Paul	10.14	24.35	2.56	3471	MN0029815	96	332813
70	Ford Motor Co	St. Paul	12.12	137.85	17.33	3711	MN0029815	2156	336112
71	Dugas Bowers Plating Co	St. Paul	0.50	9.66	0.05	3471	MN0029815	45	332813
72	The Bureau - Electronics Group	St. Paul	1.72	87.16	1.55	3672	MN0029815	200	334412
73	EDCO Products Inc	St. Paul	1.10	1.33	0.02	3444	MN0029815	125	332322
74	W E Mowrey Co	St. Paul	0.00	0.14	0.00	3341	MN0029815	50	331314
75	Thermo King Corp	St. Paul	1.21	5.18	0.07	3585	MN0030007	620	336391
76	Midwest Finishing Inc	St. Paul	400.28	3.53	14.64	3471	MN0029815	50	332813

Appendix C. MCES Industrial Users Database

ID	Facility Name	City	Average P (mg/L)	Average Flow (MG)	P_kgd	SIC_No	Permit_No	employee_count	NAICS Code
77	Minco Products Inc	St. Paul	27.31	5.95	1.68	3679	MN0029815	454	334418
78	Applied Coating Technology	St. Paul	54.16	4.26	2.39	3479	MN0029815	50	339914
79	Shaughnessy Plating Co	St. Paul	0.44	0.29	0.00	3471	MN0029815	2	332813
80	IMI Cornelius Inc	St. Paul	1.50	14.46	0.23	3581	MN0029815	200	333311
81	Physical Electronics Inc	St. Paul	28.29	2.88	0.84	3823	MN0029882	120	334513
82	Avtec Finishing Systems	St. Paul	8.02	11.28	0.94	3471	MN0029815	90	332813
83	Valmont/Applied Coating Technology	St. Paul	2.10	7.42	0.16	3471	MN0029882	44	332813
84	Leaf Industries Inc	St. Paul	37.85	4.99	1.96	3471	MN0029815	80	332813
85	Lowell Inc	St. Paul	0.64	0.39	0.00	3451	MN0029815	72	332721
86	Bo-Decor Metal Finishing Inc	St. Paul	0.52	1.19	0.01	2542	MN0030007	25	337215
87	Honeywell Advanced Circuits Inc	St. Paul	8.27	30.27	2.59	3679	MN0029815	50	334418
88	Gross-Given Mfg Co	St. Paul	31.45	5.89	1.92	3581	MN0029815	260	333311
89	Tennant Co	St. Paul	32.67	5.78	1.96	3589	MN0029815	482	333319
90	Bauer Welding & Metal Fabricators Inc	St. Paul	13.96	1.26	0.18	3498	MN0029815	75	332996
91	Quality Painting & Metal Finishing	St. Paul	12.29	0.47	0.06	3479	MN0029815	12	339914
92	Honeywell Inc	St. Paul	5.08	57.63	3.03	3822	MN0029815	1800	334512
93	Twin City Plating Co	St. Paul	0.94	0.50	0.00	3471	MN0029815	15	332813
94	Valmont - Applied Coating Technology	St. Paul	16.60	8.38	1.44	3479	MN0029815	105	339914
95	Rubber Industries Inc	St. Paul	76.00	0.74	0.58	3479	MN0029882	62	339914
96	Northwest Airlines Inc (MB)	St. Paul	1.76	131.23	2.40	4500	MN0029815	3000	481000
97	Cinch New Hope	St. Paul	0.40	0.56	0.00	3643	MN0029815	55	335931
98	Seagate Technology LLC	St. Paul	0.25	58.69	0.15	3679	MN0030007	2550	334418
99	Nor-Ell Inc	St. Paul	10.63	11.99	1.32	4299	MN0029815	40	484000
100	Holaday Circuits Inc	St. Paul	1.52	35.83	0.56	3679	MN0029882	126	334418
101	Federal Cartridge Co	St. Paul	3.78	47.45	1.86	3482	MN0029815	893	332992
102	NiCo Products Inc #3	St. Paul	0.82	24.37	0.21	3471	MN0029815	84	332813
103	World Aerospace Corp	St. Paul	5.57	2.49	0.14	3469	MN0029815	47	332214
104	Universal Plating Co Inc	St. Paul	1.11	9.99	0.12	3471	MN0029815	20	332813
105	Systems	St. Paul	5.58	1.78	0.10	3573	MN0030007	215	333000
106	Century Mfg Co	St. Paul	29.35	3.97	1.21	3623	MN0030007	50	334000
107	PolarFab LLC	St. Paul	26.10	63.56	17.21	3643	MN0030007	471	335931
108	Precision Plating Inc	St. Paul	0.71	1.32	0.01	3471	MN0029815	5	332813
109	Davis-Frost Inc	St. Paul	0.39	9.23	0.04	2851	MN0029815	10	325510
110	Interplastic Corp	St. Paul	0.66	3.67	0.03	2821	MN0029815	54	325211
111	Hiawatha Metalcraft Inc (Plant #1)	St. Paul	0.29	15.16	0.05	3479	MN0029815	31	339914
112	Manildra Milling Corp	St. Paul	183.93	16.76	31.97	2041	MN0029815	50	311211
113	The Mengelkoch Co	St. Paul	28.00	4.24	1.23	2077	MN0029815	20	311711
114	Printed Circuits Inc	St. Paul	0.76	8.29	0.07	3679	MN0030007	40	334418
115	Thomas Engineering Co	St. Paul	11.10	0.44	0.05	3469	MN0029815	77	332214
116	Minnesota Metal Finishing Inc	St. Paul	0.74	17.87	0.14	3479	MN0029815	45	339914
117	Leef Brothers Inc	St. Paul	25.33	25.99	6.83	7218	MN0029815	150	812332
118	Inland Paperboard & Packaging Inc	St. Paul	5.33	3.46	0.19	2653	MN0029882	135	322211
119	Marigold Foods Inc - Mpls Plant	St. Paul	30.92	35.93	11.52	2026	MN0029815	145	311511
120	Fremont Industries Inc	St. Paul	147.45	1.57	2.39	2842	MN0029882	37	325612
121	International Paper Co	St. Paul	20.87	4.46	0.96	2651	MN0029815	116	322000
122	Midwest Coca Cola Bottling Inc	St. Paul	4.49	107.74	5.02	2086	MN0030007	600	312111
123	Van Hoven Co Inc	St. Paul	60.51	57.58	36.13	2077	MN0029815	54	311711
124	Ecolab Inc	St. Paul	7.92	20.98	1.72	2841	MN0029815	325	325611
125	Gresen Hydraulics Div	St. Paul	17.20	2.34	0.42	3561	MN0029815	235	333911
126	Tennant Co	St. Paul	0.07	0.65	0.00	3589	MN0029815	129	333319
127	Flame Metals Processing Corp	St. Paul	19.63	4.21	0.86	3398	MN0030007	50	332811
128	Certainteed Corp	St. Paul	5.65	78.87	4.62	2952	MN0029882	75	324122
129	Cardinal Insulated Glass	St. Paul	0.07	2.64	0.00	3231	MN0029815	50	327215
130	Beckman Coulter Inc	St. Paul	14.50	4.26	0.64	2834	MN0029882	500	325412
131	Dean Foods North Central Inc	St. Paul	36.73	25.55	9.73	2026	MN0029815	220	311511
132	Pearson Candy Co	St. Paul	10.05	7.39	0.77	2065	MN0029815	171	311000
133	Schroeder Milk Co Inc	St. Paul	40.94	24.36	10.34	2026	MN0029815	205	311511
134	Johnson Screens	St. Paul	1.24	12.74	0.16	3496	MN0029815	230	332618
135	Minnesota Rubber Co #1	St. Paul	5.20	4.46	0.24	3069	MN0029815	50	315999
136	Flint Ink Corp	St. Paul	4.47	0.49	0.02	2893	MN0029815	50	325910
137	Dakota Premium Foods LLC	St. Paul	23.32	98.09	23.73	2011	MN0029815	250	311611
138	Onan - Main Plant	St. Paul	20.40	24.11	5.10	3519	MN0029815	1592	336399
139	Onan - Technical Center	St. Paul	6.00	2.20	0.14	3519	MN0029815	35	336399
140	Ken's Metal Finishing Inc	St. Paul	0.74	0.27	0.00	3471	MN0029815	3	332813
141	Old Home Foods Inc	St. Paul	28.83	8.87	2.65	2026	MN0029815	70	311511
142	Glenwood-Inglewood Co	St. Paul	5.65	8.17	0.48	2086	MN0029815	41	312111
143	Northland Aluminum Products Inc	St. Paul	14.90	3.80	0.59	3079	MN0029815	245	325200
144	St Paul Metalcraft Inc	St. Paul	2.55	0.93	0.02	3369	MN0029815	154	331528
145	Anchor Block Co	St. Paul	2.80	6.70	0.19	3271	MN0029815	97	327331
146	G & K Services	St. Paul	23.05	26.84	6.42	7218	MN0029815	83	812332
147	Northwest Automatic Products	St. Paul	0.29	1.69	0.00	3451	MN0029815	89	332721
148	3M Co	St. Paul	6.82	280.31	19.82	3291	MN0029815	10926	332999
149	3M Co	St. Paul	3.30	168.27	5.77	3291	MN0029815	1200	332999
150	3M Co	St. Paul	1.30	1.83	0.02	3079	MN0029815	50	325200
151	Minnesota Rubber Co #2	St. Paul	4.20	0.45	0.02	3559	MN0029815	50	333220
152	Minntech Corp	St. Paul	2.23	23.75	0.55	2835	MN0029815	393	325412

Appendix C. MCES Industrial Users Database

ID	Facility Name	City	Average P (mg/L)	Average Flow (MG)	P_kgd	SIC_No	Permit_No	employee_count	NAICS Code
153	Minnesota Knitting Mills	St. Paul	1.18	4.55	0.06	2281	MN0029815	60	313111
154	Graco Inc	St. Paul	116.82	5.57	6.75	3561	MN0029815	234	333911
155	Graco Inc	St. Paul	25.54	3.99	1.06	3561	MN0029815	225	333911
156	Graco Inc	St. Paul	0.34	2.07	0.01	3561	MN0029815	160	333911
157	General Mills Technology Center East	St. Paul	6.12	5.23	0.33	8731	MN0029815	350	541710
158	Central Livestock Association	St. Paul	24.27	31.60	7.95	5154	MN0029815	40	425120
159	Hitchcock Industries Inc	St. Paul	3.56	9.17	0.34	3361	MN0030007	350	332000
160	Pepsi Bottling Group LLC	St. Paul	10.79	25.84	2.89	2086	MN0030007	176	312111
161	Ziegler Inc	St. Paul	44.43	4.66	2.15	5082	MN0030007	400	423810
162	Hardcoat Inc	St. Paul	20.93	0.40	0.09	3471	MN0029815	14	332813
163	Release Coatings of Minneapolis Inc	St. Paul	2.71	2.15	0.06	7699	MN0030007	16	115210
164	Schumacher Wholesale Meats Inc	St. Paul	5.38	3.30	0.18	2013	MN0029815	28	311612
165	Hosokawa Bepex Corp	St. Paul	20.95	1.12	0.24	3551	MN0029815	10	310000
166	Cargill Research Center	St. Paul	12.35	3.78	0.48	7391	MN0029882	97	540000
167	ADM Milling Co	St. Paul	1.72	3.67	0.07	2041	MN0029815	40	311211
168	Flame Metals Processing Corp	St. Paul	12.97	1.20	0.16	3398	MN0029815	40	332811
169	Stone Container Corp	St. Paul	13.62	1.67	0.24	2651	MN0029815	180	322000
170	Community Hospital Linen	St. Paul	3.84	34.43	1.37	7211	MN0029815	180	812320
171	Greif Bros Corp	St. Paul	2.35	2.90	0.07	2643	MN0025488	200	322000
172	DiaSorin Inc	St. Paul	14.15	2.69	0.39	3829	MN0029998	130	334518
173	Grist Mill Co	St. Paul	16.78	11.82	2.06	2043	MN0045845	486	311920
174	GE Osmonics Inc	St. Paul	5.31	20.12	1.11	3589	MN0029882	536	333319
175	Andersen Corp	St. Paul	9.74	37.08	3.74	2431	MN0029998	4203	321918
176	Birchwood Laboratories Inc	St. Paul	11.30	0.55	0.06	2834	MN0029882	91	325412
177	Lake Air Metal Stampings LLC	St. Paul	143.65	0.72	1.07	3465	MN0029815	50	336370
178	Silgan Containers Corp	St. Paul	0.04	2.85	0.00	3411	MN0029815	100	332431
179	Smurfit-Stone Container Corp	St. Paul	14.56	1.43	0.22	2653	MN0029815	162	322211
180	Purina Mills Inc	St. Paul	29.84	0.27	0.08	2048	MN0029815	36	311611
181	Guidant	St. Paul	13.09	10.74	1.46	3693	MN0029815	2497	334000
182	Ry-Krisp Plant, Ralston Foods	St. Paul	13.70	0.52	0.07	2052	MN0029815	19	311919
183	GAF Materials Corp	St. Paul	0.88	3.27	0.03	2952	MN0029815	125	324122
184	Meyer Bros Dairy Inc	St. Paul	19.00	3.54	0.70	2026	MN0029882	45	311511
185	Waterous Co	St. Paul	8.40	2.67	0.23	3561	MN0029815	375	333911
186	Hospital Linen Services Inc	St. Paul	3.64	19.79	0.75	7213	MN0029815	65	812331
187	Dakota Growers Pasta Co - Minnesota Div	St. Paul	7.71	2.37	0.19	2098	MN0029815	187	311823
188	FilmTec Corp	St. Paul	11.63	44.90	5.42	3998	MN0029815	398	339000
189	Toro Co	St. Paul	75.92	1.69	1.33	3361	MN0029882	250	332000
190	Canadian Pacific Railway	St. Paul	87.17	6.48	5.86	4011	MN0029815	400	482111
191	St Paul Brass & Aluminum Foundry	St. Paul	1.45	1.06	0.02	3362	MN0029815	50	332000
192	Med Tek Inc	St. Paul	5.00	1.41	0.07	3398	MN0029815	32	332811
193	Dana Spicer Off Highway Products Div	St. Paul	21.27	1.64	0.36	3714	MN0029815	50	336330
194	G & K Services	St. Paul	13.52	46.94	6.58	7218	MN0029815	120	812332
195	Smead Mfg Co	St. Paul	13.69	3.18	0.45	2645	MN0029955	818	322000
196	Captain Ken's Foods Inc	St. Paul	21.50	2.19	0.49	2099	MN0029815	29	311830
197	Hawkins Chemical Inc	St. Paul	249.81	4.72	12.22	5161	MN0029815	87	424000
198	Electric Machinery Co	St. Paul	0.25	4.25	0.01	3621	MN0029815	180	335312
199	Timmerman Finishing	St. Paul	23.81	1.17	0.29	3444	MN0029815	20	332322
200	Crown Cork & Seal Co	St. Paul	0.19	9.17	0.02	3411	MN0045845	3	332431
201	Lau Industries Inc	St. Paul	336.50	1.24	4.31	3564	MN0029815	128	333411
202	District Energy St Paul Inc	St. Paul	2.81	17.01	0.50	4961	MN0029815	42	221330
203	Kodak Processing Labs	St. Paul	6.68	8.47	0.59	7395	MN0029815	115	540000
204	Professional Color Service Inc	St. Paul	16.50	4.64	0.79	7395	MN0029815	58	540000
205	Herff Jones Inc	St. Paul	5.23	2.15	0.12	7395	MN0030007	100	540000
206	Land O'Lakes Inc	St. Paul	12.63	7.54	0.99	2020	MN0029815	800	311000
207	Qualex Inc	St. Paul	0.49	12.30	0.06	7395	MN0030007	140	540000
208	Despatch Industries Inc	St. Paul	182.50	1.47	2.77	3567	MN0045845	62	333994
209	Ecowater Corp	St. Paul	0.12	10.00	0.01	3589	MN0029815	482	333319
210	Banta Catalog Group	St. Paul	2.86	5.02	0.15	2751	MN0029815	358	310000
211	St Paul Pioneer Press Dispatch	St. Paul	7.60	3.27	0.26	2711	MN0029815	348	511110
212	Metal Treaters Inc	St. Paul	0.14	1.39	0.00	3398	MN0029815	24	332811
213	Abbott Northwestern Hospital	St. Paul	7.76	69.17	5.57	8062	MN0029815	5000	622110
214	Fairview University Medical Center	St. Paul	13.00	61.60	8.31	8062	MN0029815	4800	622110
215	Fairview Southdale Hospital	St. Paul	8.74	36.23	3.28	8062	MN0029815	2200	622110
216	Hennepin County Medical Center	St. Paul	7.24	42.48	3.19	8062	MN0029815	4467	622110
217	Mercy Hospital	St. Paul	5.66	33.39	1.96	8062	MN0029815	1298	622110
218	Methodist Hospital	St. Paul	4.68	52.12	2.53	8062	MN0029815	3000	622110
219	Minneapolis	St. Paul	5.07	28.28	1.49	8062	MN0029815	1650	622110
220	North Memorial Health Care	St. Paul	6.87	42.21	3.01	8062	MN0029815	3000	622110
221	Regina Medical Center	St. Paul	8.12	14.48	1.22	8062	MN0029955	590	622110
222	St Joseph's Hospital	St. Paul	7.91	28.68	2.35	8062	MN0029815	1500	622110
223	Regions Hospital	St. Paul	5.03	43.81	2.29	8062	MN0029815	3100	622110
224	United Hospital	St. Paul	7.30	56.05	4.24	8062	MN0029815	4725	622110
225	Unity Hospital	St. Paul	7.23	27.67	2.08	8062	MN0029815	1688	622110
226	V A Medical Center	St. Paul	8.88	66.42	6.11	8062	MN0029815	2510	622110
227	Ridgeview Medical Center	St. Paul	5.77	10.60	0.63	8062	MN0029882	833	622110
228	Fairview University Medical Center	St. Paul	6.67	45.66	3.16	8062	MN0029815	3334	622110

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229	Continental Machines	St. Paul	16.74	3.51	0.61	3541	MN0030007	170	333512
230	Acme Tag and Label Co	St. Paul	10.50	0.13	0.01	2649	MN0029815	14	322000
231	GraF/X	St. Paul	7.10	0.36	0.03	2791	MN0029815	50	323122
232	Colorhouse/Mail-Well	St. Paul	10.83	1.27	0.14	7395	MN0029815	50	540000
233	Detector Electronics Corp	St. Paul	4.95	0.84	0.04	3679	MN0030007	230	334418
234	Sierra Corp	St. Paul	0.88	0.96	0.01	2851	MN0029882	31	325510
235	Litho Technical Service	St. Paul	8.86	0.54	0.05	2751	MN0030007	115	310000
236	Mid-Continent Engineering	St. Paul	10.72	7.36	0.82	3444	MN0029815	143	332322
237	Pechiney Plastic Packaging Inc	St. Paul	0.49	28.70	0.15	2751	MN0029815	144	310000
238	Mixon Inc	St. Paul	0.35	0.66	0.00	3691	MN0029815	33	335911
239	Conklin Co	St. Paul	36.75	0.97	0.37	2851	MN0029882	109	325510
240	Nor-Ell Inc, Powder Coating Div	St. Paul	12.27	1.44	0.18	3479	MN0029815	8	339914
241	Deburring Inc	St. Paul	1.55	0.76	0.01	3469	MN0029815	8	332214
242	Chaska Chemical Co Inc	St. Paul	140.00	0.31	0.45	2842	MN0030007	12	325612
243	NSP, dba Xcel Energy	St. Paul	0.33	27.45	0.09	4911	MN0029815	106	221113
244	Atlas Mfg Inc	St. Paul	36.34	0.85	0.32	3993	MN0029815	20	339950
245	Aztec Electronics Inc	St. Paul	3.07	1.61	0.05	3679	MN0029815	5	334418
246	GFI America Inc	St. Paul	15.72	12.35	2.01	5147	MN0029815	325	445210
247	Best Brands Inc	St. Paul	17.58	6.50	1.19	2041	MN0030007	240	311211
248	Waldorf Corp (A Rock-Tenn Co)	St. Paul	3.02	289.30	9.06	2631	MN0029815	669	322130
249	Minnesota Correctional Facility	St. Paul	9.75	116.16	7.48	9223	MN0029998	1800	922140
250	Medtronic Inc	St. Paul	7.40	11.76	0.90	3841	MN0029815	910	339111
251	3M Stillwater	St. Paul	0.00	5.13	0.00	2751	MN0029998	289	310000
252	NRG Energy Center Minneapolis LLC	St. Paul	2.40	47.72	1.19	4961	MN0029815	20	221330
253	Computype Inc	St. Paul	2.80	2.19	0.06	6709	MN0029815	126	523000
254	Medtronic Inc	St. Paul	5.51	2.33	0.13	3693	MN0029815	404	334000
255	Medtronic Inc	St. Paul	15.67	5.69	0.93	3693	MN0029815	90	334000
256	Metro Transit	St. Paul	6.33	2.18	0.14	4172	MN0029815	210	485000
257	Metro Transit	St. Paul	11.85	1.02	0.13	4172	MN0029815	55	485000
258	Metro Transit	St. Paul	6.72	3.69	0.26	4172	MN0029815	59	485000
259	Metro Transit	St. Paul	2.99	1.74	0.05	4172	MN0029815	60	485000
260	Metro Transit	St. Paul	6.05	4.35	0.27	4172	MN0029815	95	485000
261	Earthgrains/Metz Baking Co	St. Paul	6.36	8.80	0.58	2051	MN0029815	196	311812
262	Gopher Resource Corp	St. Paul	0.47	31.34	0.15	3341	MN0030007	173	331314
263	Nordic Press Inc	St. Paul	7.75	0.82	0.07	2752	MN0029815	100	323114
264	Industrial Container Services - MN, LLC	St. Paul	34.34	1.44	0.51	5085	MN0029815	10	423830
265	Buhler Inc	St. Paul	40.93	0.75	0.32	3443	MN0029815	90	333415
266	Novartis Nutrition Corp	St. Paul	6.67	136.25	9.43	2099	MN0029815	460	311830
267	Northern Package	St. Paul	70.67	2.15	1.57	2653	MN0030007	50	322211
268	Arden International Kitchens LLC	St. Paul	82.00	7.61	6.47	2038	MN0045845	120	311412
269	Professional Plating Inc	St. Paul	156.69	5.02	8.15	7399	MN0029815	17	540000
270	Metal-Tronics Inc	St. Paul	35.81	0.30	0.11	3479	MN0029815	35	339914
271	St Paul Pioneer Press Dispatch	St. Paul	16.55	1.59	0.27	2711	MN0029815	126	511110
272	Deluxe Corp	St. Paul	81.00	1.06	0.89	2782	MN0029815	50	323118
273	Tapemark Co	St. Paul	3.70	0.77	0.03	2751	MN0029815	100	310000
274	Cintas Corp	St. Paul	14.07	14.22	2.07	7218	MN0030007	110	812332
275	Maguire & Strickland Refining Inc	St. Paul	0.10	0.08	0.00	7399	MN0029815	5	512200
276	Kangas Enameling Inc	St. Paul	93.79	0.10	0.09	3471	MN0029815	6	332813
277	E/M Corp	St. Paul	13.10	5.49	0.75	3679	MN0029815	30	334418
278	Precision Painting Inc	St. Paul	1.40	0.17	0.00	3479	MN0029815	50	339914
279	Excel Metal Finishing	St. Paul	3.69	0.59	0.02	3471	MN0029815	15	332813
280	Crib Diaper Service	St. Paul	8.00	1.77	0.15	7214	MN0029815	50	812100
281	Morrissey Inc	St. Paul	202.55	0.58	1.21	3469	MN0030007	92	332214
282	ELO Engineering	St. Paul	158.64	1.43	2.35	3479	MN0029815	75	339914
283	Douglas Corp	St. Paul	5.10	3.44	0.18	3479	MN0029882	480	339914
284	TRC Circuits Inc	St. Paul	0.78	4.77	0.04	3679	MN0029815	12	334418
285	Quality Metals Inc	St. Paul	136.23	2.95	4.16	3471	MN0029815	65	332813
286	Western Container Co	St. Paul	1.05	0.12	0.00	5085	MN0029815	12	423830
287	Richald Metal Finishing Inc	St. Paul	0.40	0.10	0.00	3471	MN0029815	3	332813
288	Markhurd Corp	St. Paul	9.20	0.09	0.01	7395	MN0029815	50	540000
289	Universal Circuits Inc	St. Paul	2.00	18.70	0.39	3679	MN0029815	78	334418
290	AAA Metal Finishing Inc (Plant 1)	St. Paul	288.00	1.92	5.72	3471	MN0029815	31	332813
291	U S Filter Recovery Services Inc	St. Paul	65.31	26.09	17.67	4953	MN0029815	69	562920
292	Brechet & Richter Co	St. Paul	3.93	2.15	0.09	2033	MN0029815	44	311421
293	Grand Eagle Services	St. Paul	2.10	0.23	0.00	7694	MN0029815	50	335312
294	Delaria Transport Inc	St. Paul	3.21	0.83	0.03	7699	MN0029815	50	115210
295	Invest-Cast Inc	St. Paul	0.40	1.13	0.00	3324	MN0029815	63	331512
296	Micro Finish Co	St. Paul	3.79	0.19	0.01	3471	MN0029815	2	332813
297	Forster Packing Co	St. Paul	6.87	0.67	0.05	2011	MN0029815	50	311611
298	Kwik-File Inc	St. Paul	10.12	2.01	0.21	2522	MN0029815	67	337214
299	Eaton MDH Inc, Eden Prairie Plant	St. Paul	19.23	8.80	1.76	3569	MN0029882	315	333999
300	Kurt Mfg Co	St. Paul	4.42	12.45	0.57	3599	MN0029815	199	336399
301	Consolidated Freightways	St. Paul	16.00	1.51	0.25	4231	MN0029815	50	488490
302	Arrow Cryogenics Inc	St. Paul	19.35	7.58	1.52	3471	MN0029815	70	332813
303	Versa Iron & Machine	St. Paul	0.85	0.71	0.01	3321	MN0029815	75	331511
304	James Page Brewing Co	St. Paul	306.00	0.36	1.13	2082	MN0029815	8	312120

Appendix C. MCES Industrial Users Database

ID	Facility Name	City	Average P (mg/L)	Average Flow (MG)	P_kgd	SIC_No	Permit_No	employee_count	NAICS Code
305	Certified Painting Inc	St. Paul	72.05	0.93	0.69	3471	MN0029815	19	332813
306	Northwest Swiss-Matic Inc	St. Paul	12.80	1.03	0.14	3451	MN0029815	85	332721
307	Shakopee Valley Printing	St. Paul	8.30	5.92	0.51	2751	MN0029882	350	310000
308	Northern Screw Machine Co	St. Paul	0.04	0.26	0.00	3451	MN0029815	33	332721
309	Covanta Hennepin Energy Resource Co, LP	St. Paul	1.60	3.56	0.06	4953	MN0029815	40	562920
310	American Spirit Graphics	St. Paul	9.50	1.80	0.18	2751	MN0029815	115	310000
311	Cleanco Truck Wash	St. Paul	31.64	1.86	0.61	7699	MN0029815	5	115210
312	General Mills Inc - Bakeries & Foodservice	St. Paul	13.53	5.15	0.72	2051	MN0029882	400	311812
313	Fischer's United Supply Inc	St. Paul	0.86	0.19	0.00	2033	MN0029815	7	311421
314	Twin City Tanning Co	St. Paul	20.14	104.39	21.81	3111	MN0029815	73	316110
315	Modern Machine & Engineering	St. Paul	7.43	0.65	0.05	3471	MN0029815	40	332813
316	Linfor Inc	St. Paul	26.67	0.66	0.18	3471	MN0029815	44	332813
317	TCR Engineered Components LLC	St. Paul	6.49	2.30	0.15	3452	MN0029815	139	332722
318	Kurt Mfg Co	St. Paul	2.10	1.56	0.03	3599	MN0029815	62	336399
319	McLaughlin Gormley King Co	St. Paul	0.24	0.56	0.00	2879	MN0029882	22	325320
320	General Mills Inc - Lloyd's Barbeque Co	St. Paul	149.78	14.57	22.63	2013	MN0029815	250	311612
321	GML Inc	St. Paul	11.83	1.70	0.21	3079	MN0029815	210	325200
322	Progress Casting Group	St. Paul	7.91	2.81	0.23	3361	MN0029815	380	332000
323	Brenntag Great Lakes LLC	St. Paul	11.87	0.30	0.04	7399	MN0029815	49	540000
324	Star Tribune	St. Paul	22.00	3.57	0.81	2711	MN0029815	750	511110
325	Added Value Technology	St. Paul	8.00	1.84	0.15	3679	MN0030007	12	334418
326	BOC Edwards	St. Paul	0.41	4.87	0.02	3559	MN0029882	50	333220
327	Determan Brownie Inc	St. Paul	4.28	1.59	0.07	1795	MN0029815	90	238910
328	Conagra Foods - Snack Food Group	St. Paul	11.25	9.23	1.08	2038	MN0029815	175	311412
329	Cypress Semi-Conductor (MN) Inc	St. Paul	85.64	47.29	42.00	3674	MN0030007	581	334413
330	KIK Minnesota	St. Paul	0.04	0.98	0.00	2842	MN0030007	20	325612
331	Quali-Tech Inc	St. Paul	4.13	1.83	0.08	2048	MN0029882	32	311611
332	Schawk Minneapolis	St. Paul	29.74	1.07	0.33	2752	MN0029815	130	323114
333	LSG/Sky Chef	St. Paul	22.10	17.43	3.99	2038	MN0029815	400	311412
334	NSP, dba Xcel Energy	St. Paul	0.24	1.21	0.00	4911	MN0029815	111	221113
335	VICOM	St. Paul	7.30	5.27	0.40	2038	MN0029882	129	311412
336	St John's Hospital NE	St. Paul	7.49	16.19	1.26	8062	MN0029815	1250	622110
337	AKZO Nobel Inks Corp	St. Paul	10.85	0.79	0.09	2893	MN0029815	47	325910
338	Tiro Industries Inc	St. Paul	1.37	8.82	0.13	2844	MN0029815	50	325620
339	Screen Printed Products	St. Paul	0.87	0.13	0.00	2751	MN0029815	2	310000
340	R & D Systems Inc	St. Paul	10.41	8.17	0.88	2831	MN0029815	495	325000
341	Precision Diversified Industries Inc LLC	St. Paul	0.62	7.44	0.05	3471	MN0029815	50	332813
342	Fairview Ridges Hospital	St. Paul	5.66	11.23	0.66	8062	MN0030007	860	622110
343	Boston Scientific - Scimed Inc	St. Paul	6.30	7.10	0.46	3841	MN0029815	499	339111
344	SuperMom's LLC	St. Paul	7.07	5.68	0.42	2051	MN0029815	305	311812
345	General Mills Inc - Bakeries & Foodservice	St. Paul	26.21	23.58	6.41	2051	MN0029882	834	311812
346	Instant Web Inc	St. Paul	25.57	3.66	0.97	2759	MN0029882	50	323114
347	Smith Engineering Inc	St. Paul	2.65	3.52	0.10	3589	MN0029882	18	333319
348	Sexton Printing Inc	St. Paul	0.20	0.67	0.00	2761	MN0029815	68	323116
349	Container Graphics	St. Paul	99.80	0.48	0.50	2795	MN0029815	70	310000
350	MagStar Technologies Inc	St. Paul	0.08	0.30	0.00	3079	MN0029815	65	325200
351	Cargill Dow Polymers LLC	St. Paul	2.87	2.24	0.07	8734	MN0029882	100	541940
352	The Specialty Mfg Co	St. Paul	0.66	0.76	0.01	3499	MN0029815	25	332999
353	Rosemount Inc	St. Paul	4.85	9.90	0.50	3810	MN0029882	1149	334500
354	Technical Plating Inc	St. Paul	12.12	12.79	1.61	3471	MN0029815	20	332813
355	Minneapolis Enameling Co	St. Paul	1310.03	0.20	2.78	3479	MN0029815	20	339914
356	Domino's National Commissary Corp	St. Paul	17.89	3.42	0.63	2045	MN0030007	50	311822
357	Weyerhaeuser Co	St. Paul	18.77	2.53	0.49	2653	MN0029815	140	322211
358	Wipaire Inc	St. Paul	157.17	0.12	0.20	3728	MN0029815	11	541710
359	Kurt Mfg Co	St. Paul	8.00	1.91	0.16	3499	MN0029815	2	332999
360	Custom Business Forms	St. Paul	1.65	0.43	0.01	2761	MN0029815	74	323116
361	Zuel Co Inc	St. Paul	0.26	1.50	0.00	3231	MN0029815	10	327215
362	NRG Energy Center Minneapolis LLC	St. Paul	1.77	4.86	0.09	4961	MN0029815	2	221330
363	Modernistic Inc	St. Paul	1.30	0.46	0.01	2759	MN0029815	50	323114
364	Multi-Clean Inc	St. Paul	4.00	0.28	0.01	2842	MN0029815	25	325612
365	Kurt Die Cast Co	St. Paul	14.23	2.69	0.40	3599	MN0029815	131	336399
366	Bodycote Thermal Processing Co	St. Paul	4.86	1.28	0.06	3398	MN0029815	44	332811
367	Banta Digital Group	St. Paul	9.00	1.43	0.13	7333	MN0029882	50	813900
368	Minnesota Brewing Co	St. Paul	6.08	143.26	9.03	2082	MN0029815	50	312120
369	Lifecore Biomedical	St. Paul	13.91	11.29	1.63	2819	MN0029882	172	211112
370	Stericycle Inc	St. Paul	5.89	5.23	0.32	4953	MN0029815	33	562920
371	Rayven Inc	St. Paul	0.07	0.66	0.00	3081	MN0029815	46	326113
372	Sifco Custom Machining Co	St. Paul	2.98	3.14	0.10	3599	MN0029815	70	336399
373	Burnsville Sales & Mfg	St. Paul	3.62	0.18	0.01	3714	MN0030007	20	336330
374	Lason Inc	St. Paul	1.00	0.40	0.00	7399	MN0029815	50	512200
375	Chef Solutions	St. Paul	8.90	7.03	0.65	2051	MN0029882	181	311812
376	Menasha Packaging	St. Paul	4.09	1.35	0.06	2653	MN0029815	100	322211
377	Aveda Corp	St. Paul	3.75	8.84	0.34	2844	MN0029815	583	325620
378	Cortec Corp	St. Paul	37.00	0.49	0.19	2899	MN0029815	64	325998
379	Northstar Financial Forms	St. Paul	264.00	0.74	2.03	2782	MN0029815	130	323118
380	H B Fuller Co	St. Paul	0.94	2.57	0.03	2891	MN0029815	45	325520

Appendix C. MCES Industrial Users Database

ID	Facility Name	City	Average P (mg/L)	Average Flow (MG)	P_kgd	SIC_No	Permit_No	employee_count	NAICS Code
381	Nilfisk - Advance Inc	St. Paul	116.69	5.62	6.80	3559	MN0029815	481	333220
382	McGlynn Bakeries	St. Paul	11.03	17.37	1.99	2051	MN0029815	350	311812
383	Banta Information Services Group	St. Paul	19.00	2.34	0.46	2752	MN0029815	202	323114
384	Banta Catalog Group	St. Paul	7.45	9.28	0.72	2752	MN0029815	397	323114
385	Multi-Tech Systems	St. Paul	8.10	0.88	0.07	3661	MN0029815	50	334418
386	Engineered Finishing Corp	St. Paul	54.67	0.20	0.12	3471	MN0029815	23	332813
387	Nystrom Inc	St. Paul	7.85	0.58	0.05	2522	MN0029815	67	337214
388	GreenMan Technologies of Minnesota Inc	St. Paul	1.50	2.02	0.03	4953	MN0030007	45	562920
389	Northwest Packaging Inc	St. Paul	1.58	0.33	0.01	2652	MN0029815	58	322213
390	Anotech Inc	St. Paul	7.56	2.18	0.17	3471	MN0029882	7	332813
391	Pump & Meter Services Inc	St. Paul	0.75	0.20	0.00	1799	MN0029882	40	238290
392	Impressions Inc	St. Paul	9.50	1.43	0.14	2752	MN0029815	238	323114
393	Bell Lumber & Pole Co	St. Paul	0.46	0.02	0.00	2491	MN0029815	35	321114
394	Anchor Glass Container Corp	St. Paul	0.77	7.76	0.06	3221	MN0029882	271	327213
395	RMS Co	St. Paul	5.39	4.90	0.27	3678	MN0029815	338	334417
396	Chemrex Inc	St. Paul	10.08	0.91	0.10	2891	MN0029882	200	325520
397	Road Rescue	St. Paul	62.43	0.66	0.43	3711	MN0029815	115	336112
398	ITC Intercircuit	St. Paul	3.19	1.13	0.04	3672	MN0045845	8	334412
399	Phoenix Packaging	St. Paul	7.81	2.76	0.22	7399	MN0029815	133	512200
400	Hanson Finishing Co	St. Paul	0.56	0.98	0.01	3471	MN0029815	50	332813
401	St Jude Medical Inc	St. Paul	3.61	8.92	0.33	3841	MN0029815	235	339111
402	Longview Fibre Co	St. Paul	5.37	7.71	0.43	2653	MN0029815	147	322211
403	Aircraft Service International Inc	St. Paul	14.71	0.66	0.10	4582	MN0029815	50	481000
404	Upper River Services Inc	St. Paul	3.13	1.52	0.05	4449	MN0029815	16	483211
405	Life Fitness Consumer Div	St. Paul	210.02	5.33	11.60	3490	MN0029815	217	332000
406	Bermo Inc	St. Paul	19.07	1.61	0.32	3469	MN0029815	200	332214
407	Meyers Printing Co	St. Paul	17.77	2.68	0.49	2752	MN0029815	285	323114
408	Alpha Ceramics Inc	St. Paul	0.00	8.79	0.00	3262	MN0029815	34	327112
409	APG Cash Drawer	St. Paul	5.34	0.82	0.05	3444	MN0029815	94	332322
410	Modern Tool	St. Paul	180.35	1.37	2.57	3599	MN0029815	85	336399
411	Waymouth Farms Inc	St. Paul	28.90	0.69	0.21	2065	MN0029815	156	311000
412	Metro Airports Commission	St. Paul	0.82	9.19	0.08	4581	MN0029815	2	561720
413	Hawkins Chemical Inc - Terminal I	St. Paul	60.80	1.49	0.94	7681	MN0029815	14	811000
414	ADM Milling	St. Paul	1.71	0.85	0.02	2041	MN0029815	25	311211
415	Lake Engineering Inc	St. Paul	18.29	0.75	0.14	3599	MN0029882	32	336399
416	Mentor Corp, Minnesota	St. Paul	3.09	4.08	0.13	3069	MN0029815	200	315999
417	Brennen Medical Inc	St. Paul	13.20	0.51	0.07	3842	MN0029815	50	334510
418	Awardcraft Inc	St. Paul	15.86	0.82	0.14	3993	MN0030007	120	339950
419	U of M - Animal Waste	St. Paul	41.40	1.26	0.54	8221	MN0029815	30	611310
420	Oexning Silversmiths Co	St. Paul	0.88	0.10	0.00	8711	MN0029815	50	541330
421	Liberty Carton Co	St. Paul	2.50	8.64	0.22	2653	MN0029815	440	322211
422	Smurfit-Stone Container Corp	St. Paul	5.27	1.42	0.08	2657	MN0029815	100	322212
423	Valmont/Lexington	St. Paul	140.40	0.58	0.84	3446	MN0045845	165	332323
424	Green Bay Packaging Inc - Twintown	St. Paul	11.30	1.81	0.21	2653	MN0029815	120	322211
425	Web Label Ltd	St. Paul	15.65	0.22	0.04	2752	MN0029815	37	323114
426	Cargill Dow Polymers LLC	St. Paul	1.30	6.50	0.09	2821	MN0030007	8	325211
427	Roc-Edge	St. Paul	19.00	0.05	0.01	3425	MN0030007	50	332213
428	Swanson Meat Co	St. Paul	24.70	0.74	0.19	5142	MN0029815	49	454390
429	Phillips & Temro Industries Inc	St. Paul	29.00	0.44	0.13	3714	MN0029882	130	336330
430	ECO Finishing Inc	St. Paul	21.63	12.93	2.90	3471	MN0029815	50	332813
431	Advance Corp	St. Paul	0.77	0.34	0.00	3993	MN0029815	50	339950
432	R B Painting & Metal Finishing Inc	St. Paul	7.40	0.08	0.01	3479	MN0029815	50	339914
433	J & E Mfg	St. Paul	24.53	0.83	0.21	3469	MN0045845	85	332214
434	Electrochemicals Inc	St. Paul	13.17	1.16	0.16	2899	MN0029882	42	325998
435	UPI Mechanical Plating & Galvanizing	St. Paul	0.08	0.04	0.00	3479	MN0029815	1	339914
436	H B Fuller Co	St. Paul	11.10	0.53	0.06	2851	MN0029815	96	325510
437	Westlund's Provisions Inc	St. Paul	22.62	1.91	0.45	5147	MN0029815	160	445210
438	Flamingo Wire & Powder Coating Inc	St. Paul	47.00	0.11	0.05	2542	MN0029882	50	337215
439	APW Thermal Management	St. Paul	3.27	2.96	0.10	3585	MN0029815	283	336391
440	Diversified Mfg Corp	St. Paul	6.85	0.48	0.03	2841	MN0029815	55	325611
441	Foster Wheeler Twin Cities Inc	St. Paul	1.66	13.95	0.24	4961	MN0029815	14	221330
442	Performance Industrial Coatings Inc	St. Paul	13.60	1.95	0.27	3479	MN0045845	19	339914
443	Boker's Inc	St. Paul	0.09	0.63	0.00	3419	MN0029815	120	333000
444	Penske Truck Leasing Co	St. Paul	2.10	0.28	0.01	8513	MN0029815	32	810000
445	American Engraving Inc	St. Paul	0.05	0.11	0.00	2796	MN0029815	3	323122
446	Danalco Inc	St. Paul	4.13	0.07	0.00	3679	MN0029815	8	334418
447	C & H Chemical Inc	St. Paul	323.00	0.27	0.89	2842	MN0029815	20	325612
448	Viking Drill & Tool Inc	St. Paul	7.15	1.22	0.09	3545	MN0029815	190	333515
449	Versa Die Cast Inc	St. Paul	13.30	0.60	0.08	3363	MN0029815	70	331521
450	Brady Worldwide Inc	St. Paul	14.30	0.52	0.08	3555	MN0029815	228	333293
451	Twin City Optical	St. Paul	1.69	1.15	0.02	3851	MN0029815	135	339115
452	PGI Companies	St. Paul	7.50	0.69	0.05	2752	MN0029882	154	323114
453	Multek Inc - Roseville	St. Paul	1.02	37.85	0.40	3672	MN0029815	242	334412
454	Ferrotech Plating Corp	St. Paul	0.13	0.02	0.00	3471	MN0029815	50	332813
455	Alumiplate Inc	St. Paul	0.85	0.23	0.00	3471	MN0029815	10	332813
456	Bureau of Engraving - Printing Div	St. Paul	6.28	1.97	0.13	2752	MN0029815	78	323114

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ID	Facility Name	City	Average P (mg/L)	Average Flow (MG)	P_kgd	SIC_No	Permit_No	employee_count	NAICS Code
457	Cintas Corp Location #470	St. Paul	28.70	7.28	2.17	7218	MN0029815	50	812332
458	Happy's Potato Chip Co	St. Paul	16.43	17.21	2.93	2096	MN0029815	41	311919
459	Fox Packaging Inc	St. Paul	19.00	0.53	0.10	2842	MN0029815	80	325612
460	J I T Powder Coating	St. Paul	140.40	1.40	2.04	3479	MN0045845	54	339914
461	NVE Corp	St. Paul	11.66	0.32	0.04	3674	MN0029882	60	334413
462	Huebsch Laundry Co	St. Paul	25.00	2.14	0.55	7218	MN0030007	24	812332
463	Twin Star Electronics Inc	St. Paul	0.70	0.70	0.01	3679	MN0029815	5	334418
464	ATMI Packaging Inc	St. Paul	0.15	5.33	0.01	3089	MN0030007	132	326122
465	Greenway Research Lab	St. Paul	0.24	1.10	0.00	2844	MN0030007	72	325620
466	North Star Finishing Inc	St. Paul	3.50	2.90	0.11	3471	MN0029815	50	332813
467	Cross Technology Inc	St. Paul	9.00	0.28	0.03	3679	MN0029815	50	334418
468	Weather Rite Inc	St. Paul	114.58	1.04	1.24	3564	MN0029815	65	333411
469	ABW Plating Service Inc	St. Paul	699.00	0.63	4.54	3471	MN0029815	6	332813
470	Haagen-Dazs R & D	St. Paul	40.03	0.51	0.21	2024	MN0029815	13	311520
471	Dayton Rogers Mfg Co	St. Paul	7.31	0.78	0.06	3469	MN0029815	125	332214
472	North Star Steel Minnesota	St. Paul	0.36	20.64	0.08	3312	MN0029815	420	331111
473	FSI International Inc	St. Paul	0.32	14.63	0.05	3559	MN0029882	240	333220
474	LeJeune Bolt Co	St. Paul	0.00	0.24	0.00	3479	MN0030007	12	339914
475	Minco Products Inc	St. Paul	0.11	7.64	0.01	3679	MN0029815	227	334418
476	Color Converting Industries	St. Paul	0.97	0.24	0.00	2893	MN0029815	2	325910
477	St Francis Regional Medical Center	St. Paul	12.90	4.47	0.60	8062	MN0029882	700	622110
478	Spec Plating Corp	St. Paul	41.90	9.54	4.14	3471	MN0029815	58	332813
479	Hutchinson Technology Inc	St. Paul	54.40	4.33	2.44	3577	MN0029815	145	334613
480	Shoreview Metalcraft Inc	St. Paul	170.00	0.40	0.70	3471	MN0029815	6	332813
481	Interstate Detroit Diesel	St. Paul	10.86	0.55	0.06	4173	MN0030007	125	488490
482	Vision-Ease Lens Inc	St. Paul	2.29	14.49	0.34	3851	MN0029815	430	339115
483	Intek Plastics Inc	St. Paul	0.55	2.29	0.01	3089	MN0029955	155	326122
484	Wrico Stamping Co of Mn	St. Paul	7.37	0.79	0.06	3469	MN0029815	95	332214
485	Inno-Flex Corp	St. Paul	3.30	1.27	0.04	3663	MN0029815	50	334220
486	Hard Anodize Inc	St. Paul	2.59	0.37	0.01	3471	MN0029815	19	332813
487	Zomax Optical Media	St. Paul	0.39	1.72	0.01	3652	MN0029815	200	334612
488	J R Gold Plating Inc	St. Paul	0.01	0.01	0.00	3471	MN0029815	50	332813
489	Inthermo Inc	St. Paul	44.79	0.42	0.19	3479	MN0045845	9	339914
490	J R Williams Co Inc	St. Paul	11.49	0.08	0.01	3479	MN0029815	23	339914
491	Japs-Olson Co	St. Paul	9.90	3.35	0.34	2752	MN0029815	545	323114
492	Harvest States Foods	St. Paul	19.55	10.86	2.20	2099	MN0029815	161	311830
493	PUR Water Purification Products	St. Paul	14.76	2.23	0.34	3589	MN0029815	275	333319
494	Aramark Uniform Svcs Inc	St. Paul	12.00	16.94	2.11	7218	MN0029815	70	812332
495	Upsher Smith Laboratories Inc	St. Paul	11.77	1.41	0.17	8734	MN0029815	160	541940
496	ADC Telecommunications Inc	St. Paul	10.03	25.68	2.67	3661	MN0029882	658	334418
497	FMS Corp	St. Paul	11.68	4.37	0.53	3641	MN0030007	85	335110
498	American Medical Systems	St. Paul	3.27	5.05	0.17	3842	MN0029882	335	334510
499	Tempco Mfg Co Inc	St. Paul	4.65	1.77	0.09	3469	MN0029815	176	332214
500	Ad Graphics	St. Paul	8.10	0.67	0.06	2759	MN0029815	248	323114
501	Fuji Color Processing	St. Paul	3.64	3.80	0.14	7395	MN0029815	120	540000
502	Alliant Techsystems Inc	St. Paul	0.86	2.10	0.02	3482	MN0029815	27	332992
503	AKZO Nobel Inks Corp	St. Paul	1.76	0.28	0.01	2893	MN0029815	31	325910
504	Seagate Technology LLC	St. Paul	0.35	6.38	0.02	3573	MN0030007	50	333000
505	Spruce Co	St. Paul	27.00	5.35	1.50	7218	MN0030007	25	812332
506	Walman Optical Co	St. Paul	12.00	1.77	0.22	3851	MN0029815	50	339115
507	Huot Mfg Co	St. Paul	20.47	0.36	0.08	3499	MN0029815	46	332999
508	ADDCO Inc	St. Paul	370.53	0.34	1.31	3669	MN0029815	95	334290
509	Medtronic Perfusion Systems	St. Paul	2.33	7.22	0.17	3841	MN0029815	358	339111
510	RTC Inc	St. Paul	0.03	0.57	0.00	3089	MN0029815	96	326122
511	Summit Brewing Co	St. Paul	50.33	7.59	3.96	2082	MN0029815	36	312120
512	Imation Corp	St. Paul	6.88	8.28	0.59	8731	MN0029815	800	541710
513	Brenntag Great Lakes LLC	St. Paul	3.56	0.42	0.02	5169	MN0029815	6	425120
514	Metal Treaters Inc	St. Paul	0.56	3.96	0.02	3398	MN0029815	25	332811
515	Olsen Fish Co	St. Paul	73.00	0.99	0.75	2091	MN0029815	14	311711
516	Carter Day International Inc	St. Paul	28.20	0.56	0.16	3523	MN0029815	45	332323
517	Ryt-Way Industries Inc	St. Paul	14.96	1.44	0.22	7389	MN0045845	387	512290
518	Revest Midwest	St. Paul	118.58	2.42	2.97	3479	MN0029815	100	339914
519	Industrial Container Services - MN LLC	St. Paul	2.80	0.77	0.02	7699	MN0029815	56	115210
520	Hoffman Enclosure (SCO)	St. Paul	351.01	2.99	10.88	3644	MN0029815	210	335932
521	Foster Wheeler Twin Cities Inc	St. Paul	0.26	30.15	0.08	8221	MN0029815	20	611310
522	Phillips & Temro Industries Inc	St. Paul	106.09	0.15	0.17	3599	MN0029882	33	336399
523	Boomerang Laboratories Inc	St. Paul	0.60	4.52	0.03	2844	MN0029882	13	325620
524	Skyline Exhibits	St. Paul	51.45	1.53	0.81	3993	MN0030007	341	339950
525	Buddy's Kitchen Inc	St. Paul	3.24	2.00	0.07	5812	MN0030007	75	722211
526	Great Lakes Engineering Inc	St. Paul	0.92	0.18	0.00	3699	MN0029815	20	335129
527	M & D Metal Finishing Inc	St. Paul	0.23	0.95	0.00	3479	MN0029815	20	339914
528	Cannon Equipment	St. Paul	31.14	0.22	0.07	3535	MN0025488	122	333922
529	Siyeza Inc	St. Paul	13.50	7.34	1.03	2038	MN0029815	98	311412
530	Uponor Wirsbo	St. Paul	0.10	1.88	0.00	8083	MN0045845	110	620000
531	DIGIgraphics/Photos Inc	St. Paul	8.56	1.70	0.15	7384	MN0029815	33	812922
532	Dyneon LLC	St. Paul	9.67	1.95	0.20	1187	MN0029815	95	210000

Appendix C. MCES Industrial Users Database

ID	Facility Name	City	Average P (mg/L)	Average Flow (MG)	P_kgd	SIC_No	Permit_No	employee_count	NAICS Code
533	Metropolitan Linen Service	St. Paul	2.39	26.70	0.66	7218	MN0029815	42	812332
534	Waltek	St. Paul	0.29	0.18	0.00	3324	MN0029815	50	331512
535	Production Engineering Corp	St. Paul	2.39	0.66	0.02	3599	MN0029815	85	336399
536	Gannett Offset - Minneapolis	St. Paul	10.09	2.35	0.25	2752	MN0029815	230	323114
537	Micro Control Co	St. Paul	0.68	0.08	0.00	3479	MN0029815	6	339914
538	Protein Design Labs Inc	St. Paul	220.60	1.74	3.98	2834	MN0029815	100	325412
539	Midwest Finishing Inc	St. Paul	53.11	3.22	1.77	3471	MN0029815	20	332813
540	Water Gremlin Co	St. Paul	6.80	1.63	0.11	3364	MN0029815	50	331522
541	Alliance Steel Service Co	St. Paul	89.60	0.12	0.11	5093	MN0029815	14	425110
542	Cintas Corp	St. Paul	27.98	11.22	3.25	7218	MN0029815	138	812332
543	Electro Static Corp	St. Paul	57.85	0.59	0.35	3479	MN0029815	13	339914
544	Innovex Inc	St. Paul	1.34	15.97	0.22	3674	MN0029882	180	334413
545	Mid Minnesota Wire & Mfg Inc	St. Paul	285.00	0.50	1.47	3496	MN0029815	53	332618
546	Seagate Technology LLC	St. Paul	8.45	5.10	0.45	3572	MN0029882	950	334112
547	Remmele Engineering Inc	St. Paul	38.80	0.43	0.17	3599	MN0029815	130	336399
548	Gustafson Finishing Corp	St. Paul	812.00	0.12	1.04	8999	MN0029815	4	518112
549	G & K Services	St. Paul	117.00	4.96	6.02	7218	MN0029815	100	812332
550	Cargill Inc - Process Development Facility	St. Paul	12.99	1.80	0.24	7391	MN0030007	5	512200
551	Power Coat	St. Paul	225.97	0.06	0.13	3479	MN0029815	2	339914
552	Hoffman Enclosures Inc	St. Paul	52.81	13.23	7.25	3644	MN0029815	900	335932
553	Aspen Equipment	St. Paul	82.35	0.74	0.63	2394	MN0030007	30	314912
554	Creative Carton Corp	St. Paul	4.21	1.14	0.05	2653	MN0029815	150	322211
555	Precise Products Corp	St. Paul	13.03	0.60	0.08	3728	MN0029815	72	541710
556	Biovest International Inc	St. Paul	6.84	0.86	0.06	9900	MN0029815	45	810000
557	Sterling Water Inc dba Culligan	St. Paul	0.29	2.52	0.01	7389	MN0029998	17	512290
558	Maximum Graphics	St. Paul	7.06	1.84	0.13	2789	MN0029882	95	323121
559	C A Rose & Co LLC	St. Paul	7.00	2400.39	0.02	1541	MN0030007	12	236210
560	Wendell's	St. Paul	3.50	0.53	0.02	3471	MN0029815	50	332813
561	J & L Wire Cloth Co Inc	St. Paul	0.22	0.71	0.00	3496	MN0029815	12	332618
562	Pro-Tech Interconnect Solutions	St. Paul	0.45	7.02	0.03	3672	MN0029882	56	334412
563	Travel Tags	St. Paul	3.81	3.73	0.15	2752	MN0029815	379	323114
564	Illbruck Inc	St. Paul	2.50	2.52	0.07	3086	MN0029815	140	326150
565	Central Container Corp	St. Paul	44.80	0.86	0.40	2653	MN0029815	88	322211
566	Springs Inc	St. Paul	74.07	0.53	0.40	3495	MN0029815	43	334518
567	Woodwinds Health Campus	St. Paul	7.56	6.53	0.51	8062	MN0029815	400	622110
568	Buesing Bulk Transport Inc	St. Paul	19.28	1.83	0.37	7542	MN0029882	13	811192
569	Rupp Industries	St. Paul	3.38	0.42	0.01	1711	MN0030007	50	238210
570	LECTEC Corp	St. Paul	0.63	0.97	0.01	3842	MN0029882	54	334510
571	Hennepin County Energy Center	St. Paul	1.00	20.48	0.21	4961	MN0029815	9	221330
572	Lason Inc	St. Paul	1.70	0.46	0.01	7374	MN0029815	47	518210
573	Zenith Products	St. Paul	0.00	0.15	0.00	3271	MN0029815	13	327331
574	LAI Midwest Inc	St. Paul	17.04	0.41	0.07	3499	MN0029815	50	332999
575	Eaglemaster Inc	St. Paul	1.60	0.74	0.01	9900	MN0029815	19	810000
576	3M Co - OH & ES Pilot Plant	St. Paul	0.18	1.71	0.00	2297	MN0029815	30	313230
577	Benson Metals Inc	St. Paul	0.43	0.11	0.00	3449	MN0029815	8	332323
578	Boos Dental Laboratory	St. Paul	4.90	0.94	0.05	3079	MN0029815	55	325200
579	AAA Metal Finishing Inc (Plant 2)	St. Paul	910.41	0.48	4.48	3471	MN0029815	12	332813
580	B F Nelson Folding Cartons	St. Paul	2.94	1.68	0.05	2679	MN0030007	80	322299
581	Mate Precision Tooling	St. Paul	7.62	1.73	0.14	3544	MN0029815	310	333514
582	Hawkins Chemical Inc	St. Paul	17.65	1.14	0.21	5169	MN0029815	26	425120
583	A W Beadblasting Co	St. Paul	0.38	0.12	0.00	3479	MN0029815	6	339914
584	Powder Specialties	St. Paul	3.27	0.04	0.00	3479	MN0029815	3	339914
585	Specialty Automatics	St. Paul	8.95	0.27	0.02	3432	MN0029815	49	332919
586	Mid-City Industrial Laundry	St. Paul	9.44	0.96	0.09	7218	MN0029815	9	812332
587	Micro-Matics LLC	St. Paul	8.05	0.25	0.02	3451	MN0029815	25	332721
588	Ron-Vik Inc	St. Paul	5.87	0.84	0.05	3496	MN0029815	95	332618
589	Advance Corp		0.09	0.42	0.00	3993		60	339950
590	Wanner Engineering	St. Paul	0.28	7.06	0.02	3561	MN0029815	71	333911
591	Cima Labs Inc	St. Paul	3.84	1.35	0.05	2834	MN0029882	160	325412
592	Better Parts Co	St. Paul	26.50	0.24	0.07	3469	MN0030007	14	332214
593	Liberty Carton Co	St. Paul	0.61	0.77	0.00	2631	MN0029815	80	322130
594	Lettieri's Inc	St. Paul	26.62	2.41	0.67	5142	MN0030007	98	454390
595	MedSource Technologies	St. Paul	0.20	1.19	0.00	3841	MN0029815	240	339111
596	A&E Metal Finishing Inc	St. Paul	5.90	0.15	0.01	3559	MN0029815	3	333220
597	ViroGen Inc	St. Paul	19.30	0.02	0.00	2836	MN0029815	3	325414
598	Bell Mfg & Services Inc	St. Paul	293.32	0.19	0.57	2514	MN0029815	13	337124
599	Bell Mfg & Services Inc	St. Paul	111.36	0.32	0.37	2514	MN0029815	32	337124
600	Aggressive Industries Inc	St. Paul	201.77	1.42	2.98	3089	MN0029815	20	326122
601	Aljon Tool Inc	St. Paul	9.04	0.94	0.09	3599	MN0029815	22	336399
602	J L Industries	St. Paul	14.75	0.80	0.12	2599	MN0030007	45	339111
603	Electro-Mechanical Industries Inc	St. Paul	36.74	3546.31	28.44	3613	MN0029815	36	335313
604	Nu Coat Inc	St. Paul	0.15	0.15	0.00	2899	MN0029815	7	325998
605	Process Displays Printing	St. Paul	7.51	1.94	0.15	2752	MN0029815	120	323114
606	QX Inc	St. Paul	2.71	0.74	0.02	3463	MN0029815	84	332112
607	Metal Strippers	St. Paul	1.53	0.00	0.00	3471	MN0030007	1	332813
608	Midwest Powdercoating & Screen Printing	St. Paul	44.26	0.11	0.05	3476	MN0029815	22	310000

Appendix C. MCES Industrial Users Database

ID	Facility Name	City	Average P (mg/L)	Average Flow (MG)	P_kgd	SIC_No	Permit_No	employee_count	NAICS Code
609	ProtaTek International	St. Paul	13.24	0.16	0.02	2836	MN0029815	12	325414
610	Ritrama Inc	St. Paul	8.39	1.81	0.16	2672	MN0029815	115	322222
611	Quality Ingredients Corp	St. Paul	34.79	2.76	1.00	2023	MN0030007	37	311514
612	Conwed Plastics	St. Paul	0.09	1.02	0.00	3079	MN0029815	16	325200
613	Production Technology	St. Paul	0.34	0.10	0.00	0	MN0029815	18	921100
614	APA Optics Inc	St. Paul	3.77	0.42	0.02	3827	MN0029815	30	333314
615	Prime Plating Inc	St. Paul	0.35	0.42	0.00	3471	MN0029815	50	332813
616	The Carlson Print Group	St. Paul	7.64	0.38	0.03	2752	MN0030007	60	323114
617	Intercomp	St. Paul	0.37	2.00	0.01	3596	MN0029815	57	333997
618	Wigen Water Technologies	St. Paul	0.13	0.10	0.00	7389	MN0029882	16	512290

Appendix D

Communities Adding Phosphorus to Drinking Water Supply

Appendix D
Communities Adding Phosphorus to Drinking Water Supply

Community Name	Population	County	Phosphorus [mg/L]	Flow [GPD]
Ah Gwah Ching Center	400	Cass		43,000
Baxter	3,400	Crow Wing	1.64	650,000
Bell Hill Recovery Center	100	Wadena	4.14	9,900
Biscay	124	McLeod		10,000
Boyd	210	Lac Qui Parle		27,000
Breitung	485	Saint Louis		130,000
Brookside Mobile Home Park	500	Ramsey		51,000
Buckman	217	Morrison	0.42	19,342
Carleton College	2,485	Rice		160,000
Cass Lake	860	Cass		100,000
Centennial Square Mobile Home Park	2,000	Anoka	1.17	150,000
Charley Lake Townhomes Association	40	Ramsey		12,205
Chester Heights	300	Olmsted		30,000
Claremont	620	Dodge	1.21	45,000
Clearwater	858	Wright		150,000
Cohasset Municipal Water System	755	Itasca		40,000
Crown College	520	Carver	1.12	38,000
Cuyuna	120	Crow Wing		9,000
Cyrus	303	Pope		23,000
Dayton	268	Hennepin		16,000
Eagle Bend	595	Todd	6.48	56,323
Eagle Lake	1,787	Blue Earth	2.41	150,000
Elba	218	Winona		14,000
Empire Township	900	Dakota		80,000
Erskine	422	Polk		80,000
Federal Correctional Institution	900	Pine		250,000
Flamingo Terrace Mobile Home Park	600	Anoka		36,000
Forest Lake	7,270	Washington		850,000
Fridley Terrace Mobile Home Park	800	Anoka	0.94	62,000
Gary	204	Norman		18,000
Goodview	3,000	Winona		290,000
Granite Falls	3,070	Yellow Medicine		332,000
Hallmark Terrace Mobile Home Park	275	Olmsted		8,000
Hammond	198	Wabasha		40,000
Hillcrest Health Care Center	110	Blue Earth		21,500
Hoffman	672	Grant		100,000
Holloway	142	Swift	3.2	15,776
Iona	177	Murray		15,000
Joint Powers Board System	13,133	Wright	1.74	1,608,000
Kenyon	1,661	Goodhue		175,000
Kittson-Marshall Rural Water System	976	Marshall	1.53	50,000
Knollwood Parks LLC	340	Blue Earth		20,000
LaSalle	93	Watonwan		12,000
LeHillier Community Water Supply	530	Blue Earth		35,500
Liberty Court Mobile Home Park	150	Roseau		5,000

Community Name	Population	County	Phosphorus [mg/L]	Flow [GPD]
Lincoln-Pipestone Rural Water System	8,400	Lincoln	0.65	3,790,000

Community Name	Population	County	Phosphorus [mg/L]	Flow [GPD]
Long Lake	1,842	Hennepin		250,000
Lonsdale	1,493	Rice	1.76	160,000
Maple Hills Estates	410	Hennepin		30,000
Mapleview	253	Mower		20,000
Marshall-Polk Rural Water System	3,295	Marshall		250,000
MN Correctional Facility - Faribault	2,103	Rice	6.8	250,000
MN Correctional Facility - Moose Lake	975	Carlton	0.95	145,000
MN Correctional Facility - Red Wing	250	Goodhue	2.09	38,000
MN State Prison - Stillwater	1,900	Washington	1.96	300,000
Nerstrand	264	Rice		25,000
Nevis	364	Hubbard		45,000
New Auburn	488	Sibley		27,000
New Munich	354	Stearns		44,932
North Kittson Rural Water	3,300	Kittson	2.02	280,000
Odin	118	Watonwan		6,000
Olmsted County Waste/Energy	700	Olmsted	1.65	250,000
Ottertail Nursing Home	110	Otter Tail		10,000
Paul Revere Community	560	Anoka		56,000
Queen Anne Court	400	Dakota	1.94	0
Restwood Terrace	550	Anoka		40,000
Rock County Rural Water System	2,902	Rock	0.92	657,000
Rockville	749	Stearns		73,819
Saint Charles	2,250	Winona		450,000
Saint Hilaire	272	Pennington		25,000
School Sisters of Notre Dame	250	Blue Earth		27,350
Spring Grove	1,304	Houston		250,000
Sun Valley Mobile Home Park	150	Hennepin		0
Tintah	68	Traverse		10,000
Town's Edge Mobile Home Park	300	Stearns		23,000
Underwood	310	Otter Tail	0.89	29,000
Verndale	575	Wadena		38,000
Village Green North Mobile Home Park	355	Anoka		39,400
Walden Woods	60	Stearns	1.11	25,000
West Concord	836	Dodge		74,000
Windsor Hills First Addition	30	Olmsted		0
Wolverton	138	Wilkin		12,500
Wyoming	3,200	Chisago		262,000
Zumbro Ridge Estates	250	Olmsted		0
Lanesboro	788	Fillmore		130,000
Chisholm	4,960	Saint Louis		460,000
Montevideo	5,462	Chippewa		730,906
Luverne	4,617	Rock	1.73	845,000
New Prague	3,400	LeSueur	1.93	600,000
Detroit Lakes	7,368	Becker	1.32	1,370,000
Hoyt Lakes	2,348	Saint Louis		350,000
International Falls	6,703	Koochiching	1.46	800,000
Deer Creek	332	Otter Tail	5.34	20,000
Canby	1,903	Yellow Medicine	1.37	200,000

Community Name	Population	County	Phosphorus [mg/L]	Flow [GPD]
Redwood Falls	5,164	Redwood	2.41	600,000
Lakefield	1,721	Jackson	2.11	185,000
Blue Earth	3,621	Faribault		405,000
Monticello	7,868	Wright		1,408,178
Kerkhoven	759	Swift		93,100
Alden	652	Freeborn	1.53	50,000
LaCrescent	4,923	Houston		332,500
Babbitt	1,100	Saint Louis	0.95	340,000
Wadena	4,294	Wadena	1.05	640,000
Stewartville	5,611	Olmsted		410,000
Renville	1,323	Renville	1.43	279,000
Preston	1,426	Fillmore		210,000
Milan	329	Chippewa	3.83	33,425
Elk River	10,000	Sherburne		1,864,356
Wykoff	460	Fillmore		40,000
Olivia	2,570	Renville	1.45	361,000
Bowlus	276	Morrison		17,000
Geneva	449	Freeborn		70,000
Dodge Center	2,226	Dodge		170,000
Mantorville	737	Dodge		80,000
Mapleton	1,678	Blue Earth	1.07	130,000
Littlefork	680	Koochiching		63,000
Annandale	2,684	Wright		299,986
Glenville	720	Freeborn	1.84	95,000
Morris	5,062	Stevens	1.18	600,000
Rush City	2,100	Chisago		240,000
Saint Francis	2,998	Anoka		454,000
Starbuck	1,300	Pope		231,654
Thief River Falls	8,410	Pennington	1.85	1,000,000
Winsted	2,094	McLeod		160,000
Pequot Lakes	947	Crow Wing		115,000
Comfrey	367	Brown	1.49	30,000
Ada	1,657	Norman	2.72	170,000
Tracy	2,268	Lyon		230,000
Walnut Grove	599	Redwood		50,000
Pine City	3,043	Pine		351,560
East Grand Forks	7,501	Polk		1,250,000
Waldorf	242	Waseca	1.7	22,000
Appleton	2,871	Swift	1.96	376,697
Lake Lillian	240	Kandiyohi		34,795
Ogilvie	481	Kanabec		38,315
Lyle	566	Mower		50,000
Fosston	1,575	Polk		180,000
Watson	211	Chippewa		30,000
Marshall	12,735	Lyon	1.82	3,000,000
Wanamingo	1,007	Goodhue		85,000
Windom	4,600	Cottonwood	2.37	996,578
Pelican Rapids	2,374	Otter Tail	0.89	600,000

Community Name	Population	County	Phosphorus [mg/L]	Flow [GPD]
Glencoe	5,453	McLeod	1.68	616,000
College of St. Benedict	1,600	Stearns		206,000
Bemidji	12,090	Beltrami		1,580,000
Barnesville	2,173	Clay	0.84	250,000
Atwater	1,079	Kandiyohi		132,900
Austin	23,314	Mower		2,700,000
Barrett	349	Grant		60,000
Belle Plaine	3,700	Scott		378,000
Big Falls	264	Koochiching		25,000
Bird Island	1,195	Renville	3.79	123,000
Braham	1,295	Isanti	5.72	83,600
Bricelyn	379	Faribault		40,000
Brownton	807	McLeod		55,000
Butterfield	565	Watonwan		45,000
Cannon Falls	3,700	Goodhue		605,000
Clements	192	Redwood		18,000
Clinton	450	Bigstone	1.28	50,000
Cologne	1,012	Carver		75,000
Eveleth	4,100	Saint Louis	0.89	650,000
Finlayson	314	Pine	5.87	22,220
Garfield	280	Douglas		23,288
Graceville	605	Bigstone	1.07	60,000
Grand Meadow	945	Mower		85,000
Hancock	710	Stevens	1.37	61,000
Hayfield	1,301	Dodge		121,000
Henderson	910	Sibley	5.92	87,000
Herman	485	Grant	1.11	65,000
Hill City	479	Aitkin		41,000
Hills (Consecutive of 1670007)	565	Rock	0.8	47,000
Hinckley	4,000	Pine		338,098
Holdingford	736	Stearns		60,468
Houston	1,020	Houston	5.8	85,000
Isanti	2,334	Isanti		231,126
Isle	574	Mille Lacs	4.35	91,080
Lafayette	529	Nicollet		57,300
Lamberton	859	Redwood	2.58	105,000
Lester Prairie	1,377	McLeod		106,580
Lewiston	1,484	Winona		150,000
Litchfield	6,278	Meeker	1.43	900,000
Lowry	277	Pope		24,232
Madelia	2,340	Watonwan	1.36	716,000
Medford	1,000	Steele		71,000
Milaca	2,580	Mille Lacs	5.89	329,150
Motley	585	Morrison	1.2	300,000
Nielsville	90	Polk		10,000
North Branch	3,600	Chisago		421,128
Northfield	17,147	Rice		2,000,000
Orr	249	Saint Louis	3.21	45,000

Community Name	Population	County	Phosphorus [mg/L]	Flow [GPD]
Ostrander	293	Fillmore		31,000
Pine Island	2,337	Goodhue		275,000
Plummer	270	Red Lake		25,000
Princeton	3,933	Mille Lacs		575,000
Randall	600	Morrison	2.47	47,515
Rochester	89,870	Olmsted	0.54	12,900,000
Rockford	3,340	Wright	7.52	393,479
Sanborn	428	Redwood		24,000
Sauk Centre	3,930	Stearns	1.03	514,668
Shelly	266	Norman		20,000
Silver Lake	800	McLeod		75,300
Stacy	1,278	Chisago		90,000
Staples	3,104	Todd		345,000
Twin Valley	861	Norman	1.72	90,000
Wabasso	700	Redwood	1.35	75,000
Warroad	1,722	Roseau		200,000
Easton	214	Faribault	2	23,400
Wells	2,433	Faribault		420,000
Winnebago	1,487	Faribault		170,000
Wood Lake	436	Yellow Medicine	4.7	46,000
Zumbrota	2,800	Goodhue		475,000
Hector	1,167	Renville	3.45	151,000
Rosemount	15,900	Dakota		1,500,000
Becker	3,200	Sherburne		488,208
Rushmore	376	Nobles	3.75	41,000
Morristown	810	Rice		80,000
Baudette	1,146	Woods		175,000
Rogers	4,333	Hennepin		868,493
Andover	16,587	Anoka		2,300,000
Blaine	44,000	Anoka		4,600,000
Brooklyn Center	29,172	Hennepin		3,500,000
Brooklyn Park	67,388	Hennepin		8,767,000
Centerville	3,600	Anoka		150,000
Champlin	22,500	Hennepin		1,800,000
Columbia Heights, consecutive of 1270024	18,520	Anoka	0.68	1,400,000
Coon Rapids	63,000	Anoka	1.97	8,400,000
Crystal (Consecutive of 1270024)	22,668	Hennepin	0.59	4,000,000
Fridley	29,000	Anoka		5,000,000
Golden Valley (Consecutive of 1270024)	20,281	Hennepin	0.62	4,100,000
Hopkins	16,534	Hennepin	1.12	2,500,000
Hugo	3,880	Washington		400,000
Lexington	2,279	Anoka		120,000
Lino Lakes	10,978	Anoka		1,023,000
Mahtomedi	7,977	Washington		652,000
Maple Grove	50,365	Hennepin		7,000,000
Medina	2,623	Hennepin		165,000
Minneapolis	480,526	Hennepin	0.59	70,000,000
New Hope	20,873	Hennepin	0.63	2,310,000

Community Name	Population	County	Phosphorus [mg/L]	Flow [GPD]
Oakdale	26,500	Washington		2,567,000
Osseo	2,434	Hennepin		250,000
Plymouth	66,675	Hennepin	1.23	8,571,000
Saint Anthony Village	8,012	Hennepin		975,636
Vadnais Heights	13,500	Ramsey		1,300,000
Eden Prairie	54,901	Hennepin		6,500,000
Excelsior	2,356	Hennepin	1.64	370,000
Maple Plain	2,080	Hennepin	0.48	260,860
Minnetonka	51,607	Hennepin	1.42	6,900,000
Minnetrista	1,470	Hennepin		154,000
Orono	2,300	Hennepin	2.19	230,000
Prior Lake	17,310	Scott		1,200,000
Saint Bonifacius	2,100	Hennepin		214,000
Tonka Bay	1,540	Hennepin		190,000
Victoria	2,743	Carver		400,000
Waconia	8,600	Carver	2.11	1,000,000
Wayzata	4,113	Hennepin	1.35	800,000
Bayport	1,700	Washington		300,000
Stillwater	16,193	Washington		1,960,000
Lakeville	40,000	Dakota		4,500,000
New Ulm	13,594	Brown	1.12	2,300,000
Fairmont	10,889	Martin	1.5	1,420,000
Faribault	18,838	Rice		3,000,000
Virginia	11,495	Saint Louis		2,200,000
Mankato	32,062	Blue Earth		4,800,000
Shafer	390	Chisago		33,445
Worthington	11,285	Nobles	2.04	2,600,000
Lucan	226	Redwood	4.71	21,000
Ghent	315	Lyon		27,000
Porter	208	Yellow Medicine		5,300
Buffalo	10,001	Wright	1.18	1,200,000
Alexandria	9,247	Douglas	1.13	1,350,000
Madison Lake	837	Blue Earth		61,000
Saint Cloud	64,552	Stearns		7,023,616
Sartell	9,641	Stearns	2.25	1,444,323
Albert Lea	18,356	Freeborn	1.33	3,585,000
Henning	719	Otter Tail		90,000
Ellendale	606	Steele		60,000
Greenbush	784	Roseau		85,000
Raymond	803	Kandiyohi	7.23	91,506
Farmington	13,000	Dakota		1,500,000
Mazeppa	798	Wabasha		65,000
Avon	1,242	Stearns		170,890
Taunton	207	Lyon		8,600
Clear Lake	318	Sherburne		32,000
Foreston	503	Mille Lacs		21,000
Hollandale	290	Freeborn		38,000
Dilworth	3,030	Clay	3.37	310,000

Community Name	Population	County	Phosphorus [mg/L]	Flow [GPD]
Moorhead	34,500	Clay		4,100,000
Northome	230	Koochiching		29,000
Cokato	2,733	Wright		380,000
Byron	3,294	Olmsted		200,000
Badger	470	Roseau	2.55	35,000
Cloquet	11,201	Carlton		1,300,000
Wrenshall	308	Carlton		15,000
Buffalo Lake	773	Renville	3.58	76,000
Fergus Falls	13,470	Otter Tail		1,800,000
Marietta	174	Lac Qui Parle		14,000
Ortonville	2,766	Bigstone	2.77	390,000
Delano	3,967	Wright		354,000
Owatonna	22,434	Steele		4,300,000
Belgrade	750	Stearns	4.15	85,000
Wendell	165	Grant	3.53	37,000
Elbow Lake	1,275	Grant		130,000
Madison	1,758	Lac Qui Parle		298,000
Howard Lake	1,853	Wright	1.43	156,493
Argyle	657	Marshall	2.18	65,000
Hanska	443	Brown	1.04	55,000
Glenwood	2,594	Pope		317,353
Green Lake Water District	1,500	Kandiyohi	3	275,000
Murdock	282	Swift		42,000
Biwabik	1,428	Saint Louis		155,000
Steen (Consecutive of 1670007)	178	Rock	0.68	11,500
Carver	1,300	Carver		100,000
Hackensack	285	Cass	1.8	31,750
New York Mills	1,200	Otter Tail	2.04	115,000
Pipestone Water Utility	4,280	Pipestone	2.32	541,000
Chisago City	3,250	Chisago		300,000
Hutchinson	13,080	McLeod	1.15	2,079,802
Rice	755	Benton		71,000
Maynard	428	Chippewa		30,073
Sandstone	1,549	Pine	0.69	120,000
Kettle River	168	Carlton	1	25,000
Crosby	2,299	Crow Wing	0.52	355,000
Deerwood	590	Crow Wing		54,000
Ironton	498	Crow Wing	0.63	65,000
Pease	167	Mille Lacs		15,000
Otsego	900	Wright		111,407
Frost	251	Faribault		23,650
Bejou	94	Mahnomen		7,000
Kilkenny	148	LeSueur		17,000
Adrian	1,234	Nobles	1.07	124,000
Belview	382	Redwood		40,000
Cottonwood	1,148	Lyon		93,000
Elizabeth	140	Otter Tail		20,000
Elkton	139	Mower		12,000

Community Name	Population	County	Phosphorus [mg/L]	Flow [GPD]
Freeborn	305	Freeborn	1.17	33,000
Freeport	566	Stearns	3.4	43,000
Goodridge	100	Pennington	5.21	13,000
Jesper (Consecutive of 1410007)	600	Pipestone	0.45	51,000
Lake Bronson (consecutive of 1350006)	363	Kittson	2.45	29,000
Menahga	1,220	Wadena	6.48	108,000
Minneota (Consecutive of 1410007)	1,417	Lyon	1.45	105,000
New Germany	347	Carver		39,000
Oklee	401	Red Lake		50,000
Roseau	2,756	Roseau		460,000
Royalton	816	Morrison		70,224
Sleepy Eye	3,730	Brown	1.99	388,000
Twin Lakes	210	Freeborn		22,000
Vesta	339	Redwood		24,000
Wheaton	1,619	Traverse	2.06	150,000
Winger	205	Polk		25,000
Onamia	850	Mille Lacs		77,200
Beaver Creek	250	Rock		18,000
Cosmos	590	Meeker	4.5	70,136
Danube	553	Renville		35,000
Echo	299	Yellow Medicine		32,000
Fairfax	1,295	Renville	2.64	132,000
Clarks Grove	734	Freeborn		30,000
Kelliher	294	Beltrami		25,000
Rose Creek	371	Mower	7.99	45,000
Evansville	566	Douglas	2.97	68,000
Stewart	564	McLeod		50,000

Appendix E

Industrial Phosphorus Data Collected from Outstate POTWs

Appendix E. Industrial Phosphorus Data Collected from Outstate POTWs

ID	Facility Name	City	P_kgd	Permit_No	employee_count	NAICS Code
5527	AMPI	Glencoe	34.01	MN0022233	90	445200
5528	Kraft	New Ulm	10.81	MN0030066	800	311500
5529	3M	New Ulm	0.03	MN0030066	690	335900
5530	Schell	New Ulm	3.24	MN0030066	48	312100
5531	AMPI	New Ulm	3.94	MN0030066	200	311500
5532	Firmenich	New Ulm	21.53	MN0030066	53	325900
5533	Elgin Milk Serive	Plainview	1.47	MN0055361	19	484100
5534	PMP	Plainview	10.36	MN0055361	50	311511
5536	Honeymead	Mankato	17.86	MN0030171	50	311220
5537	AmeriPride	Mankato	1.43	MN0030171	50	333312
5538	ADM	Mankato	0.28	MN0030171	50	424510
5539	ADM Refinery	Mankato	1.86	MN0030171	50	311200
5541	Viessman Trucking	Mankato	1.30	MN0030171	50	484100
5542	Coloplast	Mankato	0.06	MN0030171	50	325600
5543	Jones Metal	Mankato	0.75	MN0030171	50	331100
5544	Year Round Cab	Mankato	0.30	MN0030171	50	331110
5545	Kato Engineering	Mankato	1.40	MN0030171	50	335312
5546	Dotson	Mankato	0.22	MN0030171	112	332900
5547	IMSJ Hospital	Mankato	1.00	MN0030171	1540	622100
5548	Mankato Clinic	Mankato	1.00	MN0030171	740	621100
5549	Associated Finishing	Mankato	2.60	MN0030171	50	332812
5550	Crown Cork & Seal	Owatonna	0.16	MN0051284	50	332431
5551	OTC Div SPx Corp.	Owatonna	1.80	MN0051284	800	335900
5552	Truth Hardware	Owatonna	1.75	MN0051284	901	333500
5553	Steel County	Owatonna	0.88	MN0051284	317	921100
5554	Dairy Farmers of America	Zumbrota	18.67	MN0025330	220	311500
5556	Agri-Energy	Luverne	0.00	MN0020141	50	221119
5557	Melrose Dairy Proteins	Melrose	27.28	MN0020290	143	311500
5558	Jennie-O Turkey Store	Melrose	67.06	MN0020290	795	311600
5559	Busch Agricultural Resources, Inc	Moorhead	17.35	MN0049069	50	424510
5560	Pactiv Corporation	Moorhead	0.09	MN0049069	50	326100
5561	American Crystal Sugar Company Tech Services Cente	Moorhead	0.13	MN0049069	380	311300
5562	Burlington NorthernSante Fe Railway - Sugar Waste	Moorhead	0.02	MN0049069	50	482100
5563	Electrolux Home Products	St. Cloud	9.84	MN0040878	50	332322
5564	Northern Wire Products	St. Cloud	0.12	MN0040878	50	332618
5565	AmeriPride Linen & Apparel Services	St. Cloud	0.47	MN0040878	50	333312
5566	G&K Services	St. Cloud	0.70	MN0040878	50	333312
5567	Grede Foundaries Landfill	St. Cloud	0.00	MN0040878	325	332700
5568	International Paper Landfill	St. Cloud	0.00	MN0040878	50	322130
5569	Dezurik Landfill	St. Cloud	0.00	MN0040878	50	562200
5570	X-Cel Optical Company	St. Cloud	0.09	MN0040878	50	333314
5571	Rapid Plating	St. Cloud	0.02	MN0040878	50	332800
5572	DBL Labs	St. Cloud	0.04	MN0040878	50	339100
5573	Essilor Coating Center	St. Cloud	0.06	MN0040878	50	339100
5574	New Flyer	St. Cloud	0.18	MN0040878	467	332900
5575	Froedtert Malt	Winona	16.56	MN0030147	53	311213
5576	Winona County Landfill	Winona	0.01	MN0030147	50	562200
5577	AMPI	Rochester	55.35	MN0024619	50	311500
5580	PACE	Rochester	5.55	MN0024619	360	311500
5581	QUEST	Rochester	9.54	MN0024619	50	311940
5583	Crenlo	Rochester	51.00	MN0024619	674	336200
5584	Marshall Labs	Marshall	26.98	MN0022179	50	541700
5585	Viessman	Marshall	0.00	MN0022179	50	484100
5586	Schwan's Beverage Plant	Marshall	1.50	MN0022179	50	311900
5587	MCP	Marshall	35.56	MN0022179	50	311200
5588	Schwan's	Marshall	22.06	MN0022179	2500	311900
5589	Turkey Store	Faribault	26.81	MN0030121	400	311600
5590	Faribault Foods	Faribault	15.71	MN0030121	290	311400
5591	Land O Lakes	Faribault	0.84	MN0030121	50	311500

Estimating Phosphorus Losses from Agricultural Lands for MPCA's Detailed Assessment of Phosphorus Sources to Minnesota Watersheds

D. J. Mulla & P. H. Gowda, University of Minnesota and G. Wilson & H. Runke, Barr Engineering

Executive Summary

The objective of this study was to assess phosphorus loadings to Minnesota's ten major drainage basins from agricultural runoff and erosion, as well as to evaluate the uncertainty in these assessments. This study was achieved by using and extending a regional phosphorus index approach published by Birr and Mulla (2001). Phosphorus index values were estimated for Minnesota watersheds and agroecoregions based on phosphorus transport and source factors such as erosion during dry, average and wet years, streamflow during dry, average and wet years, contributing distance from surface waterbodies during dry, average and wet years, soil test phosphorus, and rate and method of land applied phosphorus from fertilizer and manure.

Phosphorus index values were compared with field data on phosphorus loss from four sites over five years to estimate phosphorus export conditions. Phosphorus export coefficients show considerable variation across major drainage basins and across climatic conditions (Table 3 and Fig. 26). Export coefficients (kg/ha) during average climatic conditions vary from 0.54 kg/ha for the Minnesota River basin, 0.4 kg/ha for the Red River basin, 0.39 kg/ha for the Upper Mississippi River basin, and 0.66 kg/ha for the Lower Mississippi River basin.

Phosphorus export coefficients were multiplied by the cropland contributing area within 100 m of surface water bodies to obtain phosphorus loadings from the edge of this contributing area. Phosphorus loads exported to surface waters from agricultural lands under average climatic conditions are greatest for the Minnesota River basin (517,862 kg/yr), followed by the Red River (384,695 kg/yr), the Upper Mississippi (359,681 kg/yr) and the Lower Mississippi (232,581 kg/yr) River basins. All of the other basins have phosphorus export loads that are considerably smaller than the loads exported in these four basins. With agroecoregion based export coefficients, the magnitudes of phosphorus loadings are about

7% smaller for these same basins in an average year than the magnitudes obtained using the watershed based analysis.

Several alternative agricultural management scenarios were investigated and compared to a baseline scenario involving an average climatic year and existing rates of adoption of conservation tillage and existing rates of phosphorus fertilizer applications. The first alternative management was a scenario in which moldboard plowing is used on all row cropland. This is a worst case scenario for erosion, and exemplifies phosphorus losses typical of an era that existed twenty or more years ago. This scenario allows us to evaluate the extent of progress in controlling phosphorus losses over the last twenty years due to improvements in tillage management. In the Minnesota River basin, compared to an era when moldboard plowing was widely practiced, current day phosphorus losses from agricultural cropland have been reduced by about 146,000 kg/yr (from about 664,000 to 518,000 kg/yr), for a 28% reduction. In the Upper Mississippi River basin, current phosphorus losses from agricultural land have been reduced by about 87,000 kg/yr, for a 24% reduction. Similar comparisons show a 7% reduction for the Red River basin.

The last scenario involves decreasing or increasing the area of cropland within 100 m of surface waterbodies. Decreases in area of cropland could correspond to land retirement programs such as those promoted in the Conservation Reserve and Conservation Reserve Enhancement Programs. Increases in cropland area would correspond to putting grass or forest riparian areas into production, alternatively this could be viewed as increasing the distance for cropland areas (now assumed to be 100 m) that contribute phosphorus to surface waters. The results from this scenario indicate that every one percent decrease in the area of cropland within 100 m of surface waters leads to a one percent decrease in phosphorus loadings. Alternatively, every one percent increase in the area of cropland near surface waters leads to a one percent increase in the phosphorus loadings.

There are many possible sources of uncertainty in the estimated phosphorus loadings. These can be divided into errors in input data, errors in converting phosphorus index values to phosphorus export coefficients, errors in estimating the proportion of cropland that contributes to phosphorus loadings, and errors due to a lack of consideration for impacts of surface and subsurface drainage, wind erosion or snowmelt runoff on phosphorus loadings. This study provides a list of suggestions for further research to reduce these uncertainties.

Introduction

In 2003, the Minnesota State Legislature authorized the Minnesota Pollution Control Agency to contract for a comprehensive study to assess phosphorus loadings to Minnesota's ten major drainage basins from all major sources during low flow, average flow, and high flow conditions. These sources include point sources such as publicly owned wastewater treatment plants, privately owned wastewater treatment plants, and commercial or industrial wastewater treatment systems. Nonpoint sources addressed in the study included agricultural runoff and erosion, feedlot runoff, non-agricultural rural runoff, streambank erosion, urban runoff, individual sewage treatment systems, and atmospheric deposition. The subject of the study described below is limited simply to assessing the phosphorus loadings to Minnesota's ten major drainage basins from agricultural runoff and erosion, as well as evaluating the uncertainty in these assessments. This study was achieved by using and extending a regional phosphorus index approach published by Birr and Mulla (2001).

Methods

The following sections provide an overview of the modified phosphorus index, developed at the regional scale by Birr and Mulla (2001), and an approach for revising and utilizing the modified phosphorus index to estimate phosphorus loadings from agricultural sources to each of the ten major drainage basins in Minnesota during low, high and average flow conditions.

Overview of Modified Phosphorus Index at the Regional Scale

Birr and Mulla (2001) developed a modified version of the P Index, originally developed jointly by the USDA (ARS, CSREES, and NRCS), to prioritize phosphorus (P) loss vulnerability at the regional scale from 60 watersheds located within Minnesota. This modified (regional) version of the P Index uses readily available data associated with the transport and sources of P. Validation of the P Index rating was conducted using long-term water quality monitoring data consisting of total P concentrations collected from 37 watersheds and 1800 lakes within the study area.

A combination of transport and source factors directly influence P movement from agricultural systems to surface waters (Sharpley et al., 1993). The USDA developed a P Index that integrates both transport and source factors to identify areas vulnerable to P export (Lemunyon and Gilbert, 1993). Transport factors include the mechanisms by which P is delivered to surface waters, such as erosion and runoff. Source factors represent the amount of P available for transport, including soil test P and P applied (rate and method) in fertilizer and organic forms. Table 1 (taken from Birr and Mulla, 2001) summarizes the transport and source factors used to develop the regional P Index ratings, as well as the weighting factors for each loss class and transport or source factor. The following discussion describes how each of the transport and source factors were initially computed by Birr and Mulla (2001). The section after this discussion describes how the initial computations were modified and refined for the final analyis.

Birr and Mulla (2001) Regional Phosphorus Index Methods

- Soil erosion potential was calculated using the Universal Soil Loss Equation (USLE) as outlined by Wischmeier and Smith (1978). The Minnesota state soil geographic database (STATSGO) was used to supply many of the variables needed to calculate erosion potentials for each of the watersheds (USDA, 1991). Erosion potential was calculated for each soil type within a STATSGO map unit. Rainfall runoff factors (R) for each county were based on values provided by Wischmeier and Smith (1978). The STATSGO database provided a soil erodibility factor (K) for each soil type within a STATSGO map unit. The slope-steepness factor (S) represents an average of the high and low slope values given for each soil type within a STATSGO map unit. The slope-length factor (L) was assumed to be 46 m. A 1:250 000 scale landuse/landcover coverage developed by the USGS in the late 1970s and early 1980s was used to determine erosion potentials spatially coincident with cropland and pastureland (USEPA, 1994).

  An erosion potential value for all cropland and pastureland within a watershed was determined using the percent of each STATSGO map unit covering a watershed. The landuse coverage did not differentiate spatially between cropland and pastureland; however, Census of Agriculture data indicate that pastureland represents about 11% of this classification category in Minnesota (National Agricultural Statistics Service, 1999). Differences in potential erosion for the two land uses were accounted for in the determination of the C factor based on the proportion of hay reported for a particular county. Cropping management factors (C) were adapted from values provided by the

USDA (1975) and Wischmeier and Smith (1978) for corn, wheat, soybean, hay, sugar beet, potato, oat, and barley. The C factors were calculated for each county based on the area of each harvested crop covering the county. Watershed values for the C factors were weighted based on the proportion of the watershed that was covered by the county. The C factor calculations include crop rotation effects but not the variation in tillage effects. There is no reliable method for estimating the variation in crop residue cover across the watersheds studied. The conservation practice factor (P) was assumed to be 1, because it could not be accurately quantified at the regional scale. The overall erosion potential value for each watershed represents the product of the area-weighted C factor and the variables R, K, and LS for each watershed (A = RKLSCP).

- Average annual runoff values for each watershed were derived from the average annual discharge monitored from 1951 to 1985 for 327 stations distributed throughout Minnesota (Lorenz et al., 1997). The average annual runoff value is calculated as the average annual discharge divided by the drainage basin area defined for the station.
- The area of cropland and pastureland within 91.4 m of drainage ditches and perennial streams (the primary contributing corridor) was determined using hydrography coverages developed by the Minnesota Department of Transportation (1999) and the USGS (1999). The USGS landuse/landcover coverage (USEPA, 1994) was used to determine the percentage of cropland and pastureland within the 91.4 m proximity to watercourses for each watershed.
- Mean soil test P levels for each county represented a 5-yr database consisting of 22,421 Bray-1 extractable P (Brown, 1998) samples analyzed by the University of Minnesota's soil testing laboratory. Soil test P levels for each watershed were based on the area of the watershed covered by each county.
- Data for P-fertilizer sales by county were obtained from the Minnesota Department of Agriculture (1997). Fertilizer P values for watersheds were based on a summation of area-weighted county-based values intersecting the watersheds. The total area of fertilized land within each watershed was determined using the same procedure based on reported county values (National Agricultural Statistics Service, 1999). The aggregated fertilizer P value was divided by the aggregated reported fertilized land for each watershed to determine fertilizer P application rates.
- The P content of livestock manure was calculated based on the total number of cattle, swine, broilers, and turkeys reported within each county (Midwest Planning Service, 1985; Schmitt, 1999; National Agricultural Statistics Service, 1999). The total amount of manure P was derived for each watershed based on the summation of area-weighted county values intersecting the watersheds. The reported total cropland area

was also determined using the same procedure (National Agricultural Statistics Service, 1999). The aggregated total P content of manure was normalized by the aggregated total cropland area for each watershed to determine organic P application rates. This approach underestimates the actual rates of land applied P from manure, but at the regional scale it accurately represents the mass of P from land applied manure.

For the modified P Index (Table 1), each site characteristic is assigned a weighting factor based upon the premise that site characteristics have a varying impact on P loss to runoff. Each site characteristic has an associated P loss rating value (very low, low, medium, high, and very high) using a base of 2 to reflect the higher potential for P loss associated with higher rating values. The P Index rating is the summation of the product of the rating value and corresponding weighting value for each site characteristic. Because P application method could not be accurately depicted at the regional scale, the highest organic and fertilizer P application method rating values were used to represent a worst-case scenario. Categories corresponding to the rating values were derived by segregating the distribution of statewide values for each site characteristic into five classes using the quantile classification method available in ArcView software (ESRI, 2000).

P Index rating values resulting from the application of the modified P Index were validated using two different sets of data. The first set of data consists of a 27-yr record (1968-1994) of total P concentrations collected at the mouth and at interior points in 54 of the 60 watersheds in the study. P Index ratings were correlated with the percentage of samples in which total P concentrations exceeded 0.25 mg/L for 37 of the 60 watersheds in the study area. Seventeen of the 54 watersheds with monitoring data derived from main stems of the six major rivers were excluded from the statistical comparison to ensure that both cumulative (upstream effects from other major watersheds) and point source (urban) effects did not influence the total P observations. The second set of validation data consists of lake water quality parameters maintained by the United States Environmental Protection Agency's (USEPA) STORET national water quality database. P Index ratings were statistically compared with median total P concentration of lakes for 20 of the 60 watersheds having greater than 14 lakes assessed. A majority of the lakes (66%) were monitored during summer months (June-Sept.) between 1989 and 1998. The remaining data were collected between 1970 and 1988, including non-summer samples (Heiskary and Wilson, 2000). The regional phosphorus index of Birr and Mulla (2001) showed an excellent statistical correlation with both water quality validation data sets, with coefficients of determination between 65 and 70%.

Refined and Updated Approach for Estimating Regional Phosphorus Index

This section provides an approach for revising and utilizing the modified (regional) phosphorus index (from Birr and Mulla, 2001) to estimate phosphorus loadings from agricultural sources to each of the ten major drainage basins (Fig. 1) in Minnesota during low, high and average flow conditions. In addition, this approach will attempt to evaluate the variability and uncertainty associated with estimating phosphorus loadings from the various types of farm systems using the modified phosphorus index.

Agroecoregions were developed by the University of Minnesota's Department of Soil, Water, and Climate on behalf of the Minnesota Department of Agriculture (Hatch et al., 2001). Thirty-nine agroecoregions were delineated in Minnesota using data related to soils, surficial geology, climatic patterns, topography, and land use (Fig. 2). Birr and Mulla (2002) found that the Minnesota agroecoregion framework was effective at characterizing regional lake water quality trends. The same transport and source factor (soil erosion, average runoff, percentage of cropland and pastureland within 300 feet of a watercourse, soil test P, fertilizer P and organic P application rates) inputs, used to determine the modified phosphorus index values for each of the 37 watersheds in Birr and Mulla (2001), have already been developed for each agroecoregion unit throughout Minnesota (Mulla, 2003).

The following adjustments to the modified phosphorus index computations and supplementary tasks will be used to improve and update the analysis of phosphorus loading:

- The MPCA has developed and updated a feedlot inventory and manure management database (with an associated GIS coverage), based on registered feedlot data obtained from each of the counties. The total amount of manure P was derived for each agroecoregion and watershed based on the summation of area-weighted township values intersecting the agroecoregions or watersheds. The aggregated total P content of manure can then be normalized by the aggregated total cropland area for each agroecoregion or watershed to determine and revise the organic P application rates. Again, this underestimates the actual rates of land applied P from animal manure, but not the regional amounts applied, nor the regional patterns in amounts applied, which are critical for this analysis.

- Data for phosphorus fertilizer sales by county were obtained from the Minnesota Department of Agriculture (1997) and used in Birr and Mulla (2001) to estimate the modified phosphorus index values based on a summation of area-weighted county-based values intersecting the watersheds. Phosphorus fertilizer sales data by county for the most current crop year (2002) were obtained and used to update this part of the modified phosphorus index computations based on a summation of area-weighted county-based values intersecting the agroecoregions or watersheds.

- GIS coverages for runoff volumes in each agroecoregion or watershed under average, high and low flow conditions were developed to evaluate how phosphorus export from agricultural lands would be expected to change with varying climate conditions. Runoff volumes were estimated by Barr Engineering based on average annual discharge from long-term monitoring stations representative of the major watersheds of the state, consistent with Birr and Mulla (2001). Along with runoff volumes estimated by Barr Engineering for low, average and high flow condition s, we estimated rainfall runoff erosivity (R values) for the USLE for dry, average and wet years corresponding to the low, average and high flow conditions. These estimates were based on an algorithm developed for monthly precipitation data by Renard and Freimund (1994). The modified phosphorus index values and total phosphorus export were then computed for each of the agroecoregions or watersheds under high and low flow conditions, using the corresponding values for runoff volume and rainfall runoff erosivity.

- The highest rating for both P fertilizer and organic P application method was used by Birr and Mulla (2001). Application methods with less potential for P losses will lower the estimated P Index values; however, the relative rankings of the P Index ratings across watersheds would only change if the practices varied significantly from one basin to the next. Based on farm survey data collected by the Minnesota Department of Agriculture, phosphorus application methods are generally much better than those assumed by Birr and Mulla (2001). A majority of farmers apply their phosphorus fertilizer with the planter or using incorporation before crop planting. In view of this, we have chosen to use a statewide medium loss potential for method of fertilizer P application method, corresponding to fertilizer applied before the crop and incorporated immediately.

An initial scenario involving a medium loss potential for the method of manure application was developed for the entire state. Subsequently, a second scenario was developed assuming variability in the loss potential associated with method of manure application. Manure P application methods vary primarily in response to the type of animal species. Manure from beef, dairy, and poultry is high in solids, while manure from hogs is high in liquid. Beef operations tend to be small in scope, have a tendency towards inadequate manure storage facilities, and manure from these operations tends to be hauled on a daily basis. Beef operations also tend to involve cattle wading in streams. Dairy operations tend to have adequate manure storage facilities, and manure is applied followed by a tillage operation to incorporate manure. Poultry operations tend to have adequate manure storage facilities, and the manure is incorporated using tillage following land application. Hog operations tend to have adequate storage facilities, and the manure is land applied using injection. In terms of the phosphorus index, this means that beef operations tend to have a very high phosphorus loss potential, dairy and poultry operations tend to have a medium loss potential, while hog operations tend to have a low loss potential. The geographic variability in phosphorus loss potential associated with these variations in method of manure application was evaluated using the number of animal units of different species from the MPCA feedlot inventory database. The effect of this variability and/or uncertainty in method of manure application was estimated using the modified phosphorus index.

- Birr and Mulla (2001) states that spatial trends in soil erosion potential observed throughout Minnesota are potentially influenced by both the underlying assumptions used in the methodology and the exclusion of factors that control soil erosion. A lack of detailed information pertaining to the spatial variation in C and P factors may have caused the spatial distribution of erosion potential values to vary more gradually across the region than is realistic. The spatial variation in the C factor of the USLE was estimated by accounting for the effects of crop rotations, the effects of conservation tillage on crop residue levels, and the effects of existing acreage of land in Conservation Reserve Program (CRP). Typically the C factor for land in CRP is 0.001 or so, while row cropland has a C factor varying from 0.05 to 0.4 depending on the rotation and the amount of crop residue present.

  Three scenarios were evaluated to account for the influence of tillage methods on crop residue levels remaining after planting. These were a scenario involving conventional tillage with no residue left (worst C scenario), and a scenario involving conservation tillage leaving more than 50% of the soil covered by crop residue (best C scenario). This is not typical of existing crop rotations or tillage management systems in Minnesota, nor is it a goal of existing watershed restoration or conservation programs to achieve this high level of crop residue cover. Also estimated was a scenario for average crop residue cover (average C scenario) based on county tillage transect data for the percent of fields with conservation tillage (30% residue cover). In the average C scenario, we developed a weighted C factor based on the relative area of cropland in conservation tillage versus moldboard plowing. Data for the C factors of various crop rotations with varying levels of crop residue were estimated using tables provided by the USDA-NRCS. Thus, using information on crop rotations, crop residue levels, and acreage of land in CRP, we developed scenarios for both soil erosion by water and the modified phosphorus index involving the C factor of the USLE.

  Variability in the P factor of the USLE was estimated using the Local Government Annual Reporting System (LARS) database of conservation practices provided by the

Board on Soil and Water Resources (BWSR). This database was edited to estimate the area of supporting conservation practices affecting the P factor implemented from 1997-present in Minnesota counties. These practices include terracing, contour strip cropping, filter strips, sediment basins, and restored wetlands. Each practice was assigned a typical P factor. Since supporting conservation practices have typically been implemented for the last 50 years, we assumed that the area where these practices were implemented was 10 times greater than the area determined using the LARS database. A county average P factor was then determined using the area weighted P factors for land with supporting practices and the land without supporting practices (P=1). The variability and/or uncertainty associated with conservation practices, such as conservation tillage, contour stripcropping, terracing, and other supporting practices was then estimated for agroecoregions and watersheds using the modified phosphorus index.

Regional Modified Phosphorus Index Results

Water Erosion Estimates for Agricultural Land

Average Rainfall Runoff Erosivity, Varying Cover Management Conditions

The first scenario for erosion involves using the worst possible values for the cover management factor (C) in the USLE, and keeping all other factors from the first scenario constant. This represents erosion rates that could be expected when moldboard plowing is used on cropland, thereby burying all crop residue. As shown in Fig. 3a, most of the watersheds in southern Minnesota have erosion rates greater than 21 Mg/ha/yr (11.2 Mg/ha corresponds to 1 ton/ac) due to poor crop residue cover. The maximum rate of erosion estimated was about 190 Mg/ha (about 17 ton/ac). Erosion rates typically decrease towards northern Minnesota. Similarly, erosion rates greater than 21 Mg/ha/yr occur in a large number of agroecoregions located in southern Minnesota (Fig. 3b).

The second scenario illustrates the erosion rates that correspond to average cover management conditions based on tillage transect surveys of the percent of cropland with 30% residue cover at planting. About one-third of all watersheds have erosion rates that exceed

21 Mg/ha/yr (Fig. 4a), these are located primarily in southern Minnesota. About one-fourth of all watersheds have erosion rates less than 5 Mg/ha/yr, these are located primarily in northern Minnesota. Agroecoregions with erosion rates greater than 21 Mg/ha/yr include the Blufflands, Rolling Moraine, Rochester Plateau, Steep Wetter Moraine, Coteau, Undulating Plains, Inner Coteau, Wetter Blue Earth Till, Level Plains, and Steep Dryer Moraine (Fig. 4b). These are located primarily in the Minnesota River basin and the Lower Mississippi River basin in southeastern Minnesota.

The third scenario involves using the best possible values for the cover management factor (C) in the USLE, representing erosion rates that could be expected when all cropland uses conservation tillage that leaves at least 50% of the soil surface covered with crop residue at planting (Fig. 5ab). As expected, rates of erosion are generally smaller in this scenario in comparison with the previous two scenarios. With widespread adoption of conservation tillage, watersheds in the northern half of Minnesota have erosion rates that are less than 5 Mg/ha/yr, and much of central, south central and southwestern Minnesota have erosion rates ranging between 6 and 14 Mg/ha/yr (Fig. 5a). The number of watersheds in southeastern Minnesota having erosion rates greater than 21 Mg/ha is relatively unchanged in comparison to the results from the first scenario which uses the lowest possible C factors based on moldboard plowing (Fig. 3a). This is because southeastern Minnesota has steep landscapes and heavy precipitation which are conducive to high rates of erosion.

Low and High Rainfall Runoff Erosivity, Best Cover Management Conditions

The next erosion scenarios involve using best cover management factor (C) values based on widespread adoption of conservation tillage, existing crop rotations and acreage of CRP, but with varying values of rainfall runoff erosivity (R). The first of these scenarios is with low rainfall runoff erosivity values that represent dry climatic conditions typical of low flow hydrologic conditions. As shown in Figs. 6a and 6b, erosion rates in this scenario are typically less than 5 Mg/ha/yr for watersheds and agroecoregions across the entire state. The second scenario is with high rainfall runoff erosivity values that represent wet climatic conditions typical of high flow hydrologic conditions. As shown in Figs. 7a and 7b, erosion rates with this scenario are typically greater than 21 Mg/ha/yr in most of central and southern

Minnesota. Only the northeastern portion of Minnesota has erosion rates smaller than 5 Mg/ha/yr in this scenario. Based on these model predictions, it is clear that erosion rates are much more sensitive to variations in climate than variations in tillage management.

Runoff Estimates for Hydrologic Flow

Runoff estimates for average, dry and wet flow regimes are shown in Figs. 8-10. Runoff under average conditions typically increases from west to east across the state (Fig. 8). The greatest runoff occurs in watersheds along Lake Superior in northeastern Minnesota (up to 15 cm), followed by watersheds in southeastern Minnesota (Fig. 8). The smallest runoff occurs in watersheds in northwestern and west central Minnesota (less than 4 cm). For dry years (Fig. 9), runoff increases from west to east, but the magnitudes of runoff are much smaller (maximum runoff of about 11 cm). For wet years the greatest runoff occurs in northeastern and southern Minnesota (Fig. 10), and the magnitude of runoff is considerably greater than for average years (up to about 21 cm).

Agricultural Land in Close Proximity to Rivers and Ditches

The transport of phosphorus to surface waters depends to a large extent on the percent of land in a watershed that is within 91.4 m (300 ft) of a waterway. As the proximity of agricultural land to a waterway increases, so too does the potential for transport of phosphorus to the waterway (Gburek et al., 2000, Soranno and Hubler, 1996). The latter two citations indicate that the risk for P transport is greatest for lands from 50 – 300 m from surface waterways. Gburek et al. (2000) studied agricultural phosphorus losses in a small watershed located in Pennsylvania. This watershed receives on average 1100 mm/yr of precipitation, has landscapes with slopes ranging from 1-19% in steepness, and is dominated by silt loam soils. Gburek et al. (2000) found that the distance of cropland contributing phosphorus loads to surface waters varied with the amount of rainfall, with contributing distances varying from 5 to 100 m in dry to wet years.

In most of Minnesota, we believe that the risks of phosphorus transport to surface waters are greatest in the contributing corridor within about 100 m from surface waterbodies. This is consistent with research results from across the country, and with recommendations of the primary group of soil scientists conducting research on phosphorus transport to surface waters (the SERA-17 group). Due to topographic variations along surface waterbodies, in some areas phosphorus contributions from overland runoff and erosion may occur from as far away as several hundreds of meters. In contrast, where berms are present along waterbodies it may be unlikely for any surface runoff or erosion to enter surface water. Thus, the 100 m contributing corridor should be viewed as a regional average for contributions of P to surface waters from runoff and erosion on adjacent cropland.

In the Minnesota River basin, where significant acreage of cropland has surface tile intakes and subsurface drains, the transport of phosphorus to surface waters can arise from cropland much farther than 100 m from surface waterbodies. The critical contributing corridor in the case of surface tile intakes is the area of cropland immediately surrounding the surface tile intake that contributes surface runoff and erosion to the intake. The risks of phosphorus transport from surface tile intakes and subsurface drains have not been studied extensively, however, and so P losses from these sources will be addressed in the section at the end of this report dealing with uncertainties.

To estimate the losses of P from surface runoff and erosion, we used an approach that identifies the contributing corridor around surface waterbodies for dry, average and wet climatic conditions. Three methods were used to estimate the percent of land in close proximity to waterways for these conditions The first method was based on hydrologic coverages for perennial streams and ditches (these reflect the potential for transport in average climatic years), the second was based on coverages for perennial streams and ditches plus intermittent streams. Intermittent streams flow primarily during wet years and are generally dry during dry years. The third method was based on hydrologic coverages for perennial streams only, this is based on the observation that ditches flow only sporadically during dry years.

Figs. 11ab show the percent of cropland and pastureland within 91.4 m of perennial streams and ditches for Minnesota watersheds and agroecoregions, normalized for watershed or agroecoregion area. Up to 12% of the cropland lies within 91 m of perennial streams and ditches. Watersheds with the highest percentage of cropland near streams and ditches include the Lac Qui Parle, Grand Marais, South Fork of the Crow, Hawk Creek-Yellow Medicine, and Lower Minnesota watersheds (Fig. 11a). The corresponding agroecoregions include Swelling Clay Lake Sediments, Very Poorly Drained Lake Sediments, Dryer Clays and Silts, and Wetter Clays and Silts (Fig. 11b). Figs. 12ab show the percent of cropland and pastureland within 91.4 m of perennial streams and ditches and intermittent streams for watersheds and agroecoregions. When intermittent streams are included in the analysis, the percent of cropland within 91.4 m of waterways is greatly increased in comparison with the cropland near perennial streams and ditches. The percent of cropland within the 91 m of perennial and intermittent streams and ditches is as great as 50% when intermittent streams are included. Large increases in the percent of cropland in close proximity to surface waters occur in watersheds and agroecoregions of northwestern Minnesota, the Coteau of southwestern Minnesota, and southeastern Minnesota. Figs. 13ab show the percent of cropland and pastureland within 91.4 m of perennial streams only. The maximum percent of crop and pastureland within 91 m of perennial streams is about 5% for watersheds and about 12% for agroecoregions. In general, these percentages are much lower than the percentages for perennial streams and ditches as would be expected. The greatest concentration of cropland near perennial streams is in three areas, southeastern, southwestern, and central Minnesota (Fig. 13b).

Soil Test Phosphorus Levels on Agricultural Land

Soil test phosphorus (STP) is typically measured in Minnesota using the Bray or Olson extractants. For consistency, we show spatial patterns in Bray-P soil test levels. As Bray-P soil test levels increase, there can be an increase in the risk of phosphorus loss from agricultural land. Bray-P levels are affected by several factors, including natural sources of phosphorus in soil, as well as additions of phosphorus from fertilizer and manure.

Bray-P soil test levels are typically largest in watersheds or agroecoregions of central Minnesota (Figs. 14ab) due to naturally high soil P levels and applications of animal manure to cropland. As a general guideline, the University of Minnesota does not recommend application of phosphorus fertilizer for crop production if Bray-P soil test levels exceed 21 ppm. Only 21 out of 81 major watersheds in Minnesota have average Bray-P levels less than

21 ppm. Caution should be used in interpreting these data, because there can be considerable spatial variability in Bray-P levels within and across farms. Just because the average is above 21 ppm does not mean that no phosphorus fertilizer should be applied. As much as one-third of the area within a farm may have Bray-P levels less than 21 ppm, even if the average is above 21 ppm.

Fertilizer Phosphorus Application Rates for Agricultural Land

Addition of phosphorus fertilizer to cropland increases the risk of phosphorus transport to surface waters under certain conditions. Figs. 15ab show that rates of phosphorus fertilizer application vary considerably throughout Minnesota watersheds and agroecoregions. This is due to variations in crop rotation, variations in soil test phosphorus levels, and variations in the rates of manure application. Application rates are generally the highest in watersheds and agroecoregions of the Minnesota River Basin. Application rates are generally smallest in northeastern and north central Minnesota.

Manure Phosphorus Application Rates for Agricultural Land

Manure is applied to cropland as a by product of animal production practices. Manure is typically enriched in phosphorus relative to nitrogen. If applied at high rates using improper application methods, manure can increase the potential for losses of phosphorus to surface waters. Figs.16ab show the variation in phosphorus application rates from animal manure across Minnesota watersheds. Application rates are greatest in central and southeastern Minnesota, where there are large concentrations of dairy and/or poultry operations. Watersheds with high rates of manure P application include the Sauk, Platte-Spunk, and North Fork of the Crow in central Minnesota, the La Crosse-Pine, Buffalo-Whitewater, Cannon, Zumbro, and Root watersheds in southeastern Minnesota, and the Blue Earth, Middle Minnesota, and Lower Minnesota watersheds in south central Minnesota (Fig. 16a). Application rates are lowest in the Red River of the North Basin and in northeastern Minnesota.

Phosphorus Risk Index Estimates for Agricultural Land

Average Hydrologic Runoff Volume, Average Rainfall Runoff Erosivity, Poor Crop Residue Cover Management Conditions

This scenario was based on long-term average stream flows, average rainfall erosivity, and no crop residue cover due to moldboard plow tillage methods. It is a worst case scenario for tillage methods, and is similar to the scenario developed in Birr and Mulla (2001), except that the effects of supporting conservation practices such as contour strip cropping, terracing, and filter strips are here considered. From a practical standpoint, most areas of Minnesota use tillage systems that leave more crop residue than assumed in this scenario, so the phosphorus risks are overestimated in this scenario. As a rough guideline to identify impaired surface waters, Birr and Mulla (2001) suggested that values of the phosphorus index should not exceed 32 in Minnesota watersheds, except in the Red River of the North Basin, where a critical level of 25 should not be exceeded. There are seventeen watersheds in south central Minnesota with a phosphorus index value greater than 32 (Fig. 17a), these include the Lower Minnesota, Winnebago, Upper Cedar, Hawk Creek-Yellow Medicine, Blue Earth, Lac Qui Parle, Cannon, Rush-Vermillion, Middle Minnesota, South Fork of the Crow, Cottonwood, and Watonwan watersheds. Note that watersheds in southeastern Minnesota that had a high rate of soil erosion (Zumbro and Root) have only intermediate values for the phosphorus index (27-30). This is because of other factors that are not conducive to high risk, such as a moderate density of cropland near waterways and moderate to low application rates of phosphorus fertilizer. Watersheds such as the Le Sueur, Redwood, Chippewa, Watonwan and South Fork of the Crow also have high phosphorus index scores (ranging from 30-31). It is well known that the Minnesota River basin generates the largest phosphorus losses of any major river basin in Minnesota. Thus, it is not surprising that nine of the twelve major watersheds in the Minnesota River basin have a phosphorus index value that exceeds 30. Watersheds in the northern half of Minnesota generally have phosphorus index values less than 21. Agroecoregions with phosphorus index values greater than 32 in this scenario are primarily located in the Minnesota River Basin, and include the Wetter Clays and Silts, Dryer Clays and Silts, Steeper Till, Wetter Blue Earth Till, and Dryer Blue Earth Till (Fig. 17b).

Average Hydrologic Runoff Volume, Average Rainfall Runoff Erosivity, Average Crop Residue Cover Management Conditions

This scenario is similar to the previous one, except that erosion and phosphorus index values are based on the average crop residue levels as reported in tillage transect surveys. Fig. 18a shows that thirteen watersheds have phosphorus index values that exceed 32, including the Lower Minnesota, Blue Earth, Shell-Rock, Cannon, Rush-Vermillion, Middle Minnesota, South Fork of the Crow, and Watonwan watersheds. These are primarily in the Minnesota River basin and Lower Mississippi River basin. Not as many watersheds have phosphorus index values exceeding 32 in this scenario as in the previous scenario, due to greater crop residue cover in this scenario. Agroecoregions with phosphorus index scores greater than 32 in this average crop residue scenario are located primarily in the Minnesota and portions of the Lower Mississippi River basins, including Steeper Till, Wetter Blue Earth Till, Wetter Clays and Silts, Dryer Clays and Silts, and the Steep Wetter Moraine (Fig. 18b).

Average Hydrologic Runoff Volume, Average Rainfall Runoff Erosivity, Best Crop Residue Cover Management Conditions

This scenario was the same as the previous scenario, except that we assumed that conservation tillage leaving 50% of the soil covered by crop residue was practiced on row cropland. From a practical standpoint, most areas of Minnesota use tillage systems that leave less crop residue than assumed in this scenario, so the phosphorus risks are underestimated in this scenario. In general, the increase in crop residue cover produces lower phosphorus index scores in this scenario in comparison with the previous scenario involving average residue cover. Phosphorus index values exceed a score of 32 with this scenario for the Lower Minnesota, Winnebago, Cannon, Rush-Vermillion, and La Crosse-Pine watersheds (Fig. 19a). Then next highest scores occur primarily in the Minnesota River basin and in southeastern Minnesota, including the Coon-Yellow, Buffalo-Whitewater, Shell-Rock, Root, Hawk Creek-Yellow Medicine, Zumbro, Blue Earth, and Lac Qui Parle watersheds. Most of the northern half of Minnesota shows low risks for phosphorus transport in this scenario. For agroecoregions (Fig. 19b), the phosphorus index scores exceed 32 primarily in the Steep Wetter Moraine agroecoregion. The Wetter Clays and Silts and Rolling Moraine agroecoregions also have relatively high phosphorus index scores that are in the range of 30 and 31.

Dry Hydrologic Runoff Volume, Dry Rainfall Runoff Erosivity, Best Crop Residue Cover Management Conditions, Cropland Contributing Corridor Based on Perennial Streams and Ditches

In this scenario, the hydrologic runoff and rainfall runoff erosivity values were typical of dry years. Crop residue cover was based on widespread adoption of conservation tillage. One caveat is that the percent of cropland within 91.4 m of perennial streams and ditches may be unrealistic for this scenario. In dry years the cropland that contributes eroded sediment and runoff to surface waters may be considerably less in area than the cropland that contributes in average years. Thus, the phosphorus index values in this scenario may be overestimated. Phosphorus index values for this scenario are always smaller than those for the scenario based on an average climatic year. The maximum phosphorus index value for watersheds in the dry year scenario is about 29, whereas the maximum value for an average year is about 41. Figs. 20ab show the spatial patterns in phosphorus index values for Minnesota watersheds and agroecoregions. No watersheds exceed the critical phosphorus index value of 32 in this scenario, and none are in the next highest category ranging from 31 to 34 either. Only one watershed, the Lower Minnesota watershed has a phosphorus index score between 27 and 30. Only a handful of watersheds have phosphorus index scores ranging from 22-26, while a majority have scores below 21 (Fig. 20a). Agroecoregions with phosphorus index scores between 22 and 26 fall mainly in the Minnesota River Basin (Fig. 20b), but the vast majority of agroecoregions have scores less than 21.

Dry Hydrologic Runoff Volume, Dry Rainfall Runoff Erosivity, Best Crop Residue Cover Management Conditions, Cropland Contributing Corridor Based on Perennial Streams Only

This scenario is the same as the previous, except that the cropland contributing corridor is reduced in area by assuming that only croplands near perennial streams contribute to phosphorus losses in dry years. This is reasonable, since most ditches flow only sporadically during dry years. Figs. 21ab show the phosphorus index values for this scenario in Minnesota watersheds and agroecoregions. No watersheds or agroecoregions have phosphorus index values that exceed 25 or 27, respectively, in this scenario. Only two small watersheds have phosphorus index scores greater than 21, the La Crosse-Pine and Rush-Vermillion watersheds of southeastern Minnesota. Only two small agroecoregions have phosphorus index scores greater than 21, the Steeper Stream Banks and Steeper Alluvium agroecoregions. This scenario is probably a more accurate representation of the risks of phosphorus transport to surface waters in dry years than the scenario that was based on a contributing corridor around both perennial streams and ditches.

Wet Hydrologic Runoff Volume, Wet Rainfall Runoff Erosivity, Best Crop Residue Cover Management Conditions, Cropland Contributing Corridor Based on Perennial Streams and Ditches

This scenario indicates the risk of phosphorus transport to surface waters from agricultural land during wet years. It is based on runoff volumes and rainfall runoff erosivity values for wet years, on widespread adoption of conservation tillage, and on a cropland contributing corridor 91.4 m wide around perennial streams and ditches. Comparing this scenario (Figs. 22ab) with that for an average climatic year (Figs. 19ab), it is evident that the risks of phosphorus loss have increased by a large amount (phosphorus index scores as high as 43) in a significant number of watersheds and agroecoregions. In the wet year scenario there are 24 watersheds with a phosphorus index score exceeding 32, whereas there were only 5 in the average year scenario. The watersheds exceeding the critical score in wet years are spread across south central and central Minnesota, as well as the Red River of the North basin (Fig. 22a). It is interesting to note that many of the watersheds in southeastern Minnesota are still below this critical threshold in wet years. This is primarily because of their relatively smaller percent area of cropland within 91.4 m of perennial streams and ditches. As will be shown in the next scenario, if the effects of intermittent streams are considered, the risk of phosphorus transport is considerably increased in southeastern Minnesota.

Wet Hydrologic Runoff Volume, Wet Rainfall Runoff Erosivity, Best Crop Residue Cover Management Conditions, Cropland Contributing Corridor Based on All Streams and Ditches

This scenario differs from the previous one in that the effects on phosphorus transport of cropland near intermittent streams, which flow during wet years, was considered. Figs. 23ab show that the risks of phosphorus transport to surface waters are considerably increased all across Minnesota in comparison to the scenario for wet years which does not consider intermittent streams (Figs 22ab). Most of the southern two thirds of Minnesota watersheds and agroecoregions exceed the critical phosphorus index score of 32 in this scenario. Only the watersheds and agroecoregions in the far northeastern portion of Minnesota are relatively unaffected by including the effects of intermittent streams on phosphorus transport. This scenario is probably a more accurate representation of the risks of phosphorus transport to surface waters in wet years than the scenario based on a contributing corridor around only perennial streams and ditches.

Average Hydrologic Runoff Volume, Average Rainfall Runoff Erosivity, Average Crop Residue Cover Management Conditions, Reduced Phosphorus Fertilizer, Cropland Contributing Corridor Around Perennial Streams and Ditches

This scenario illustrates the reductions in risk of phosphorus transport to surface waters (based on a contributing corridor around perennial streams and ditches only) due to reductions in rate of application of phosphorus fertilizer. These reductions were only made in watersheds or agroecoregions that had both high soil test phosphorus levels and high rates of phosphorus fertilizer application. More specifically the reductions were made where STP was greater than 32 ppm and fertilizer P application rates exceeded 27 kg/ha or where STP was greater than 39 ppm regardless of fertilizer P application rates. In both these cases, the rate of phosphorus fertilizer application was reduced to 5 kg/ha. These reductions reduce the risk of phosphorus transport in about one third of watersheds and agroecoregions, namely those units where the soil is generally capable of supplying P for crop production with little or no phosphorus fertilizer application. The phosphorus index values for this scenario are shown in Figs. 24ab for Minnesota watersheds and agroecoregions. For watersheds (Fig. 24a), the phosphorus index values in the Middle Minnesota, Cottonwood, Lower Minnesota, Rush-Vermillion and Cannon watersheds are reduced significantly in this scenario in comparison to their phosphorus index values for the scenario shown in Fig. 18a (scores decrease from generally above 32 to generally below 27), thus bringing them below the critical threshold. Large reductions in phosphorus index values also occur in the Le Sueur watershed. Agroecoregions with a significant reduction in phosphorus index scores include the Anoka Sand Plains, Dryer Blue Earth Till, Rochester Plateau, and Wetter Blue Earth Till (Fig. 23b). A moderate reduction also occurred in the Undulating Plains agroecoregion.

Average Hydrologic Runoff Volume, Average Rainfall Runoff Erosivity, Average Crop Residue Cover Management Conditions, Variable Manure Application Method

This scenario involves consideration of the variations in manure application method arising from differences in animal species and manure storage facilities. The baseline scenario represented by Figs. 18ab assumes that manure is applied and incorporated immediately just before planting a crop. This is most likely an overly optimistic scenario for most manure applications in the state. More realistic are the phosphorus index values illustrated in Figs. 25ab for Minnesota watersheds and agroecoregions based on consideration of differences across regions in manure application methods. Phosphorus index scores increase in this scenario relative to the baseline scenario that assumes relatively good methods of manure application. The increases are particularly noteworthy in northern Minnesota, where beef cattle operations are relatively abundant relative to other types of animal production. Beef cattle operations tend to be small, and many lack adequate manure storage facilities. This results in frequent hauling and land application of manure, generally without incorporation, including application of manure during the winter to frozen or snow covered cropland. Agroecoregions where the risk of phosphorus loss to surface waters increases due to poor manure application methods include the Red Lake Loams, Forested Lake Sediments, Peatlands, Northern Till, and Northshore Moraine (Fig. 25b). Increases in phosphorus index values in these northern regions are still not large enough to produce scores that are greater than the criticial threshold of 32, in fact the scores are still far below the critical threshold value. Small increases in phosphorus index scores occur in the Blufflands and Rochester Plateau agroecoregions of southeastern Minnesota, where dairy operations predominate. These increases do bring the phosphorus risks close to the critical threshold value of 32. Small increases in phosphorus index scores also occur in portions of the Red River of the North basin, in areas with relatively abundant beef cattle. These small increases bring the phosphorus index scores close to the critical threshold value of 25 in that region. Phosphorus index scores are relatively unaffected in southern Minnesota in regions where hog production dominates, because hog producers tend to have adequate manure storage and inject their manure rather than spreading it on the soil surface where it is very susceptible to losses by erosion and runoff.

Estimating Phosphorus Losses from Edge of Cropped Fields to Surface Waters

Two different approaches were tested for converting phosphorus index values to edge of field phosphorus losses to surface waters. The first method attempted to estimate phosphorus losses from the edge of field based on monitoring data for phosphorus loads in 53 Minnesota streams and rivers. This method was unsuccessful, but is described below. The second method estimated phosphorus losses from the edge of cropland fields based on export coefficients which were derived from the phosphorus index values. This is the method used for final estimates of basin wide phosphorus loadings to surface waters from the edge of cropland fields. The detailed methodology is described below.

Unsuccessful Method for Estimating Phosphorus Losses Based on Monitoring Data

Barr Engineering summarized existing data for phosphorus loads measured by water quality monitoring in 53 ditches, streams and rivers throughout Minnesota. They separated the data according to flow conditions into phosphorus loads for dry, average and wet years. They also supplied estimates for phosphorus losses discharged to surface waters in the same watersheds from non-agricultural rural, streambank erosion, and point sources of phosphorus. No data were supplied for the phosphorus losses from individual septic treatment systems (ISTS), atmospheric deposition, or urban runoff in these watersheds.

The phosphorus loads supplied by Barr Engineering were adjusted by subtracting the losses from non-agricultural rural and point sources of phosphorus, and by subtracting half of the phosphorus losses from streambank erosion. Only half of the streambank erosion losses were subtracted because much of the sediment from streambank erosion is transported as bedload, which is not measured in most water quality monitoring studies. The remaining phosphorus loadings were then divided by the area of cropland within 91 m of streams and ditches to provide an estimate of the potential phosphorus losses from the edge of cropland fields.

The resulting adjusted phosphorus yields were not very consistent with expected results, and were not deemed meaningful. Many of the adjusted phosphorus yields were negative in dry years because the point source loadings were larger than the monitored phosphorus loadings in the watershed. This could be due to phosphorus uptake by algae or plants. In wet years the adjusted phosphorus yields exhibited a huge range, from nearly zero to several hundreds of kg P/ha. This was most likely the result of several factors. The first factor is that the phosphorus monitoring load data were collected using a variety of methods, ranging from grab samples to automated water quality sampling. The second is that the monitored loads were collected over different lengths of time, ranging from a single season to multiple years. The third factor is that the adjusted phosphorus losses were not corrected to account for contributions of phosphorus from ISTS, atmospheric deposition, or urban runoff. This led to unrealistically high adjusted phosphorus loads during average and wet years. The fourth factor is that the phosphorus delivery ratio from each non-agricultural source should be varied by source and by flow regime when adjusting the monitored loads. For example, the delivery ratio for point sources would probably be a number between 0.8 and 1, but this would vary for dry and wet years. Similarly, the delivery ratio for streambank erosion (assumed to be 0.5) would vary with flow regime. One can conclude from this exercise that a considerable amount of additional research and monitoring effort is needed before this approach can provide accurate estimates of edge of cropland field phosphorus losses. As a result, this approach for estimating edge of field phosphorus losses from agricultural sources was abandoned.

Successful Method for Estimating Phosphorus Losses Based on Export Coefficient Approach

Birr et al. (2002) found that there is a strong linear correlation (r^2 =0.82) between a version of the modified phosphorus index values (from Birr and Mulla, 2001) and the pathway (or field scale) phosphorus index values. The modified phosphorus index values are typically thirteen times higher than the pathway phosphorus index values. Similarly, there is a strong linear correlation between the estimated pathway phosphorus index values and the observed phosphorus export (expressed in kg/ha/yr) at the field scale. The pathway phosphorus index values are typically five times higher than the total phosphorus export, at the field scale (Mulla, 2003). This suggests that we can estimate phosphorus losses from the edge of cropland fields by dividing the phosphorus index results by a factor of approximately 65. This gives an estimate of the losses of total phosphorus to surface waters from cropland and pastureland in units of kg/ha/yr, which represents the phosphorus export coefficient for agricultural land. Basin scale phosphorus losses from the edge of cropland fields to surface waters can then be estimated by multiplying the phosphorus loss per ha (export coefficient) by the area of cropland within 91 m of surface water bodies for the entire basin.

Since the version of the modified phosphorus index used in this study is slightly different from the one used by Birr et al. (2002), we decided to develop a relationship between the phosphorus index and the phosphorus export coefficient using phosphorus loss data compiled from University of Minnesota research at four sites in or near Minnesota. The sites are located near Morris, Minnesota (Ginting et al., 1998), Lancaster, Wisconsin (Munyankusi, 1999), and two sites in Scott County, Minnesota (Hansen et al., 2001). These sites involved measurements of total phosphorus losses from the edge of agricultural fields (typically a corn and soybean rotation) ranging in area from 0.5 to 1.6 ha. Data from these sites were collected between 1996 and 2000. Two of these years experienced average climatic conditions, two were a little wetter than average, and one was a little drier than average. Fields were treated using a range of tillage and manure management methods. The tillage treatments included moldboard plowing, chisel plowing, ridge tillage, and no-tillage. Manure treatments included no manure, heavy rates of manure, and variations in timing of manure application. Total phosphorus losses from the fourteen individual treatments at these four sites ranged from 0.1 to 2.3 kg/ha/yr, with an average of 0.68 kg/ha/yr in total phosphorus loss from the edge of field.

The counties where these four research sites are located have a range of tillage practices, with the percent of farmland having at least 30% crop residue cover ranging from about 47% in Scott and Stevens counties to about 64% of cropland with at least 30% residue cover in Houston county, the nearest county in Minnesota to Lancaster, Wisconsin. The phosphorus index values for an average climatic year and the existing residue cover adoption rates indicated above are 24, 32, and 43 in the Chippewa, Root and Lower Minnesota watersheds, respectively. If we take the P Index values for each watershed and divide them by the average phosphorus losses for the study sites in that watershed, the resulting conversion factor (or divisor) is 78. If on the other hand, we take the average phosphorus index value for these three regions of 33 and divide this by the average phosphorus loss from the edge of field in these experiments at four sites (0.68 kg/ha), we obtain 48.5 as the conversion factor between the phosphorus index and the phosphorus losses from the edge of field. This conversion factor is somewhat lower than both the conversion factor of 65 initially obtained using the relationship between the matrix and pathway versions of the phosphorus index, and the conversion factor of 78 obtained by averaging the divisors obtained for each watershed. A sensitivity analysis of the effects of varying the divisors (and hence the resulting export coefficients) on phosphorus loadings is included in the section of this report dealing with uncertainties.

Taking the divisor of 48.5 as the most realistic estimate for the conversion factor, and rounding this conversion factor up to 50 for significant digits, we then divided all the phosphorus index values for each watershed and agroecoregion in Minnesota by 50 to obtain phosphorus export coefficients. The resulting phosphorus export coefficients for an average year are 0.43 kg/ha/yr for major watersheds and 0.44 kg/ha/yr for agroecoregions. For wet years the export coefficients are 0.65 kg/ha/yr for watersheds and 0.68 kg/ha/yr for agroecoregions. For dry years the export coefficients are 0.21 kg/ha/yr for watersheds and 0.22 kg/ha/yr for agroecoregions. According to Heiskary and Wilson (1994), recommended phosphorus export coefficients for Minnesota agricultural lands are 0.2, 0.4, or 0.6 kg/ha/yr for low, mid, and high export risk conditions. Hence, our statewide average export coefficients for low, mid, and high export risk conditions (0.21, 0.43, and 0.65 kg/ha/yr) compare favorably with those recommended by Heiskary and Wilson (1994).

The procedure for estimating basin wide loads of phosphorus exported from the edge of agricultural fields is to multiply the export coefficients described above by the area of cropland within a distance of 100 m of surface water bodies (perennial and intermittent streams, ditches, wetlands, and lakes). On average, about 32% of all cropland lies within this distance of surface water bodies statewide, with a range of from 21 to 52% in major river basins (Table 2). This procedure accounts for the variability in risk of phosphorus loss from the edge of field due to climatic effects as well as the variability in soil, management and hydrologic factors. Variability in the phosphorus index values across the state are translated into variability in phosphorus losses from the edge of field using the export coefficient. On top of this, we added another 10% to the phosphorus loadings to account for contributions from cropland farther than 100 m from surface waterbodies. This is consistent with results from research conducted by Sharpley et al. (1994), Daniel et al. (1994) and Gburek et al. (2000), who concluded (SERA-17, 2004) that only 10% of the phosphorus loadings to surface waters from overland transport on agricultural lands arise from outside the primary contributing corridor (100 m or farther from surface water bodies). This 10% does not include additional phosphorus contributions that arise from surface tile inlets or subsurface tile drains.

Phosphorus Loads to Minnesota Surface Waters from Agricultural Lands

Major Watershed Based Analysis

Phosphorus export coefficients show considerable variation across major drainage basins and across climatic conditions (Table 3 and Fig. 26). Export coefficients (kg/ha) during average climatic conditions vary from 0.54 kg/ha for the Minnesota River basin, 0.4 kg/ha for the Red River basin, 0.39 kg/ha for the Upper Mississippi River basin, and 0.66 kg/ha for the Lower Mississippi River basin. During wet years, the export coefficients are increased to 0.81 kg/ha for the Minnesota River, to 0.54 kg/ha for the Red River, to 0.69 kg/ha for the Upper Mississippi River, and to 0.80 kg/ha for the Lower Mississippi River basin. The export coefficients decrease during dry years to 0.28, 0.13, 0.22, and 0.36 kg/ha for the Minnesota, Red, Upper Mississippi, and Lower Mississippi River basins, respectively.

Phosphorus export coefficients for river basins with relatively sparse agricultural cropland are smaller than the coefficients for river basins with intensive agricultural land use. For example, during average climatic years, the phosphorus export coefficients for the Lake Superior, Rainy, and St. Croix River basins are only 0.24, 0.23 and 0.38 kg/ha, respectively.

Phosphorus loads exported to surface waters from agricultural lands under dry, average and wet climatic conditions are shown in Table 4 and Fig. 27 (based on an analysis of phosphorus index values and export coefficients for major watersheds). Under average climatic conditions, the phosphorus loads exported to surface waters from the edge of agricultural fields are greatest for the Minnesota River basin (517,862 kg/yr), followed by the Red River (384,695 kg/yr), the Upper Mississippi (359,681 kg/yr) and the Lower Mississippi (232,581 kg/yr) River basins. All of the other basins have phosphorus export loads that are considerably smaller than the loads exported in these four basins.

As expected, phosphorus loads exported from agricultural lands to surface waters are considerably greater during wet years than average years. Under wet climatic conditions, the phosphorus loads exported in the Minnesota, Red, Upper Mississippi, and Lower Mississippi River basins are 759,749, 545,247, 652,266, and 282,780 kg/yr, respectively. In dry years the phosphorus loads exported are 262,851, 131,311, 200,865, and 116,810 kg/yr, respectively, for these same basins.

Phosphorus loads exported from agricultural lands are much smaller for the Rainy, Lake Superior and St. Croix River basins than the basins with larger proportions of agricultural cropland (the Minnesota, Red, Upper and Lower Mississippi River basins). For example, during years with average climatic conditions, phosphorus loads exported from agricultural land to surface waters are only 13,112, 20,713, 59,931 kg/yr for the Lake Superior, Rainy and St. Croix River basins, respectively. Similar comparisons can be made for wet and dry climatic years.

Agroecoregion Based Analysis

Phosphorus loads exported to surface waters from agricultural lands during dry, average and wet climatic conditions based on phosphorus index values and export coefficients calculated using agroecoregion boundaries are shown in Table 5 and Fig. 28. The relative rankings of major drainage basins are similar for the agroecoregion and watershed based analyses. With agroecoregion based export coefficients, the Minnesota River basin generates more phosphorus loadings to surface waters (516,768 kg/yr) than any other basin, a result that is consistent with the watershed based analysis. Significant phosphorus loadings for other basins include 361,759 kg/yr in the Red River basin, 332,313 kg/yr in the Upper Mississippi River basin, and 203,702 kg/yr in the Lower Mississippi River basin. In general, the magnitudes of phosphorus loadings are about 7% smaller for these basins in an average year than the magnitudes obtained using the watershed based analysis.

Evaluation of Phosphorus Loadings Under Alternative Agricultural Management Scenarios

Four alternative agricultural management scenarios were investigated and compared to a baseline scenario involving an average climatic year and existing rates of adoption of conservation tillage and existing rates of phosphorus fertilizer applications. The first alternative management was a scenario in which moldboard plowing is used on all row cropland. This is a worst case scenario for erosion, and exemplifies phosphorus losses typical of an era that existed twenty or more years ago. This scenario allows us to evaluate the extent of progress in controlling phosphorus losses over the last twenty years due to improvements in tillage management. The second scenario involves reductions in the rate of phosphorus fertilizer applications in watersheds where soil test phosphorus levels are higher than 27 ppm. In this case, fertilizer P application rates were reduced on row cropland to reflect the fact that soil phosphorus levels are sufficient for crop production. The third scenario involves improvements in manure application methods. Manure application methods were improved in watersheds where manure is primarily applied to the soil surface without incorporation (weighting factor of 8 in P Index matrix). In these watersheds the method of manure application was improved so that manure was incorporated immediately after application (weighting factor of 2 in P Index matrix). The fourth scenario involves variation in the area of cropland within 91 m of surface waterbodies.

The results of the first three alternative scenarios are shown in Fig. 29. In the Minnesota River basin, compared to an era when moldboard plowing was widely practiced, current day phosphorus losses from agricultural cropland have been reduced by about 146,000 kg/yr (from about 664,000 to 518,000 kg/yr), for a 28% reduction. In the Upper Mississippi River basin, current phosphorus losses from agricultural land have been reduced by about 87,000 kg/yr, for a 24% reduction. Similar comparisons show a 7% reduction for the Red River basin. No significant reductions have occurred in the Lower Mississippi River basin.

The potential future impacts of improved phosphorus fertilizer management can be quite significant (Fig. 29). Reductions in phosphorus fertilizer usage could occur if University of Minnesota recommendations were followed more consistently. For instance, phosphorus fertilizer is spread on significant areas of land in the Minnesota River basin even if soil test phosphorus levels exceed the threshold set by the University above which crops do not respond to additional fertilizer. This is because recommendations made by the fertilizer industry are often based on the concept of fertilizing at a rate equivalent to crop removal, if soil test phosphorus levels are above 21 ppm. In the Minnesota River basin, reductions in the rate of phosphorus fertilizer application could potentially reduce phosphorus losses to surface waters by about 81,000 kg/yr as compared to existing conditions, for a 16% reduction. Comparable levels of reduction could occur with improved phosphorus fertilizer management in the Red River, and the Upper and Lower Mississippi River basins.

The potential impact of improved manure application methods is illustrated in Fig. 29. In the Red River basin, phosphorus loads to surface waters could be reduced by about 75,000 kg/yr, for a 20% reduction. Reductions are much smaller in other basins with significant phosphorus loads from agricultural land. Improved manure application methods could potentially reduce phosphorus loads to surface waters by 12%, 7% and 7% in the Upper Mississippi, Lower Mississippi, and Minnesota River basins. In general, the effects on phosphorus loads of improvements in method of manure application are greatest for basins that have large numbers of beef cattle, and least for basins with large numbers of hogs.

The last scenario involves decreasing or increasing the area of cropland within 100 m of surface waterbodies. Decreases in area of cropland could correspond to land retirement programs such as those promoted in the Conservation Reserve and Conservation Reserve Enhancement Programs. Increases in cropland area would correspond to putting grass or forest riparian areas into production, alternatively this could be viewed as increasing the distance for cropland areas (now assumed to be 100 m) that contribute phosphorus to surface waters. The results from this scenario (Fig. 30) indicate that retiring land in close proximity to surface waters would decrease the phosphorus loadings as expected. Every one percent decrease in the area of cropland within 100 m of surface waters leads to a one percent decrease in phosphorus loadings. Alternatively, every one percent increase in the area of cropland near surface waters leads to a one percent increase in the phosphorus loadings.

Uncertainties in Estimated Phosphorus Loadings

There are many possible sources of uncertainty in the estimated phosphorus loadings. These can be divided into errors in input data, errors in converting phosphorus index values to phosphorus export coefficients, errors in estimating the proportion of cropland that contributes to phosphorus loadings, and errors due to a lack of consideration for impacts of surface and subsurface drainage, wind erosion or snowmelt runoff on phosphorus loadings. The primary sources of errors in input data include those due to spatial variations in farm management practices at scales smaller than watersheds or agroecoregions, errors in estimating slope length for erosion calculations, and errors due to out of date landuse information (all cropland estimates in the contributing corridor around surface water bodies are based on 1992 landuse data).

Errors in estimating phosphorus export coefficients also lead to uncertainties in phosphorus loadings. A sensitivity analysis was conducted to determine the impact of uncertainties in export coefficients on phosphorus loadings. We estimated phosphorus loadings under three scenarios for watershed based phosphorus index values, namely; phosphorus index divisor factors of 50 (recommended baseline value from this study), 70 and 30. For phosphorus index divisors greater than 50, the basin phosphorus loadings decreased on average by 1.4% for an increase of one in the divisor (e.g. a 1.4% decrease when the divisor is increased from 50 to 51). For phosphorus index divisors less than 50, the basin phosphorus loadings increased on average by 3.3% for an decrease of one in the divisor (e.g. a 3.3% increase when the divisor is decreased from 50 to 49).

Errors can arise from improperly estimating the area of cropland within 100 m of surface water bodies. This influence was described in the section above (Fig. 30). Also, we do not vary the area of cropland within 100 m of surface water bodies when computing basin scale phosphorus loadings for dry, average, and wet years. For each climatic scenario we are using the maximum possible area of cropland, thus overestimating the agricultural contributions during average and dry years. To illustrate the effects of this uncertainty, we estimated the percent of all cropland within 91 m of waterbodies for dry, average and wet years using different hydrologic coverages. For dry years, using hydrologic coverages for perennial streams, there was only 1.14% of all cropland within 91 m of surface waters. Using perennial streams plus ditches in average years, 3.8% of all cropland was within 91 m of surface waters. In wet years, using perennial streams, ditches, and intermittent streams, 17.2% of all cropland was within 91 m of surface waters. These area percentages were used to account for the effects of climatic variability in estimating phosphorus index values. However, in calculating phosphorus loads from agricultural areas phosphorus export coefficients were multiplied by the area of cropland within 100 m of perennial streams, ditches, intermittent streams, lakes and wetlands (accounting on average for 32% of cropland area). In view of these results, phosphorus loadings from agricultural lands are overestimated for average and dry years.

Our method of estimation does not consider the influence that surface tile intakes farther than 100 m may have on phosphorus loadings. To include the effects of surface tile intakes we would need to know the number of tile intakes per unit area, the area of cropland contributing to tile intake flow, and the phosphorus export coefficients for surface tile intakes. These data are not available for Minnesota in enough detail to be confident about their representativeness. Since depressional areas around tile inlets generally trap 60-80% of the sediment and phosphorus flowing to the inlets, the phosphorus export coefficient for surface tile intakes is smaller than that for direct overland flow to surface waters (Ginting et al., 2000). Ginting et al. (2000) studied phosphorus loads carried by surface tile intakes in two small catchments located in the Watonwan watershed of the Minnesota River basin. They found that, over a three year period with slightly below precipitation amounts, phosphorus loads carried by surface tile intakes averaged 0.099 kg/ha annually, with measured concentrations of phosphorus in surface tile intakes as high as 4 mg/L. This loading (0.099 kg/ha) is significantly smaller than the amounts of phosphorus transported by surface runoff and erosion in the same region (0.68 kg/ha).

There were three surface tile intakes studied by Ginting et al. (2000), and the average phosphorus load transported by each tile intake annually was 2.82 kg/yr. Surveys of surface tile intake density in 32 small watersheds within the Minnesota River basin (MPCA, 1994) show that there is one surface tile intake for every 23 to 1210 acres in the watershed. The average is one surface tile intake for every 100 or so watershed acres (the acreage that actually contributes to surface tile intake P loads is smaller than this, but few data exist to know what the contributing acreage actually is). If we assume that there is one surface tile intake for every 100 acres within the poorly drained soils of the Minnesota River basin, we estimate that there are roughly 33,333 surface tile intakes in the basin. At a phosphorus loading of 2.8 kg/yr for each tile intake, the total phosphorus loading from surface tile intakes to surface water bodies in the Minnesota River basin would be about 94,000 kg/yr. This is approximately 18% of the phosphorus loading from cropland within 91 m of surface waters in the Minnesota River basin during an average year (517,862 kg/yr).

Similarly, our method does not consider the influence of subsurface tile drainage on phosphorus export to surface waters. Randall et al. (2000) studied losses of phosphorus in subsurface drainage in a four year manure and fertilizer study on a Webster clay loam typical of the poorly drained soils in the Minnesota River basin. According to Randall et al. (2000), on average over half of the drainage flows carry non-detectable amounts of phosphorus. The remainder of drainage flows have a concentration of total phosphorus averaging about 0.03 mg/L (with maximum observed concentrations of about 0.12 mg/L), for an average annual loss of 0.027 kg P/ha. If this rate is applied to the area of cropland in the Minnesota River basin having tile drainage, it gives a phosphorus loading of about 30,000 kg/yr, which is quite small (6% of total) compared to the phosphorus loading from cropland within 91 m of surface waters during an average year (517,862 kg/yr). Subsurface drainage phosphorus loads from other basins would be much smaller, because tile drainage is of limited extent in basins other than the Minnesota River basin.

The phosphorus loadings from subsurface tile drains collected by Randall et al. (2000) are the only data published in peer reviewed journals from Minnesota studies. Other studies of phosphorus losses in Minnesota subsurface tile drainage include those conducted by Alexander and Magdalene (1998) from 1995 to 1997 at the Rollings East Tile (RET) site, and by the Minnesota Department of Agriculture from 1998 to 2001 at the Red Top farm, both of which are located in the Minnesota River basin. The study by Alexander and Magdalene (1998) does not estimate phosphorus loadings from subsurface tile drainage, instead, it reports only the concentrations of phosphorus measured. The concentrations of phosphorus measured in subsurface tile drainage by Alexander and Magdalene (1998) are very comparable in seven out of ten storms they monitored to the concentrations measured by Randall et al. (2000) over a four year period. In two other storms monitored by Alexander and Magdalene (1998), the phosphorus concentrations ranged between 0.42 and 1.5 mg/L, much higher than those measured by Randall et al. (2000). At the Red Top farm study, based on 9 field years of water quality monitoring data for average climatic years, the annual average phosphorus loading from subsurface tile drains was 0.11 kg/ha. These larger field drainage systems were constructed of concrete tiles which differ from the smaller plot based plastic drain tiles studied by Randall et al. (2000). Based on this comparison, we conclude that more research is needed to accurately define the mean and range in phosphorus loading from subsurface drainage tiles in the Minnesota River basin.

Not enough research data are available to reliably estimate the phosphorus loadings from surface tile intakes or subsurface tile drains to surface waters in the Minnesota River basin during dry or wet climatic years. As a first approximation, we can scale the phosphorus loadings from tile drains so that they have the same relative ratio as the phosphorus index based loadings for the Minnesota River basin in dry, average and wet years (262,851; 517,862; and 759,749 kg/yr, respectively). This gives phosphorus loadings from subsurface tile drains of 15,227 kg/yr during dry years and 44,013 kg/yr during wet years. Using the same approach, phosphorus loadings from surface tile inlets during dry and wet years would be 47,711 and 137,906 kg/yr, respectively. As mentioned previously, this approach substantially overestimates the phosphorus loadings in dry years.

Finally, we do not explicitly account for the effects of wind erosion or snowmelt runoff on phosphorus loadings to surface waters. Wind erosion may be particularly important in the Red River basin. Snowmelt erosion is indirectly accounted for in the regional phosphorus index through the runoff factor, as well as in the method of manure application factor, so this error may not be large.

Recommendations

This study provides a broad overview of the impacts of agricultural lands on phosphorus loadings to surface waters. There are many detailed questions remaining that could be studied in further detail. Some of these are listed below:

- Comparison of watershed based phosphorus loadings with agroecoregion based phosphorus loadings at the scale of major watersheds
- Development of phosphorus delivery ratios for agricultural as well as non-agricultural sources of phosphorus as a function of area of contribution watershed, area of lake and wetland storage in the watershed, and landscape characteristics
- Investigation of the impacts that farm scale variability has on estimated phosphorus loadings within watersheds
- Further study of the distance from surface waters within which the majority of phosphorus losses from cropland to surface waters originate
- Further investigation of the variable source area concept as applied to phosphorus transport during dry, average and wet climatic years
- Further investigation of the contribution of surface tile intakes and subsurface drainage to phosphorus loads
- Study of the impact that wind erosion has on phosphorus loading to surface waters

Summary

The risk of phosphorus transport to surface waters depends on many factors. These include factors affecting soil erosion by water (conservation tillage, landscape steepness, climate), soil test phosphorus levels, rate of application of phosphorus from fertilizer or manure, and method of application of manure. Extensive databases for Minnesota watersheds and agroecoregions were developed to explore the variation in risks of phosphorus transport to surface waters in response to these factors. The results show that phosphorus losses are more sensitive to climatic variability than any other factor. The fraction of cropland near streams and ditches also has a large impact on phosphorus losses, during both wet and dry years.

Watersheds and agroecoregions in Minnesota exhibit a considerable amount of variation in the risks of phosphorus loss. In general, the watersheds and agroecoregions with the greatest potential for phosphorus loss are located in the Lower Mississippi and Minnesota River basins. This is because of a combination of high rates of erosion, high rates of phosphorus application from fertilizer or manure, and a high percentage of cropland near streams and ditches. From a basin wide perspective, however, the greatest phosphorus loads are exported from agricultural lands to surface waters in the Minnesota River basin, followed by the Red River, Upper Mississippi, and Lower Mississippi River basins. Basins with relatively small areas of agricultural land use, such as the Lake Superior, Rainy and St. Croix River basins have significantly smaller phosphorus loads exported from agricultural lands to surface waters than basins with significant amounts of agricultural land use.

Analysis shows that farmers have made considerable progress in controlling phosphorus losses from agricultural cropland over the last twenty years or more due to accelerated adoption of conservation tillage. Additional progress can be made through continued adoption of best management practices, including reductions in the amount of phosphorus fertilizer applied to cropland when soil phosphorus levels are sufficient for crop production. Improved methods of manure application are also important in northern drainage basins for reductions in phosphorus loads to surface waters. Land retirement programs can be effective at reducing phosphorus loads to surface waters if cropland near surface waters is targeted for retirement.

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Table 1

(from Birr and Mulla, 2001)

The modified version of the P Index representing conditions controlling P movement in Minnesota (adapted from Lemunyon and Gilbert, 1993)

	Phosphorus loss potential (value)				
Site characteristic (weight)	**Very low (0)**	**Low (1)**	**Medium (2)**	**High (4)**	**Very high (8)**
Transport factors					
Soil erosion (1.5)†	0	1-5	6-14	15-21	> 21
Runoff (0.5)‡	0-8	9-13	14-16	17-21	> 21
Percentage of cropland and pastureland within 91.4 m of a watercourse (1.5)	0-1.2	1.3-3	3.1-4.2	4.3-6.2	> 6.2
Source factors					
Soil test P (0.75)§	0-19	20-26	27-31	32-39	> 39
Fertilizer P application rate (1.0)¶	0-7	8-13	14-19	20-24	> 24
Fertilizer P application method (0.5)	None applied	Placed with planter deeper than 5 cm	Incorporated immediately before crop	Incorporated >3 mo before crop or surface applied <3 mo before crop	Surface applied >3 mo before crop
Organic P source application rate (0.5)¶	0-2	3-6	7-8	9-11	> 11
Organic P source application method (1.0)	None applied	Placed with planter deeper than 5 cm	Incorporated immediately before crop	Incorporated >3 mo before crop or surface applied <3 mo before crop	Surface applied >3 mo before crop

† Units for soil erosion are Mg/ha.

‡ Units for runoff are cm.

§ Soil test P is Bray-1 extractable P and units are mg P/kg.

¶ Units for P application are kg P/ha

Table 2: Percent of Cropland Area in River Basins in the Primary Contributing Corridor for Phosphorus Loading to Surface Waters.

Basin	Cropland Area in the Primary Contributing Corridor* (%)
St. Croix River	42.8
Upper Mississippi	36.9
Lower Mississippi	23.9
Red River	29.5
Rainy River	40.8
Lake Superior	52.2
Minnesota River	23.5
Missouri River	25.9
Cedar River	20.9
Des Moines River	20.7

*The primary contributing corridor includes cropland within 100 m of surface water bodies. Significant phosphorus loadings to surface waters can arise from surface tile inlets and subsurface tile drainage that are outside the primary contributing corridor.

Table 3: Phosphorus Export Coefficients (kg/ha) from Agricultural Cropland by Major Drainage Basin Based on a Watershed Analysis of Phosphorus Index Values.

	Phosphorus Export Coefficients* from Agricultural Land (kg/ha)		
Basin	Dry Year	Average Year	Wet Year
St. Croix River	0.18	0.38	0.69
Upper Mississippi	0.22	0.39	0.70
Lower Mississippi	0.36	0.66	0.80
Red River	0.36	0.66	0.54
Rainy River	0.09	0.23	0.41
Lake Superior	0.15	0.24	0.43
Minnesota River	0.28	0.54	0.81
Missouri River	0.25	0.44	0.79
Cedar River	0.26	0.63	0.79
Des Moines River	0.27	0.44	0.78

*These export coefficients are an average of the export coefficients for each of the major watersheds within each river basin. These do not include contributions from surface tile inlets or subsurface tile drains.

Table 4: Phosphorus Loadings (kg/yr) to Minnesota Surface Waters from Agricultural Cropland by Major Drainage Basin Based on an Analysis of Phosphorus Index Values in Major Watersheds.

	Phosphorus Loads* Exported from Agricultural Land (kg/yr)		
Basin	Dry Year	Average Year	Wet Year
St. Croix River	27857	59931	110046
Upper Mississippi	200865	359681	652266
Lower Mississippi	116810	232581	282780
Red River	131311	384695	545247
Rainy River	8988	20713	36072
Lake Superior	7617	13112	22528
Minnesota River	262851	517862	759749
Missouri River	36055	58758	109222
Cedar River	13722	33270	42444
Des Moines River	24670	37743	73149

*These loads are computed by multiplying the phosphorus export coefficients for each major watershed by the area of cropland within the contributing corridor for the same major watershed, and then summing over all major watersheds with the river basin. An additional 11.1% load is then added to account for phosphorus contributions by overland flow from outside the contributing corridor, excluding the contributions from surface tile inlets and subsurface tile drains.

Table 5: Phosphorus Loadings (kg/yr) to Minnesota Surface Waters from Agricultural Cropland by Major Drainage Basin Based on an Analysis of Phosphorus Index Values in Agroecoregions.

	Phosphorus Loads* Exported from Agricultural Land (kg/yr)		
Basin	Dry Year	Average Year	Wet Year
St. Croix River	49193	84486	148546
Upper Mississippi	183184	332313	595252
Lower Mississippi	98474	203702	270490
Red River	130163	361759	561684
Rainy River	16524	30050	56620
Lake Superior	14145	24416	45569
Minnesota River	259198	516768	750293
Missouri River	30110	52024	102969
Cedar River	14138	31890	45137
Des Moines River	26575	51182	80991

*These loads are computed by multiplying the phosphorus export coefficients for each agroecoregion by the area of cropland within the contributing corridor for the same agroecoregion, and then summing over all agroecoregions with the river basin. An additional 11.1% load is then added to account for phosphorus contributions by overland flow from outside the contributing corridor, excluding the contributions from surface tile inlets and subsurface tile drains.

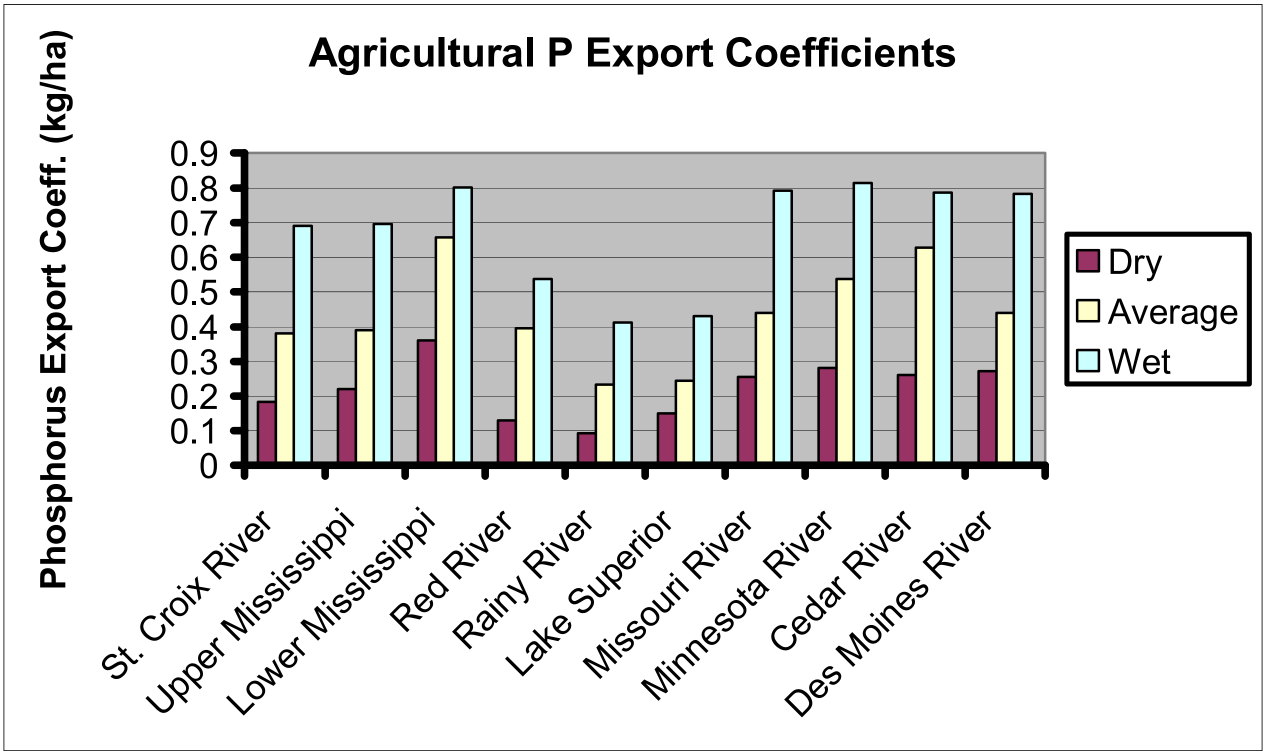

Fig. 26: Agricultural P export coefficients (kg/ha) for major drainage basins in dry, average, and wet climatic years. Export coefficients are derived from major watershed based phosphorus index values. These do not include contributions from surface tile inlets or subsurface tile drains.

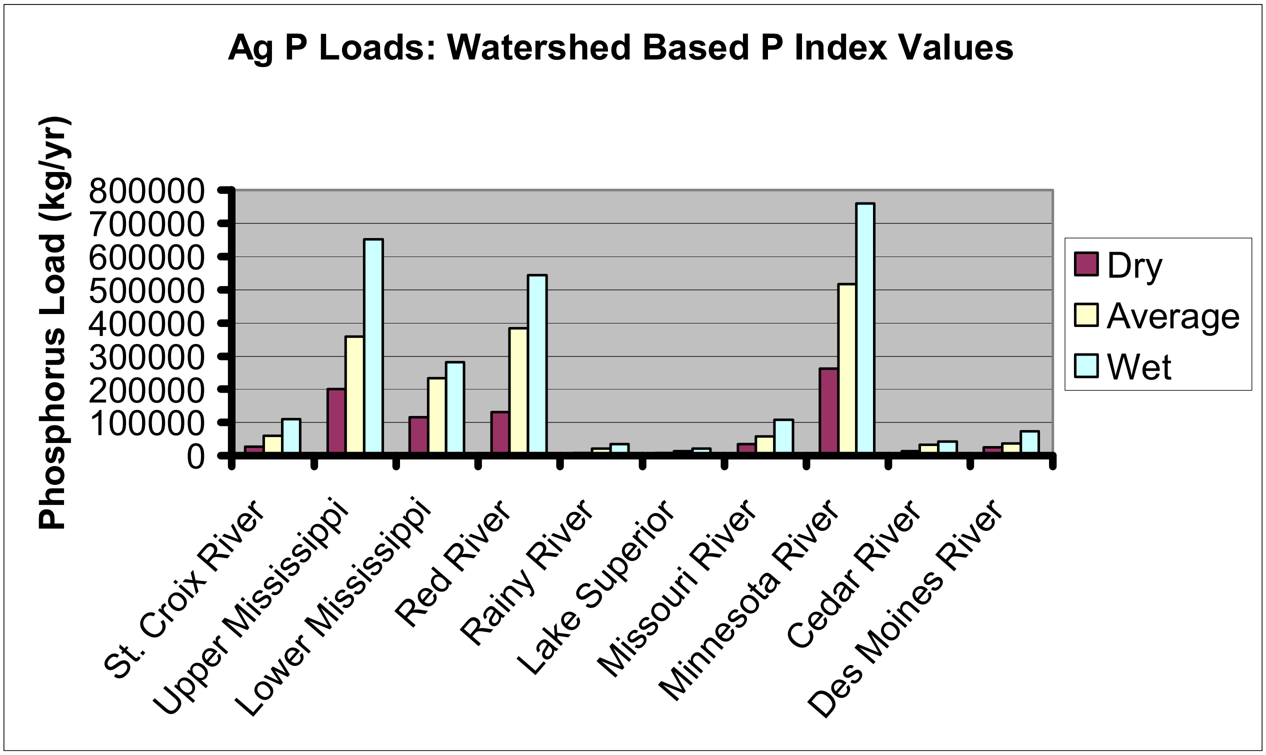

Figure 27: Agricultural phosphorus loads (kg/yr) exported to surface waters in major drainage basins of Minnesota under dry, average and wet climatic conditions. These results are based on phosphorus export coefficients derived from major watershed based phosphorus index values. These do not include contributions from surface tile inlets or subsurface tile drains.

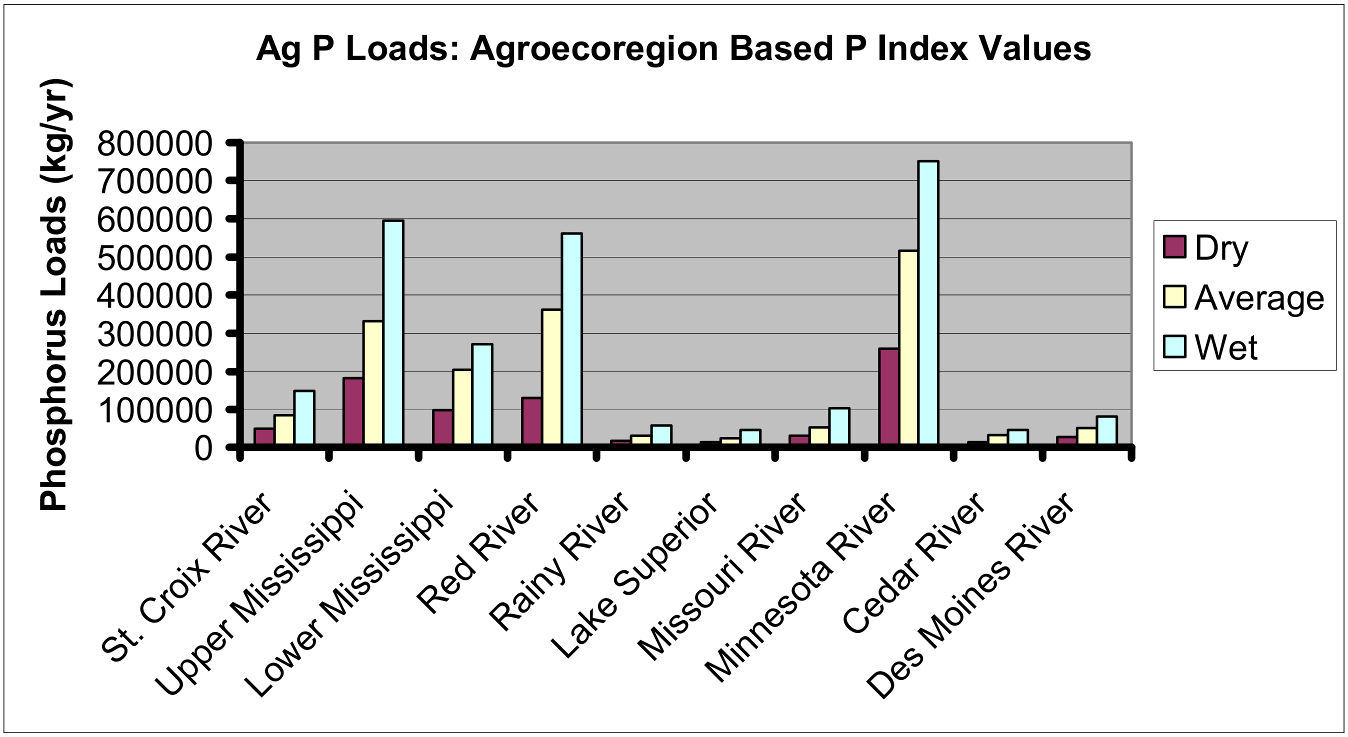

Figure 28 Agricultural phosphorus loads (kg/yr) exported to surface waters in major drainage basins of Minnesota under dry, average and wet climatic conditions. These results are based on phosphorus export coefficients derived from agroecoregion based phosphorus index values. These do not include contributions from surface tile inlets or subsurface tile drains.

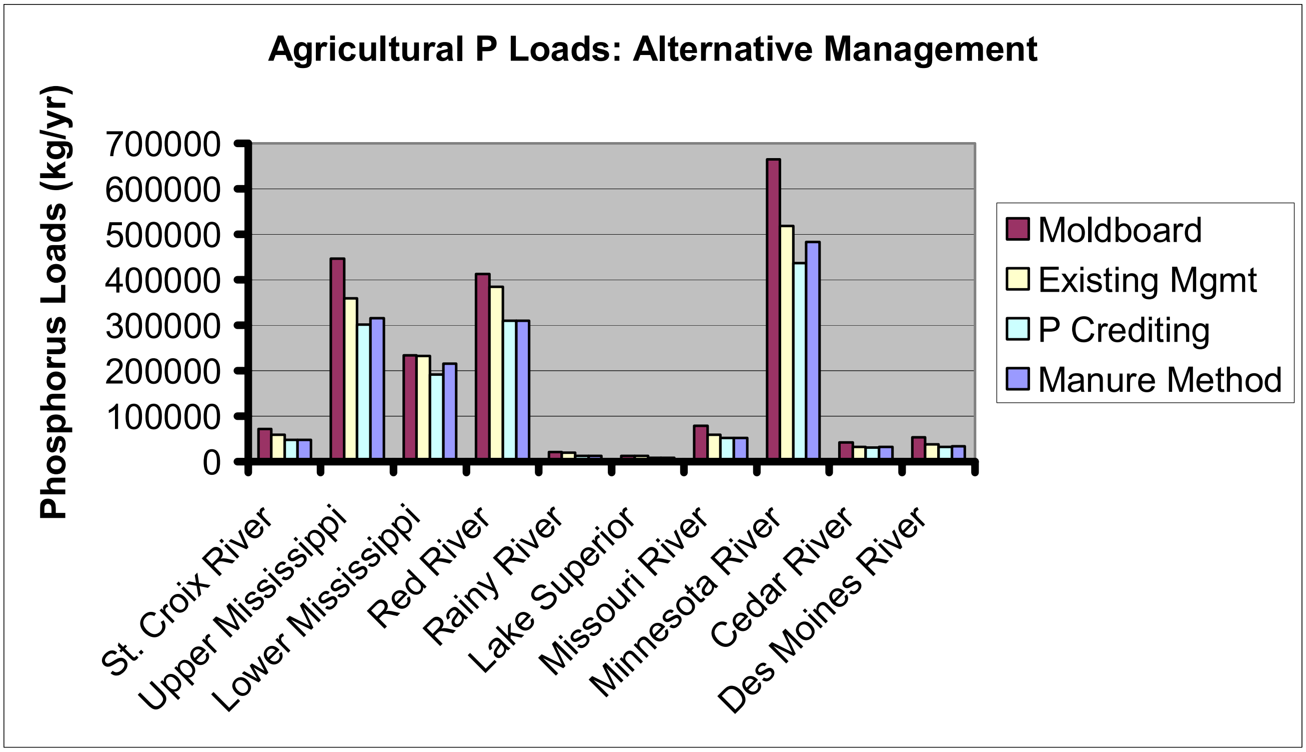

Figure 29: Agricultural phosphorus loads (kg/yr) exported to surface waters in major drainage basins of Minnesota under average climatic conditions for a worst case scenario involving moldboard plowing on all row cropland, a scenario involving improved phosphorus fertilizer management, a scenario for improved methods of manure application, and a baseline scenario for existing rates of phosphorus fertilizer and existing rates of adoption of conservation tillage. These results are based on phosphorus export coefficients derived from major watershed based phosphorus index values. These do not include contributions from surface tile inlets or subsurface tile drains.

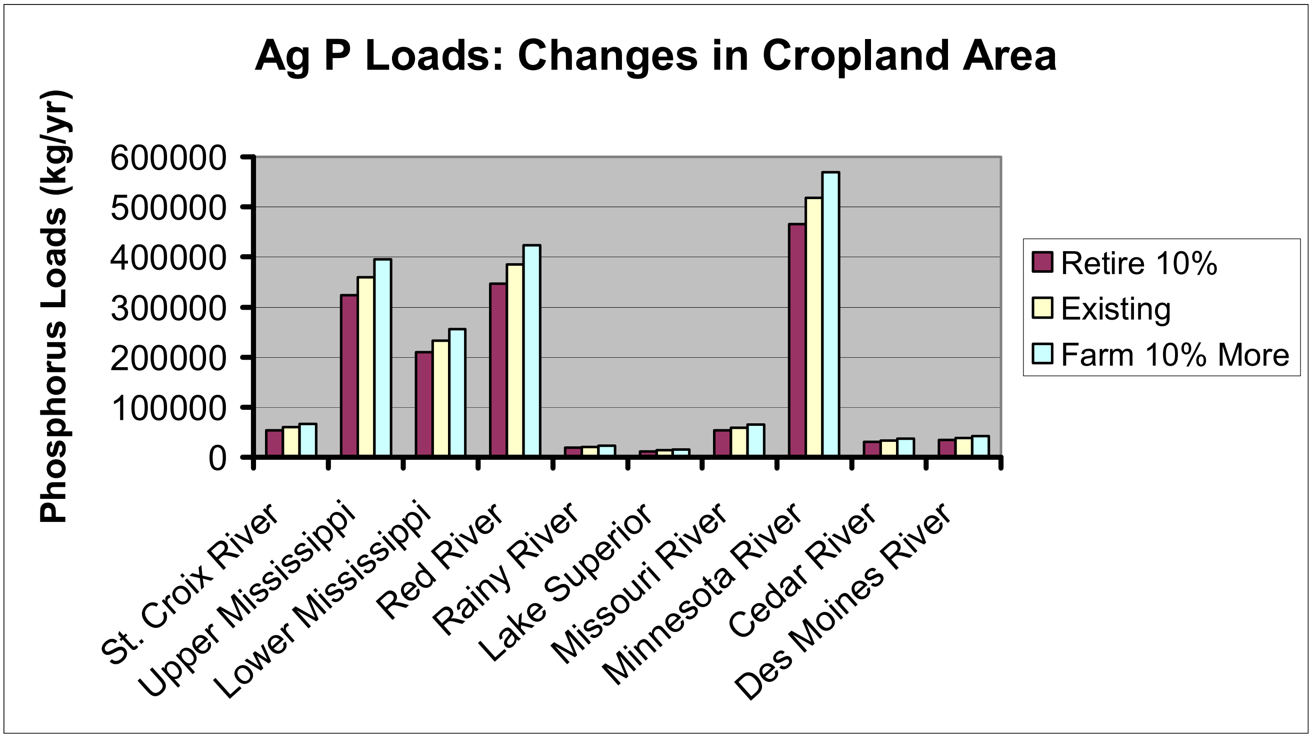

Figure 30: Agricultural phosphorus loads (kg/yr) exported to surface waters in major drainage basins of Minnesota under average climatic conditions for a scenario involving retirement of 10% of the row cropland within 100 m of waterbodies, a scenario involving a 10% increase in the area of row cropland within 100 m of waterbodies, and a baseline scenario for the area of cropland within 100 m of waterbodies under existing conditions. These results are based on phosphorus export coefficients derived from major watershed based phosphorus index values. These do not include contributions from surface tile inlets or subsurface tile drains.

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Figure 28 Agricultural phosphorus loads (kg/yr) exported to surface waters in major drainage basins of Minnesota under dry, average and wet climatic conditions. These results are based on phosphorus export coefficients derived from agroecoregion based phosphorus index values. These do not include contributions from surface tile inlets or subsurface tile drains.

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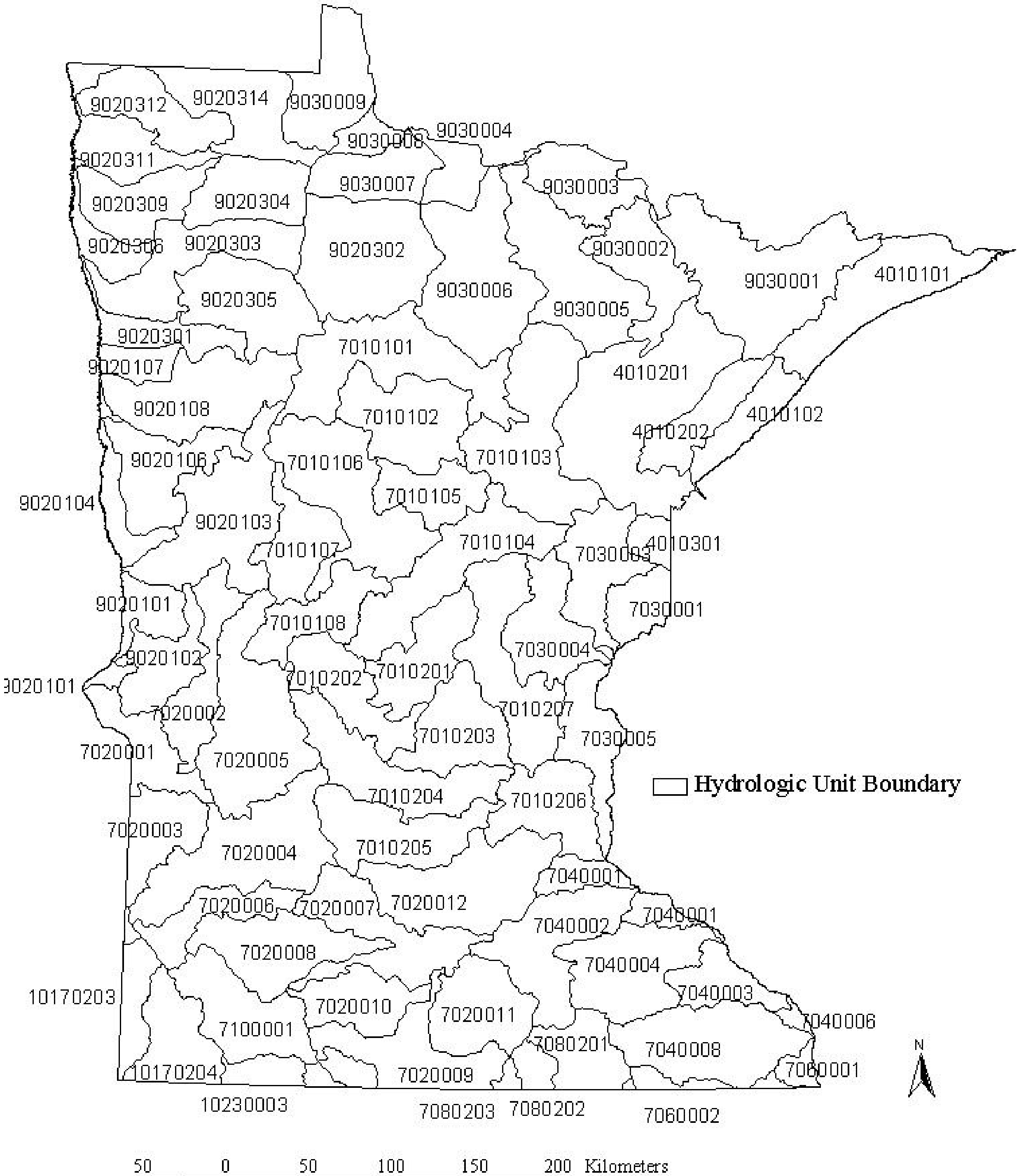


Fig. 1: Major river basins and 8-digit Hydrologic Unit Codes for watersheds in Minnesota.

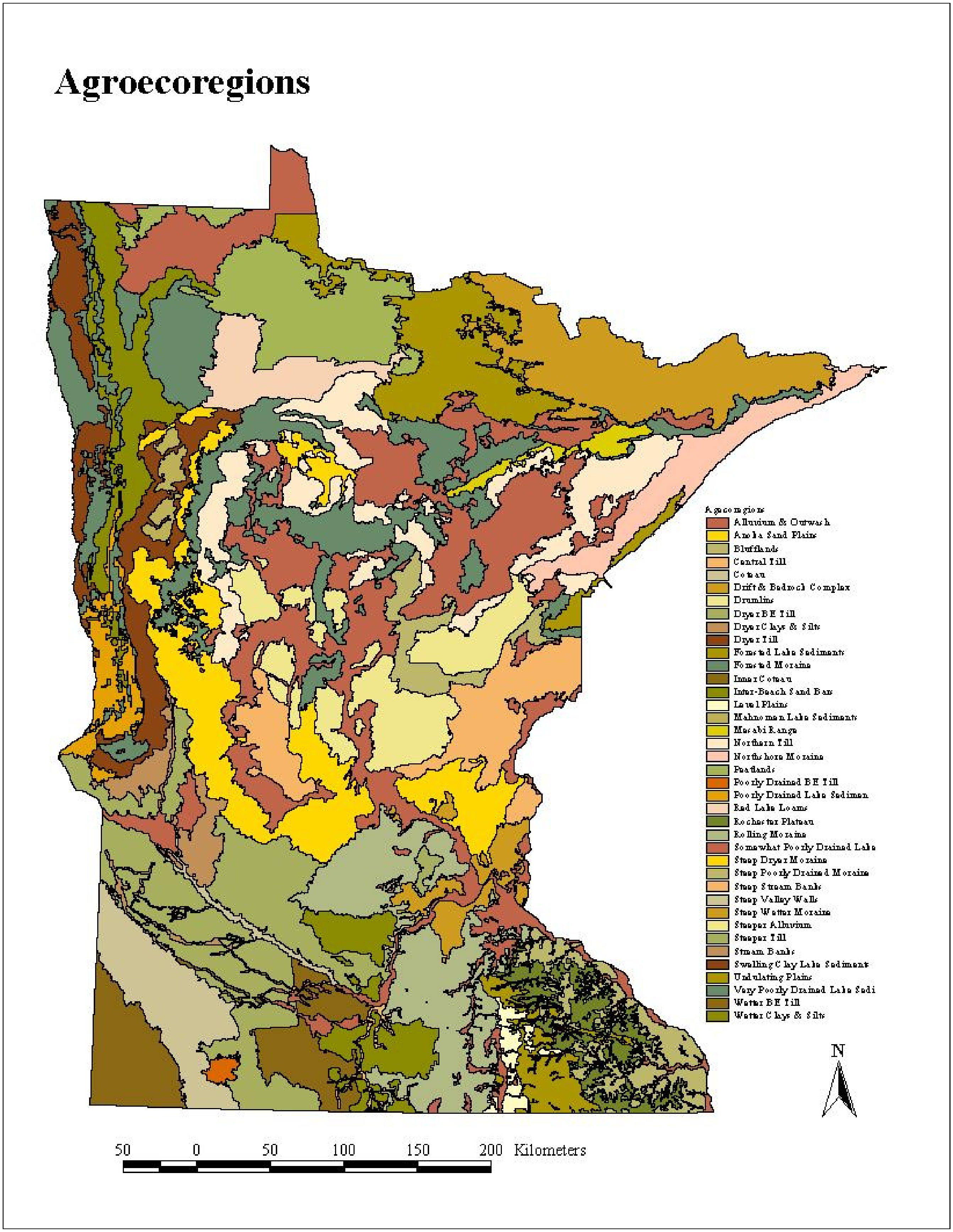


Fig. 2: Agroecoregions of Minnesota.

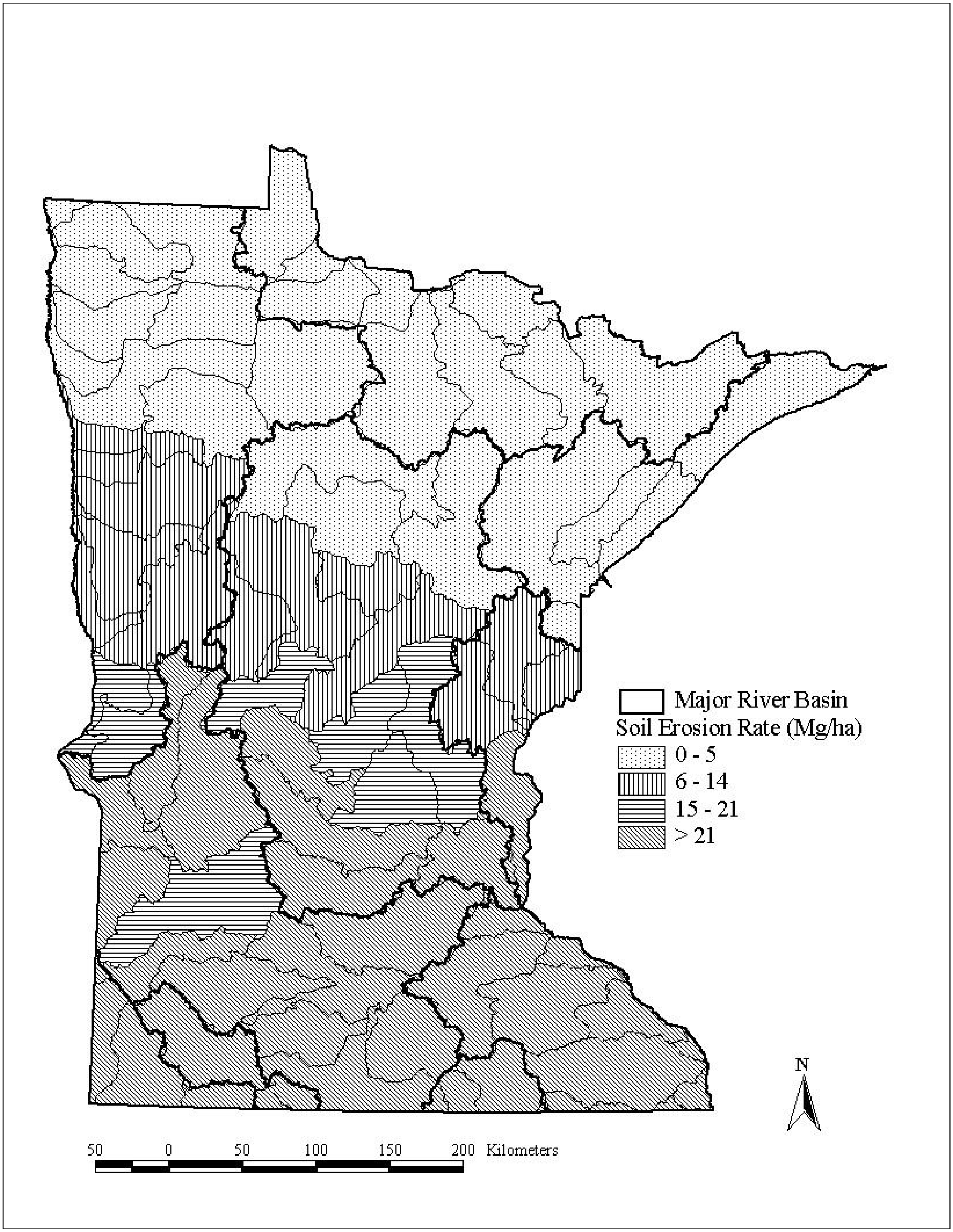


Fig. 3a: Water erosion estimates based on average rainfall runoff erosivity and no crop residue cover at planting for watersheds of Minnesota.

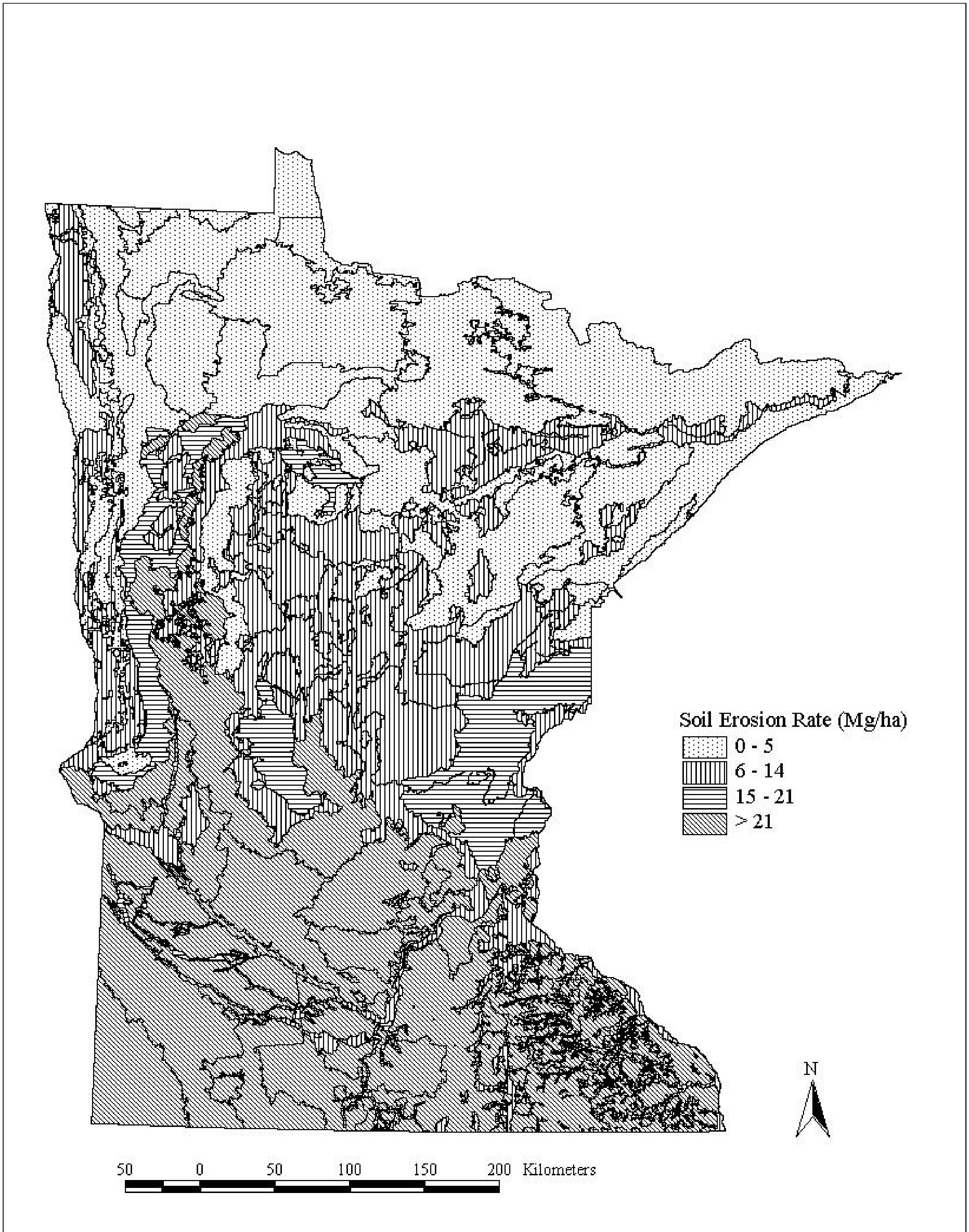


Fig. 3b: Water erosion estimates based on average rainfall runoff erosivity and no crop residue cover at planting for agroecoregions of Minnesota.

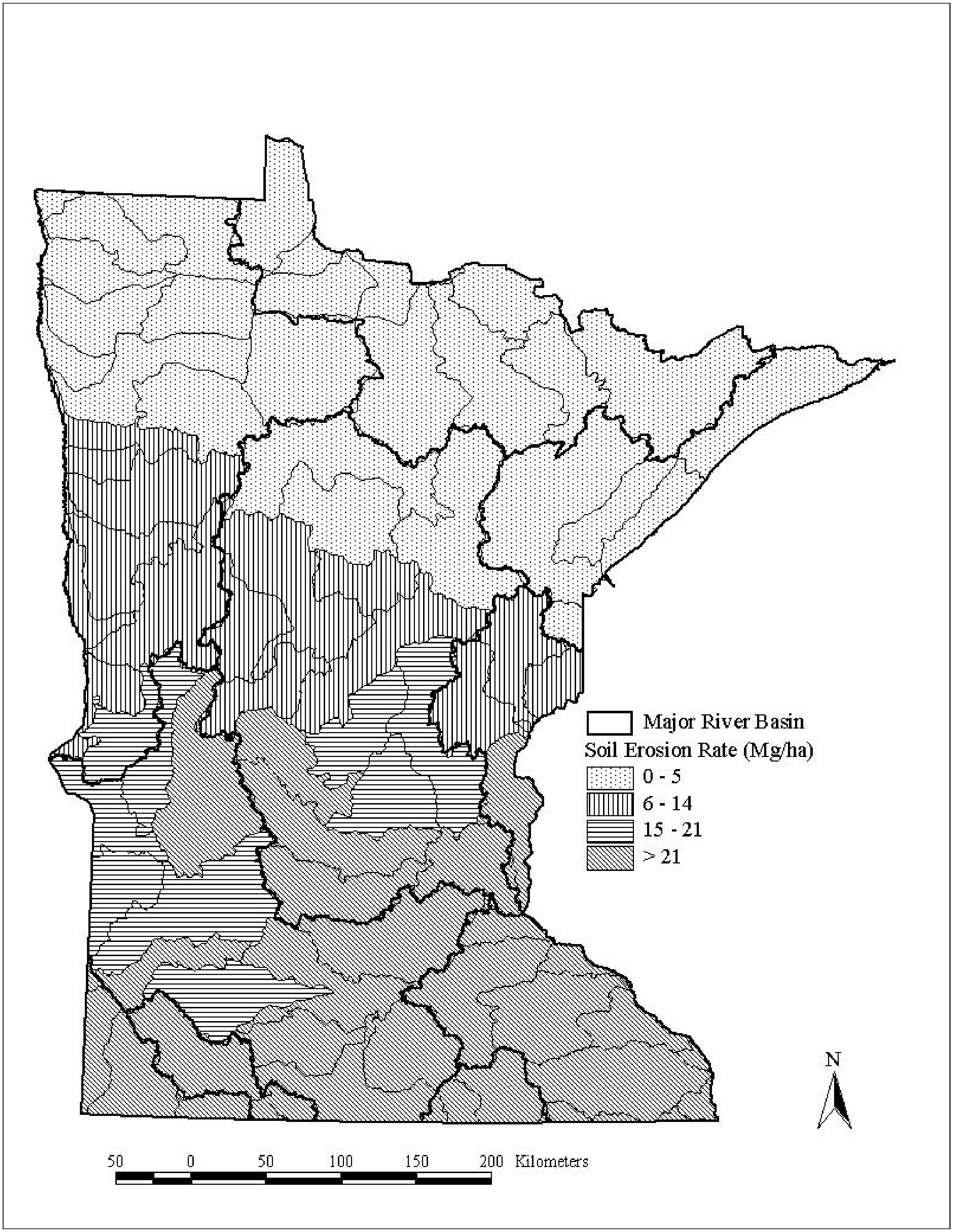


Fig. 4a: Water erosion estimates based on average rainfall runoff erosivity and average crop residue cover at planting for watersheds of Minnesota.

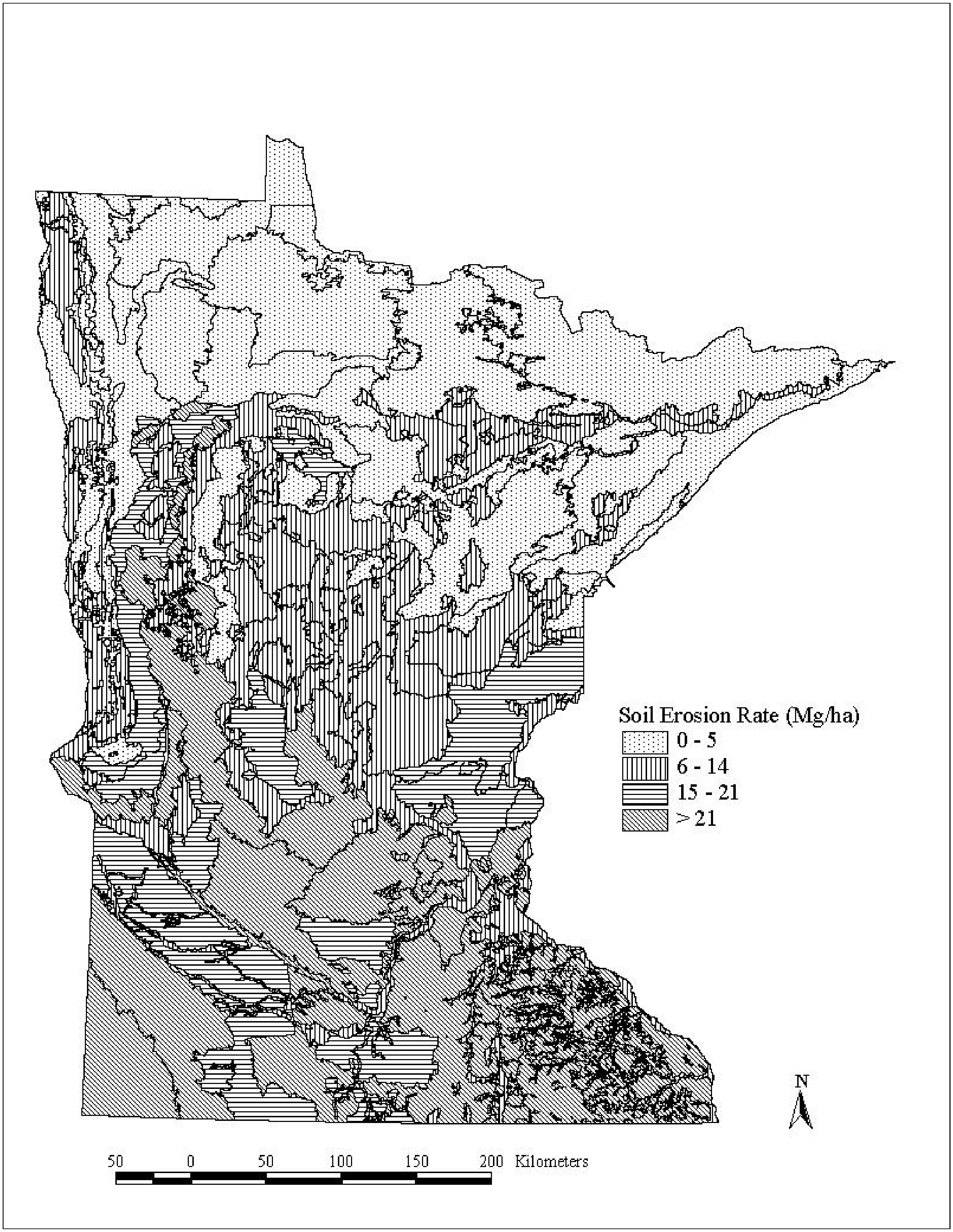


Fig. 4b: Water erosion estimates based on average rainfall runoff erosivity and average crop residue cover at planting for agroecoregions of Minnesota.

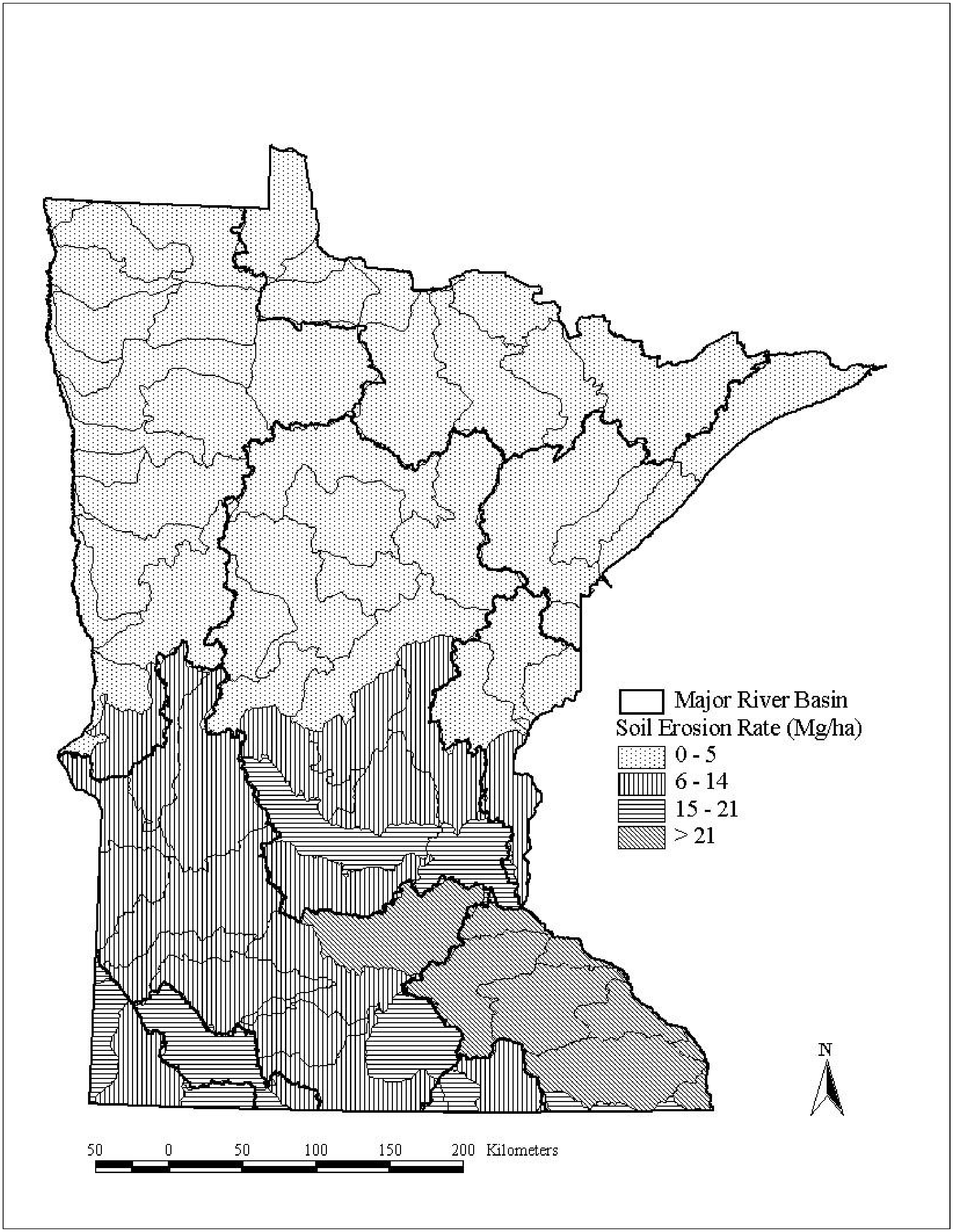


Fig. 5a: Water erosion estimates based on average rainfall runoff erosivity and 50% crop residue cover at planting for watersheds of Minnesota.

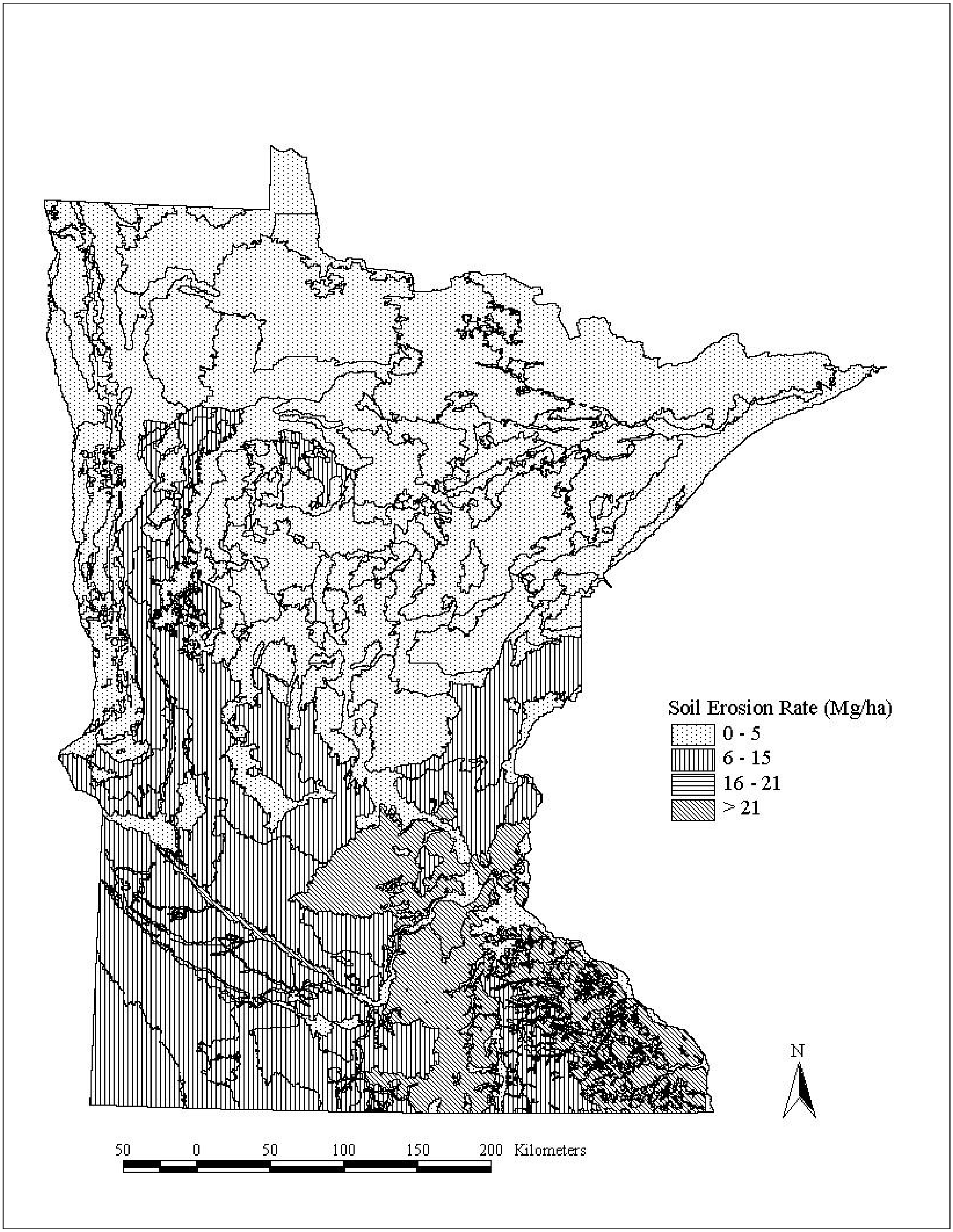


Fig. 5b: Water erosion estimates based on average rainfall runoff erosivity and 50% crop residue cover at planting for agroecoregions of Minnesota.

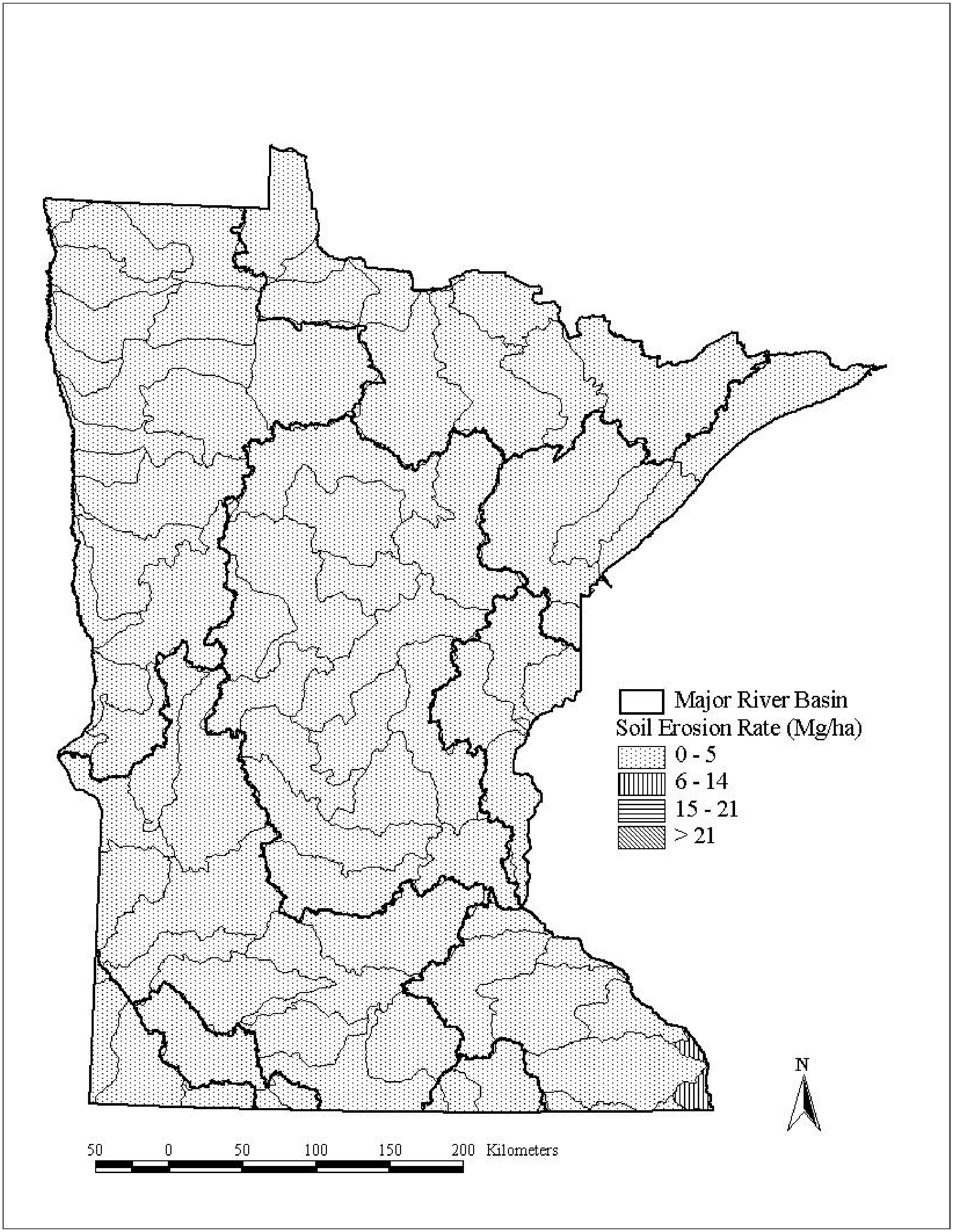


Fig. 6a: Water erosion estimates based on low rainfall runoff erosivity and 50% crop residue cover at planting for watersheds of Minnesota.

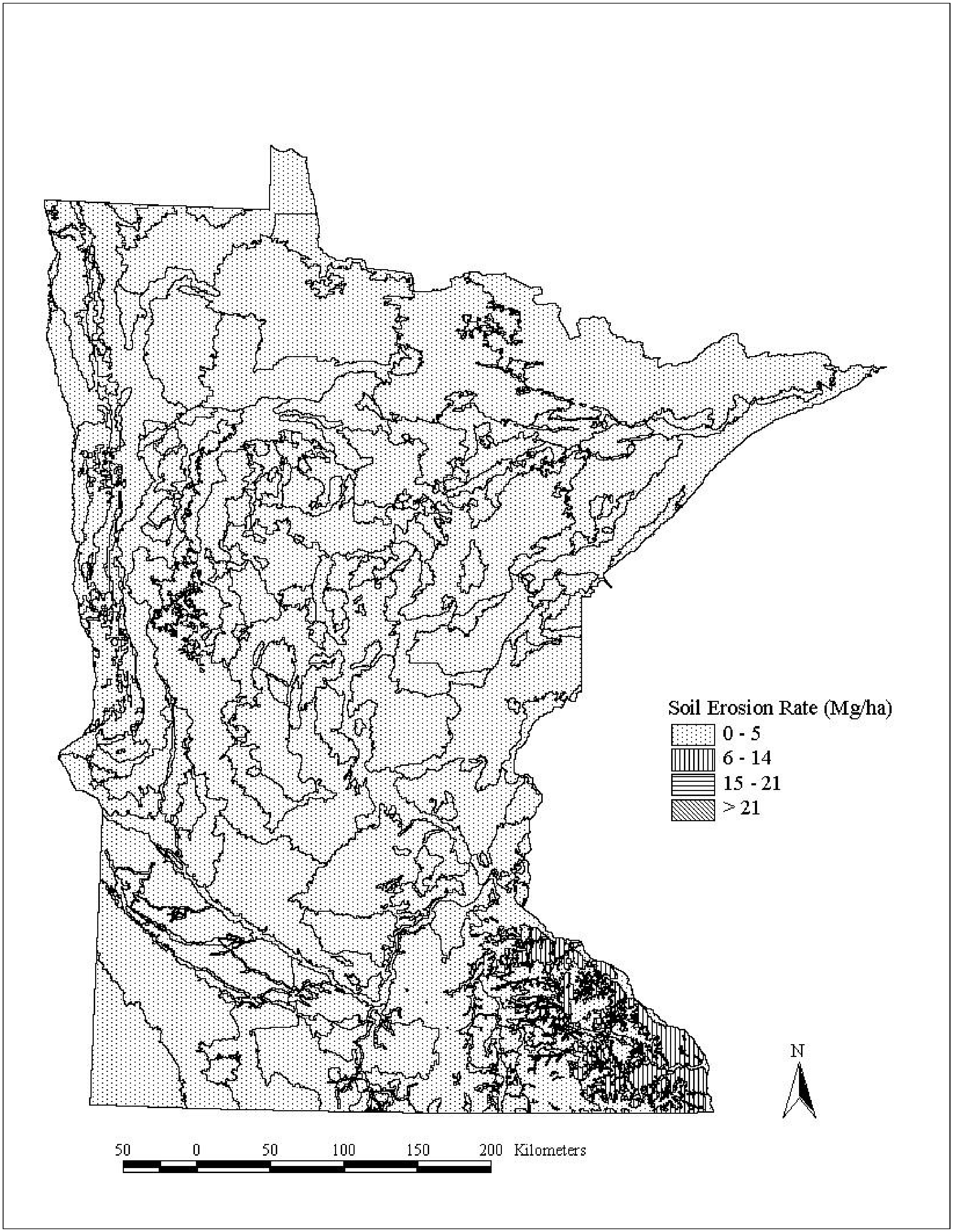


Fig. 6b: Water erosion estimates based on low rainfall runoff erosivity and 50% crop residue cover at planting for agroecoregions of Minnesota.

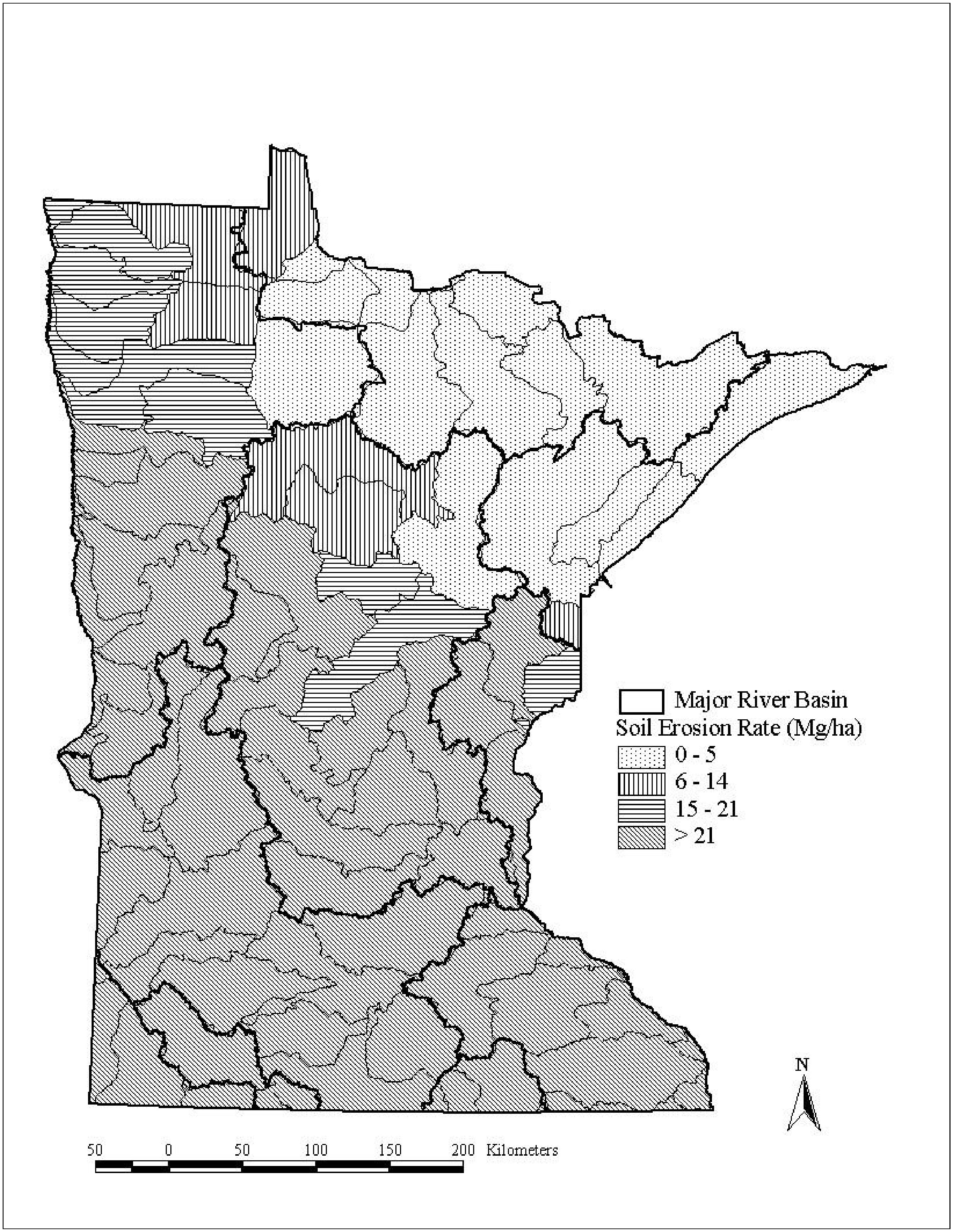
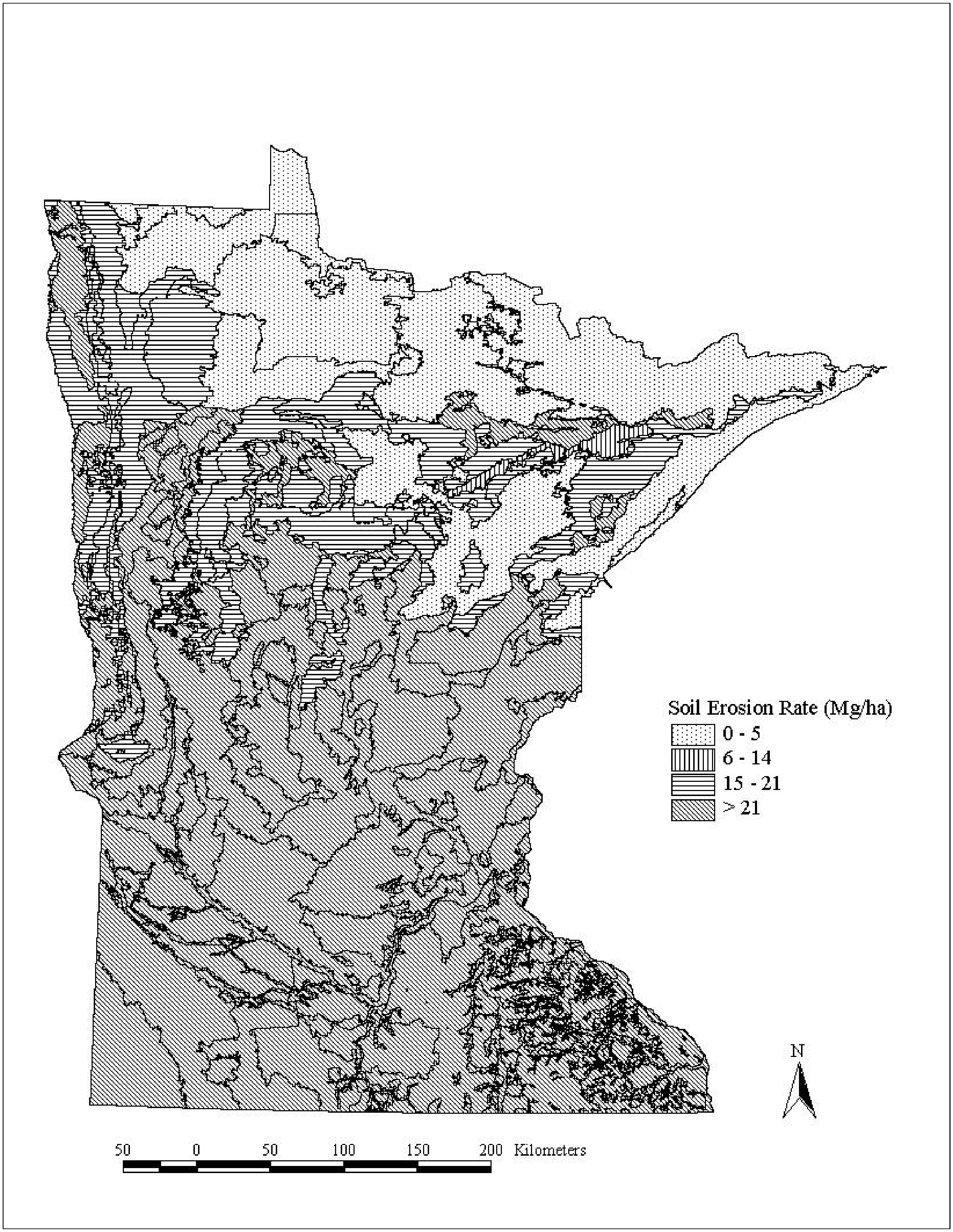


Fig. 7a: Water erosion estimates based on high rainfall runoff erosivity and 50% crop residue cover at planting for watersheds of Minnesota.



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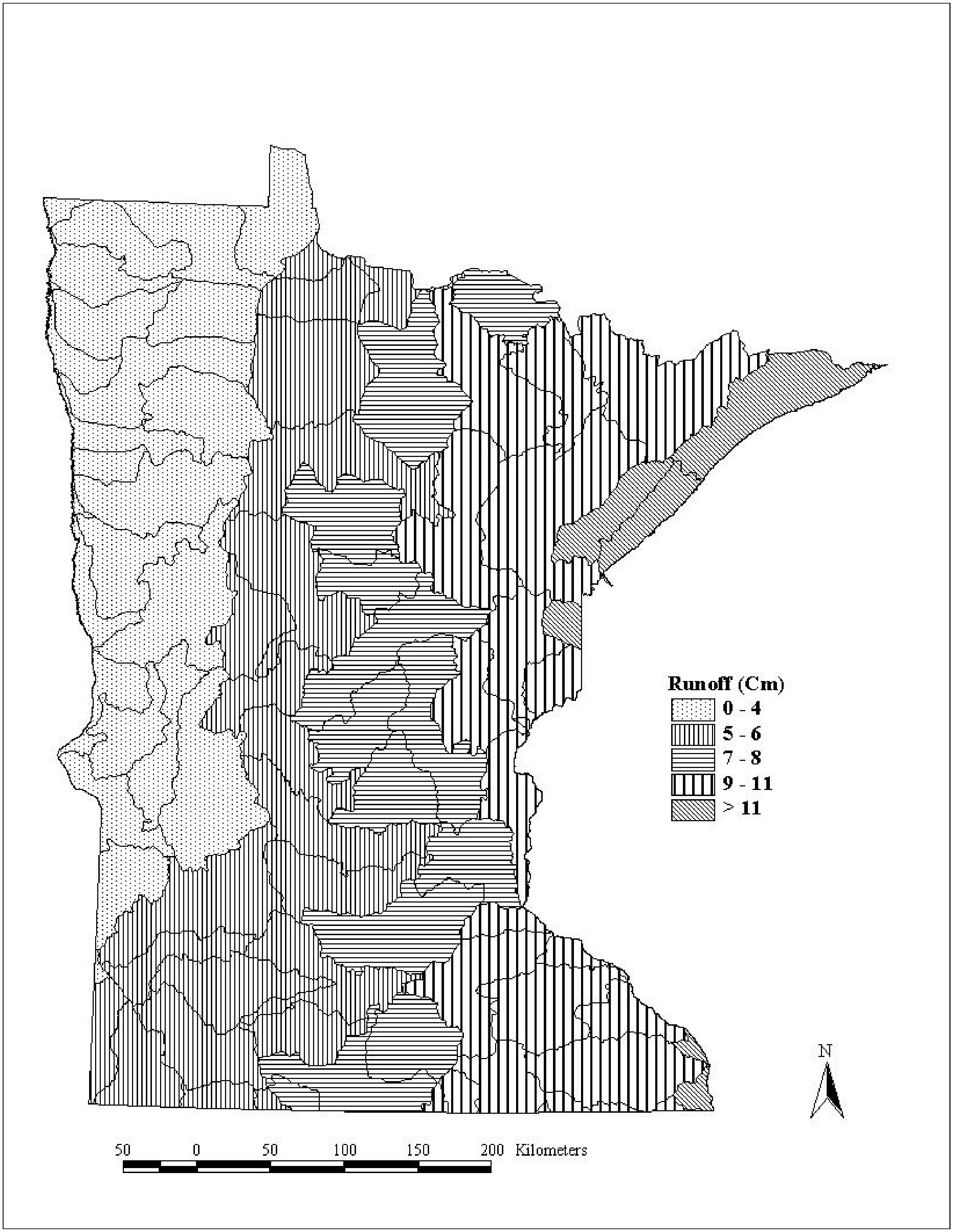

Fig. 8: Streamflow runoff yield estimates based on historical average hydrologic runoff volume for watersheds of Minnesota.

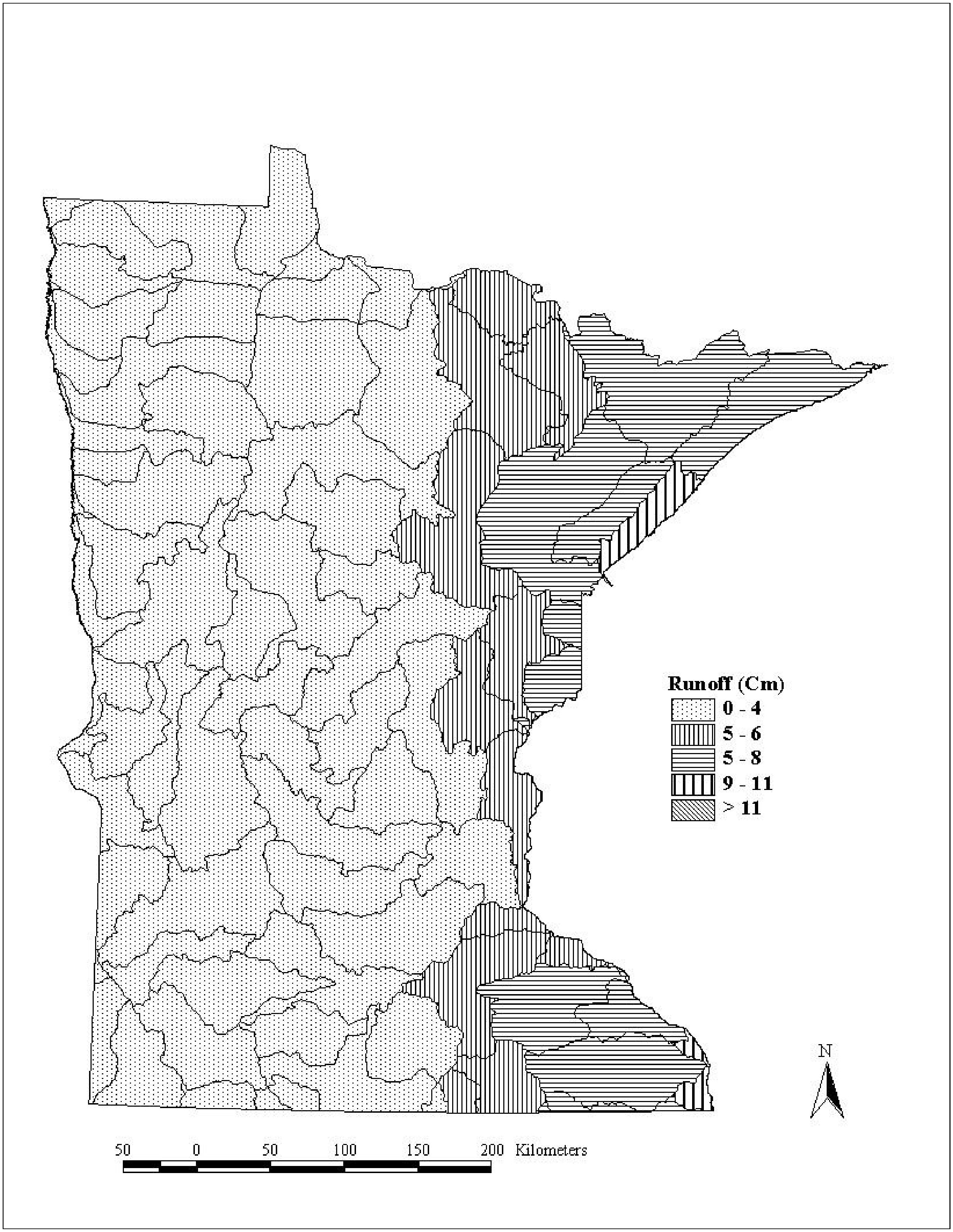

Fig. 9: Streamflow runoff yield estimates based on historical low hydrologic runoff volume for watersheds of Minnesota.

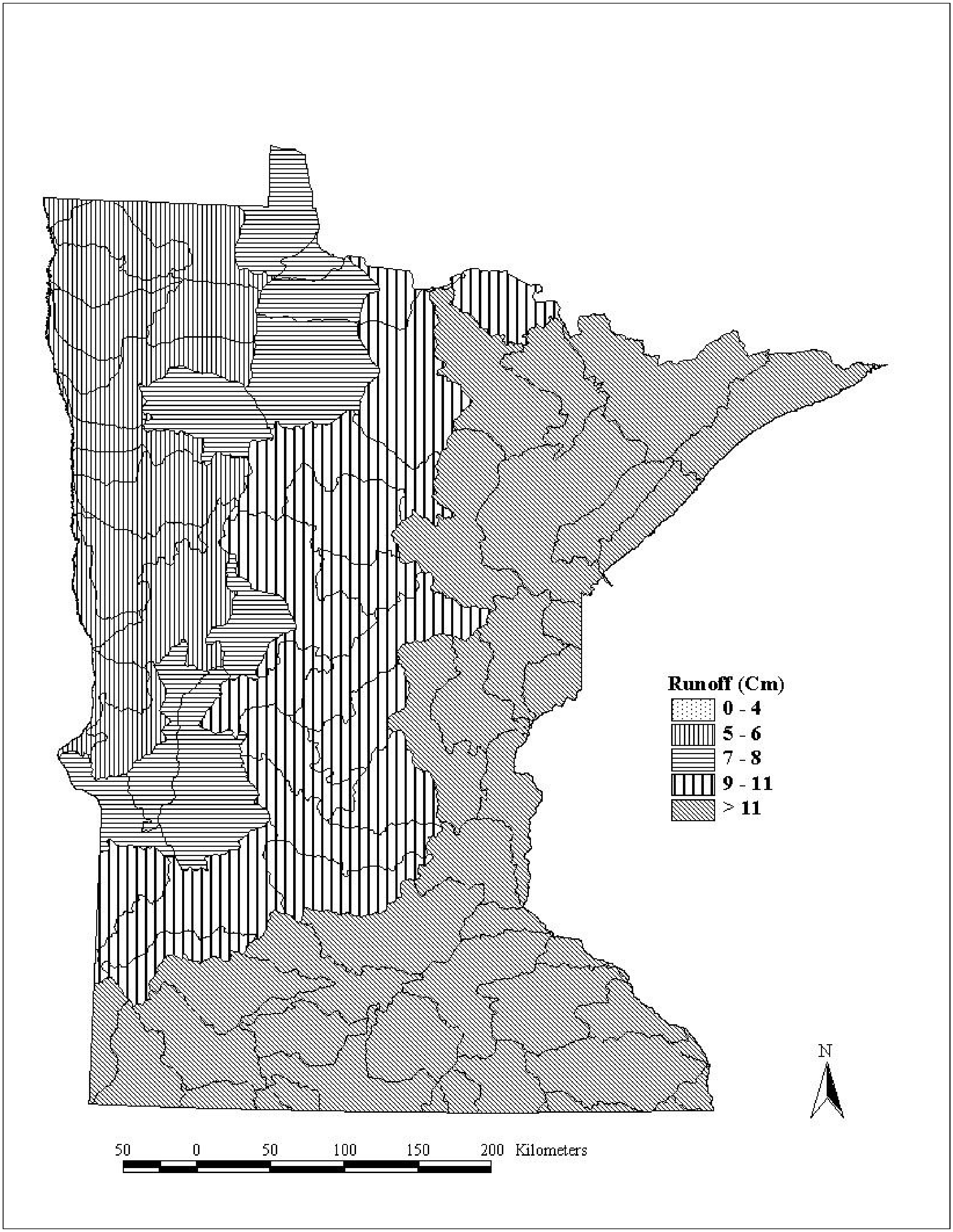

Fig. 10: Streamflow runoff yield estimates based on historical high hydrologic runoff volume for watersheds of Minnesota.

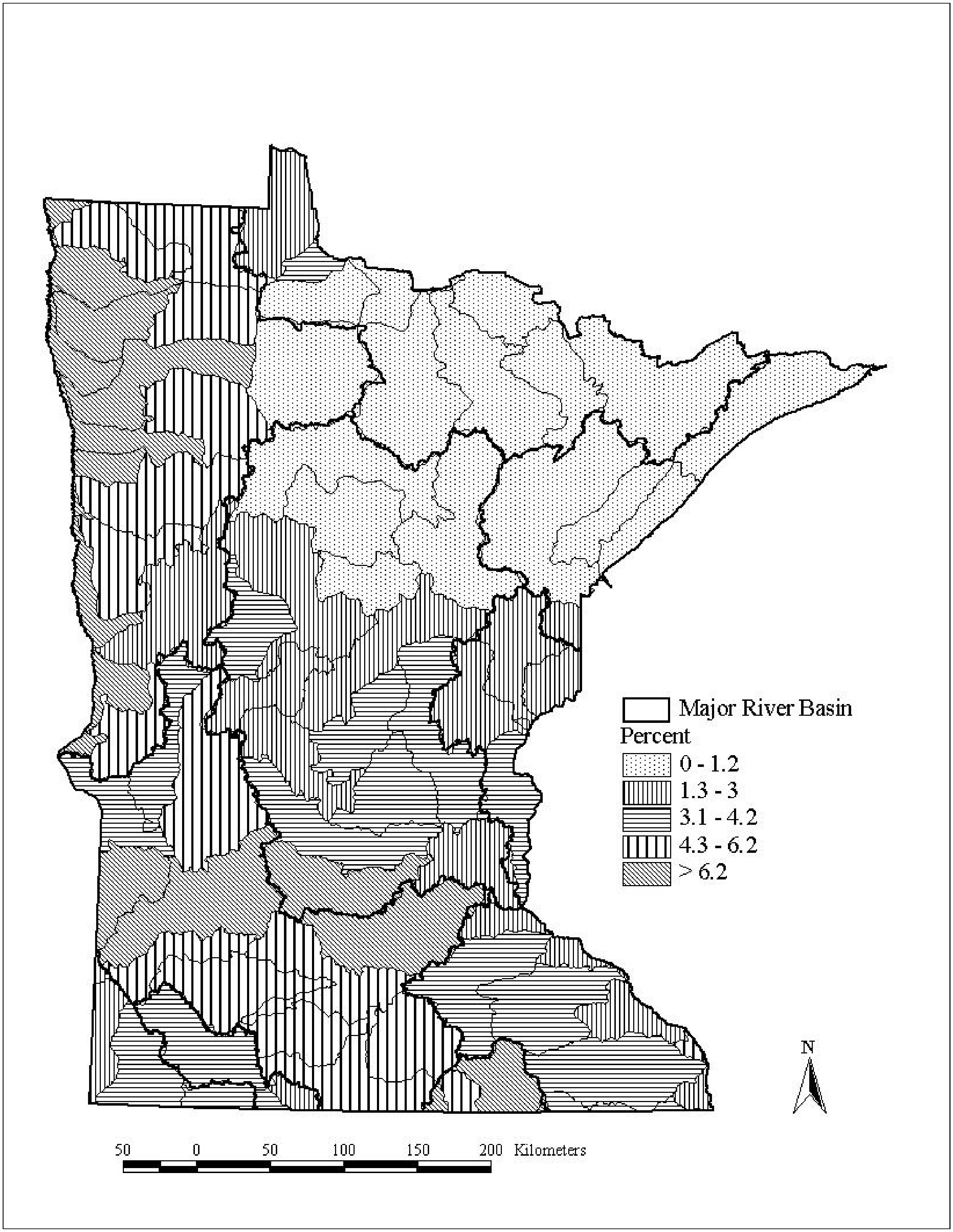

Fig. 11a: Percent of crop and pasture land within 300 ft of perennial streams and ditches for watersheds of Minnesota.

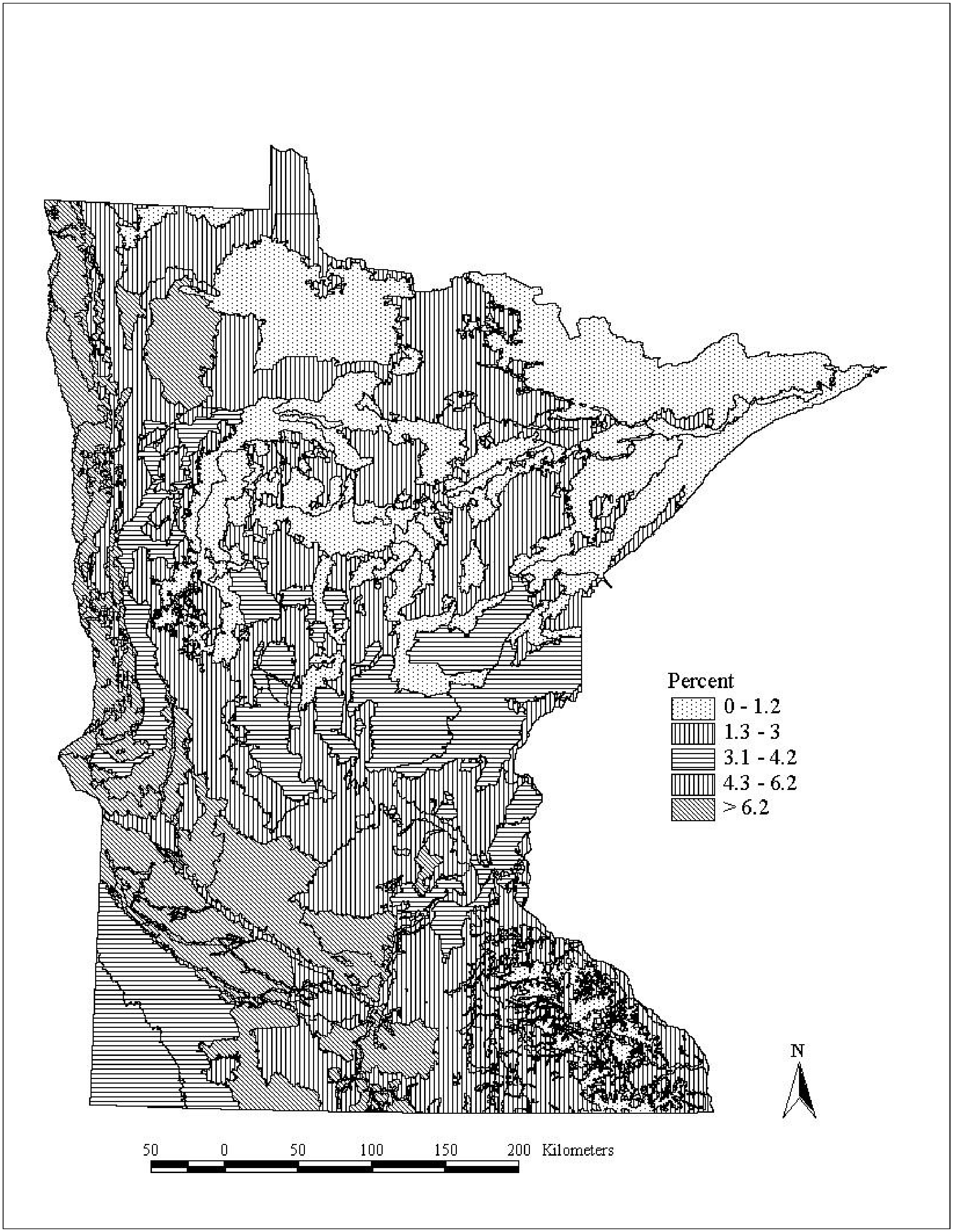

Fig. 11b: Percent of crop and pasture land within 300 ft of perennial streams and ditches for agroecoregions of Minnesota.

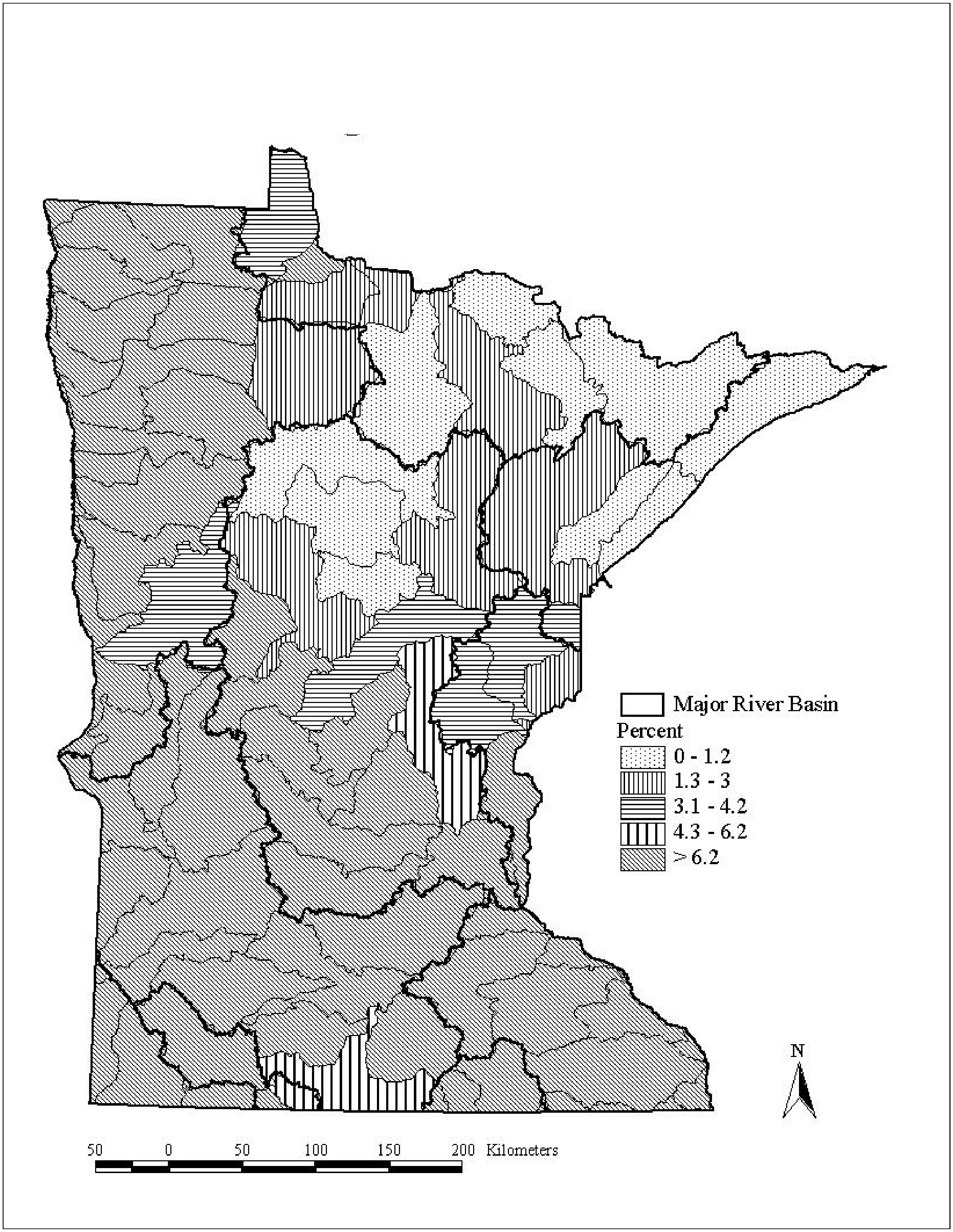

Fig. 12a: Percent of crop and pasture land within 300 ft of ditches, perennial and intermittent streams for watersheds of Minnesota.

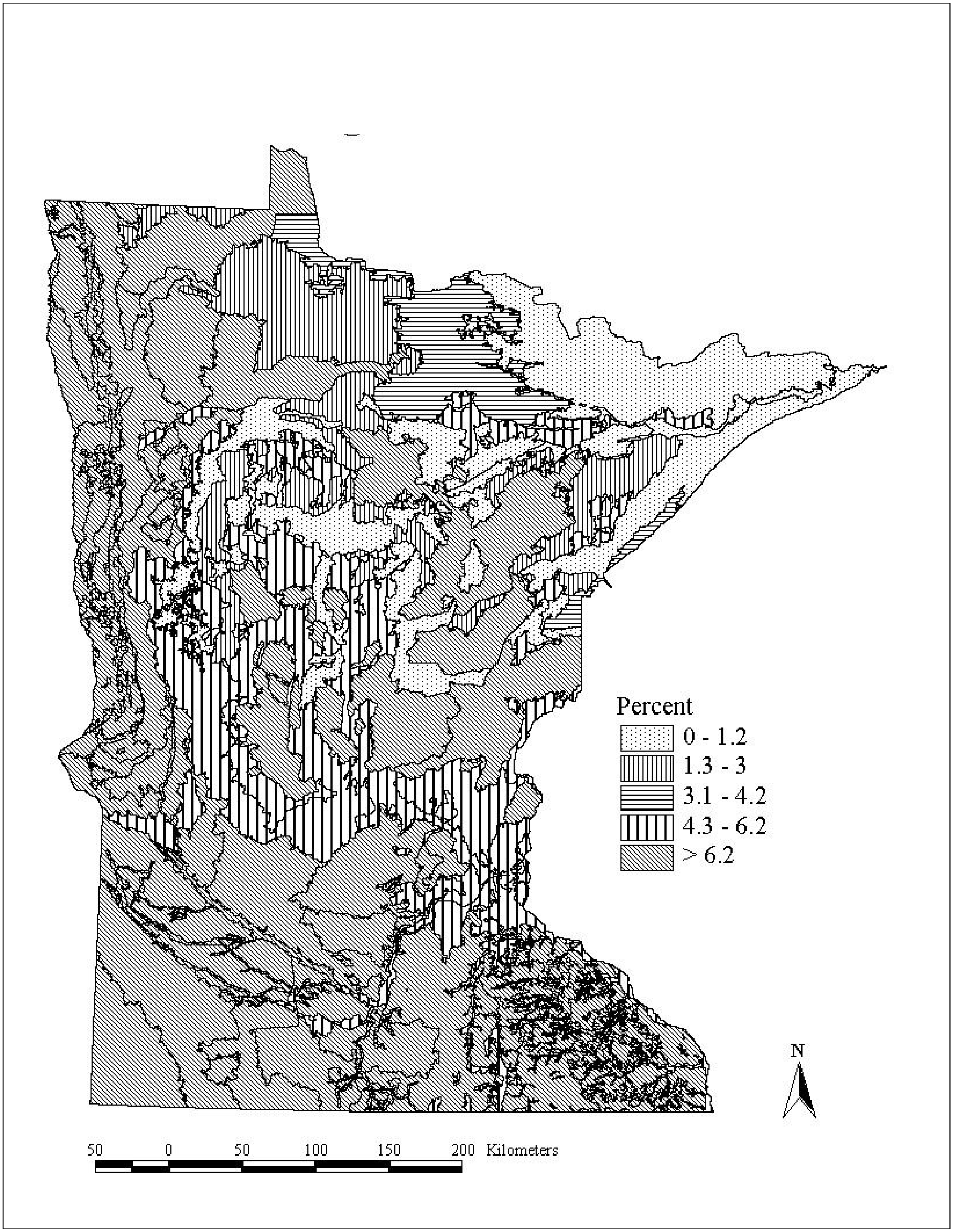

Fig. 12b: Percent of crop and pasture land within 300 ft of ditches, perennial and intermittent streams for agroecoregions of Minnesota.

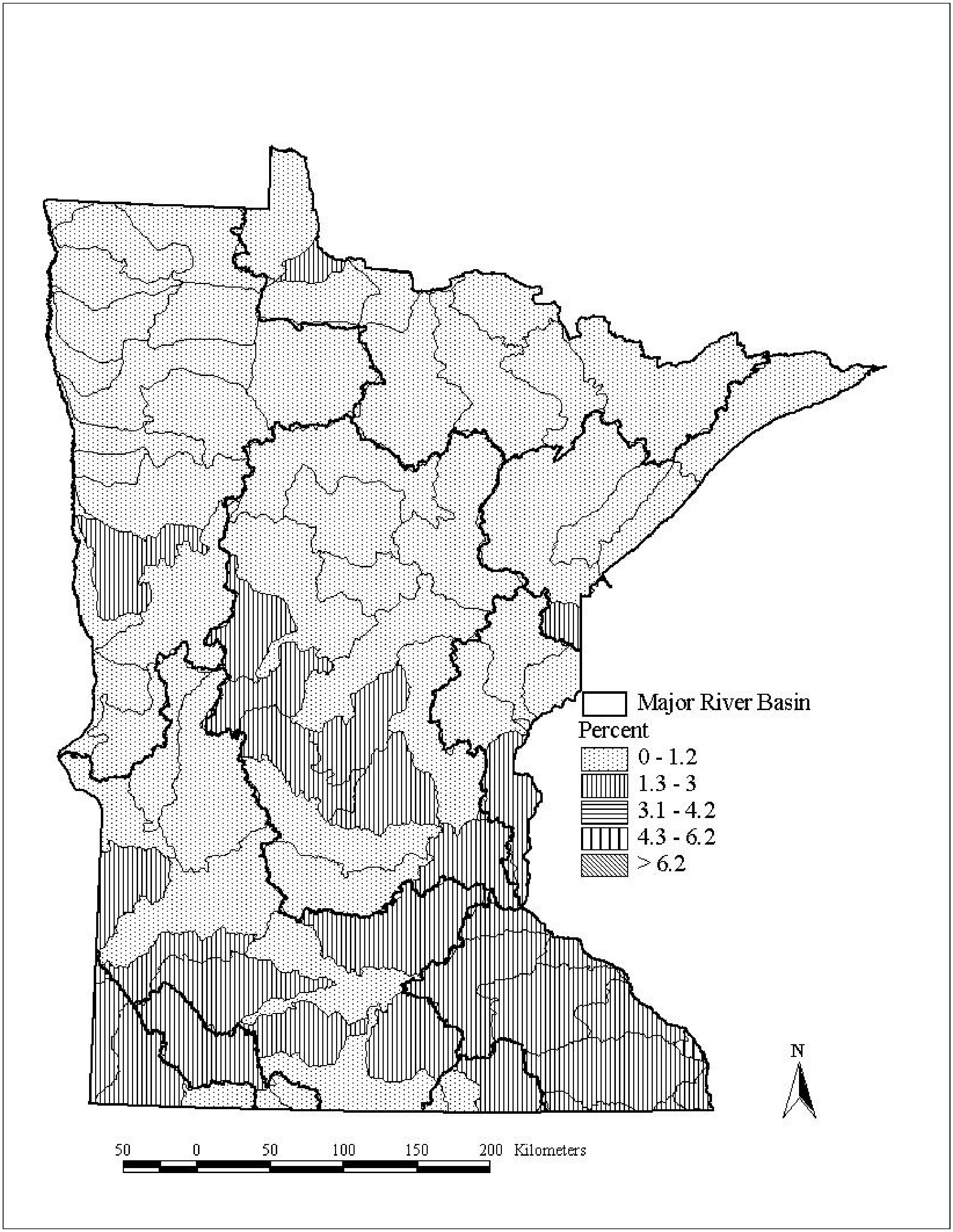

Fig. 13a: Percent of crop and pasture land within 300 ft of perennial streams for watersheds of Minnesota.

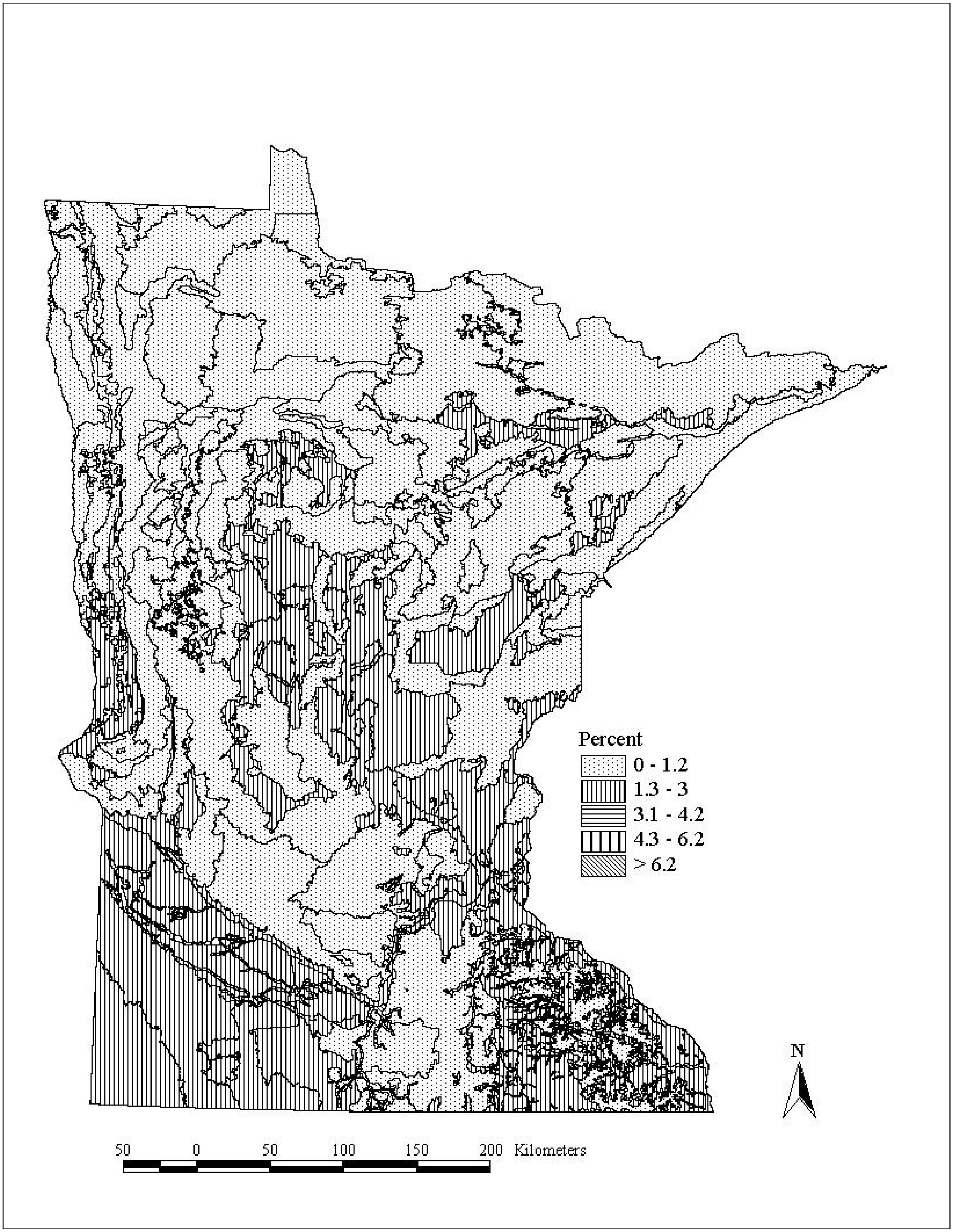

Fig. 13b: Percent of crop and pasture land within 300 ft of perennial streams for agroecoregions of Minnesota.

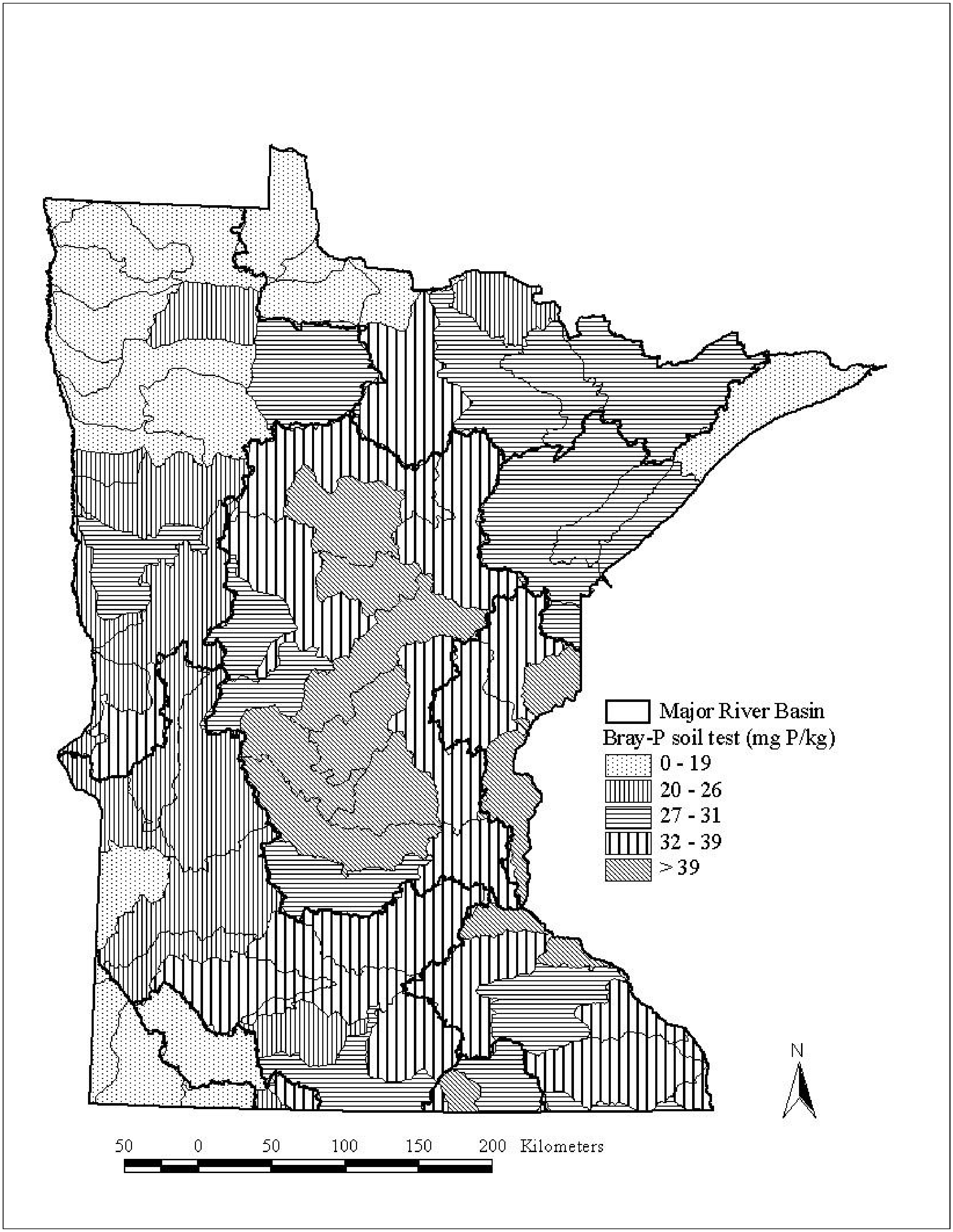

Fig. 14a: Average soil test phosphorus levels from the Bray-P extractant for watersheds of Minnesota.

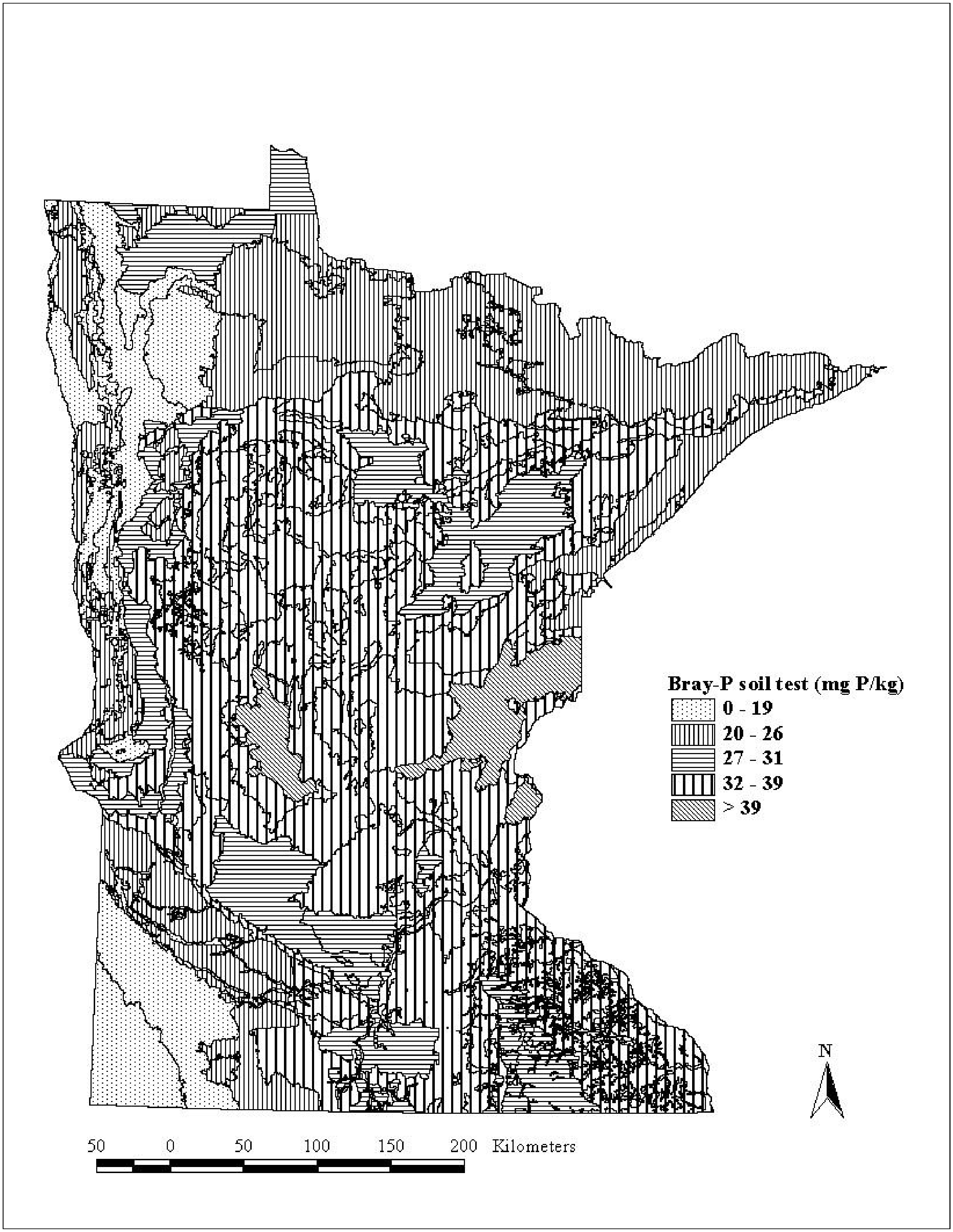

Fig. 14b: Average soil test phosphorus levels from the Bray-P extractant for agroecoregions of Minnesota.

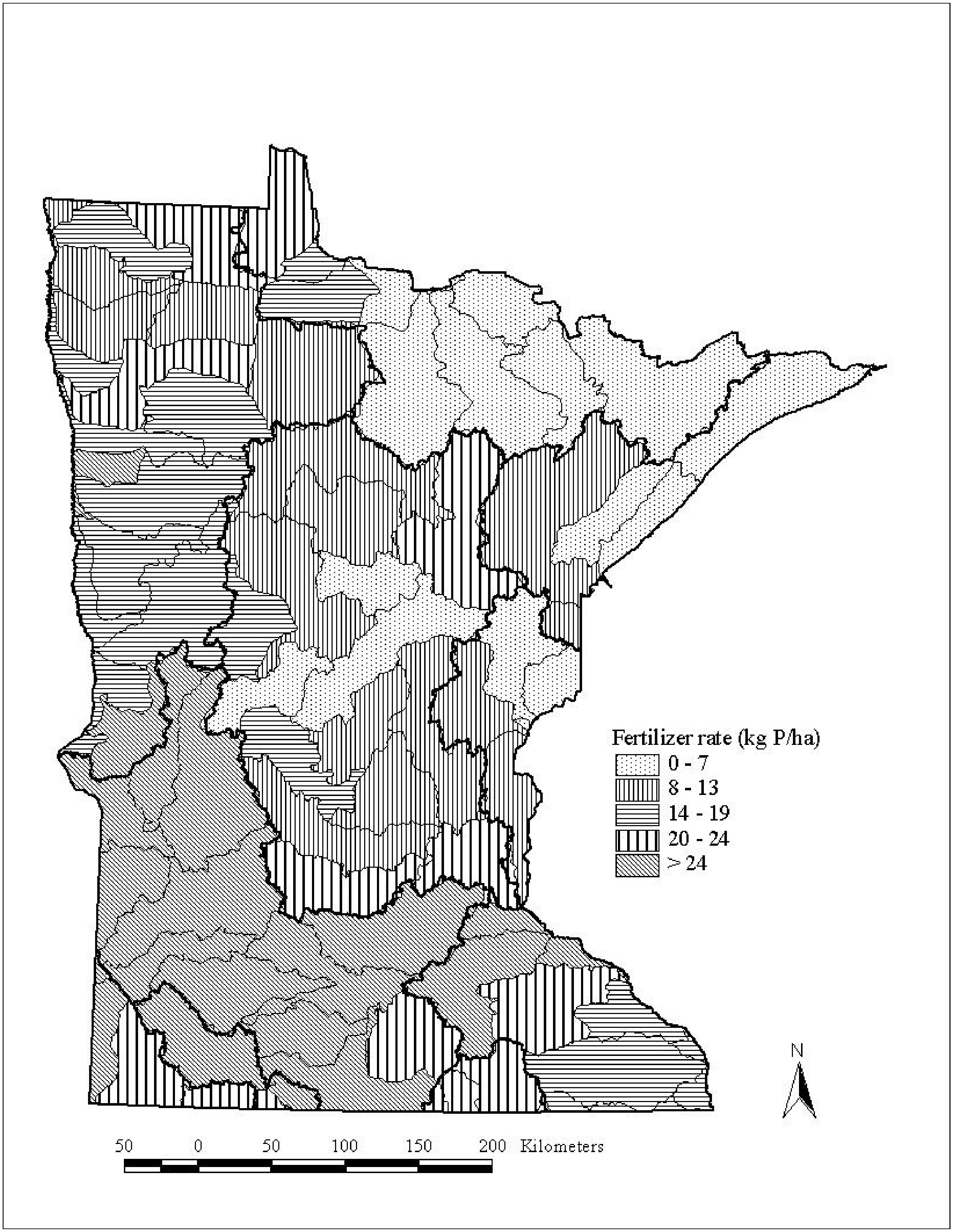

Fig. 15a: Average rates of fertilizer phosphorus application to fertilized crop land for watersheds of Minnesota.

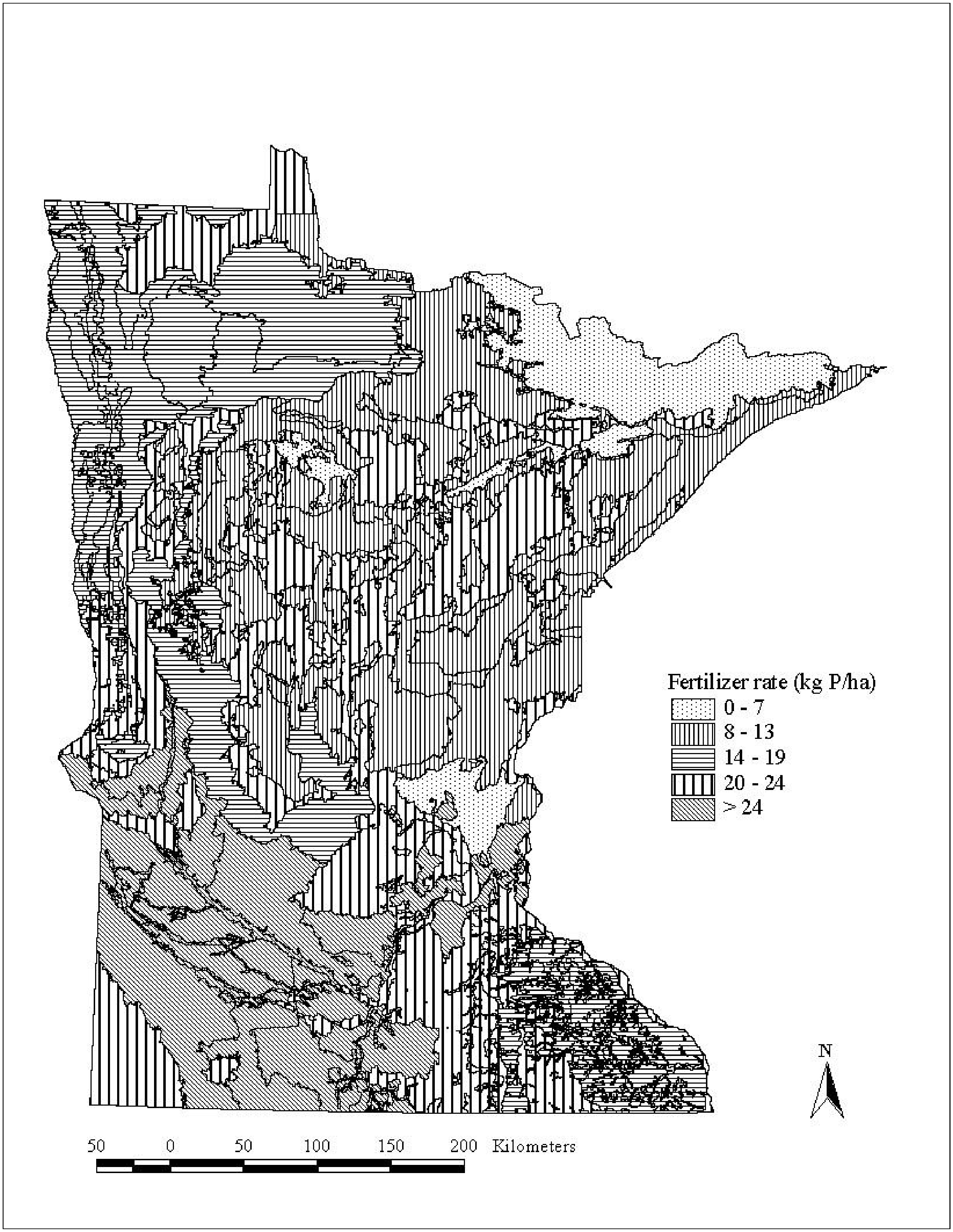

Fig. 15b: Average rates of fertilizer phosphorus application to fertilized crop land for agroecoregions of Minnesota.

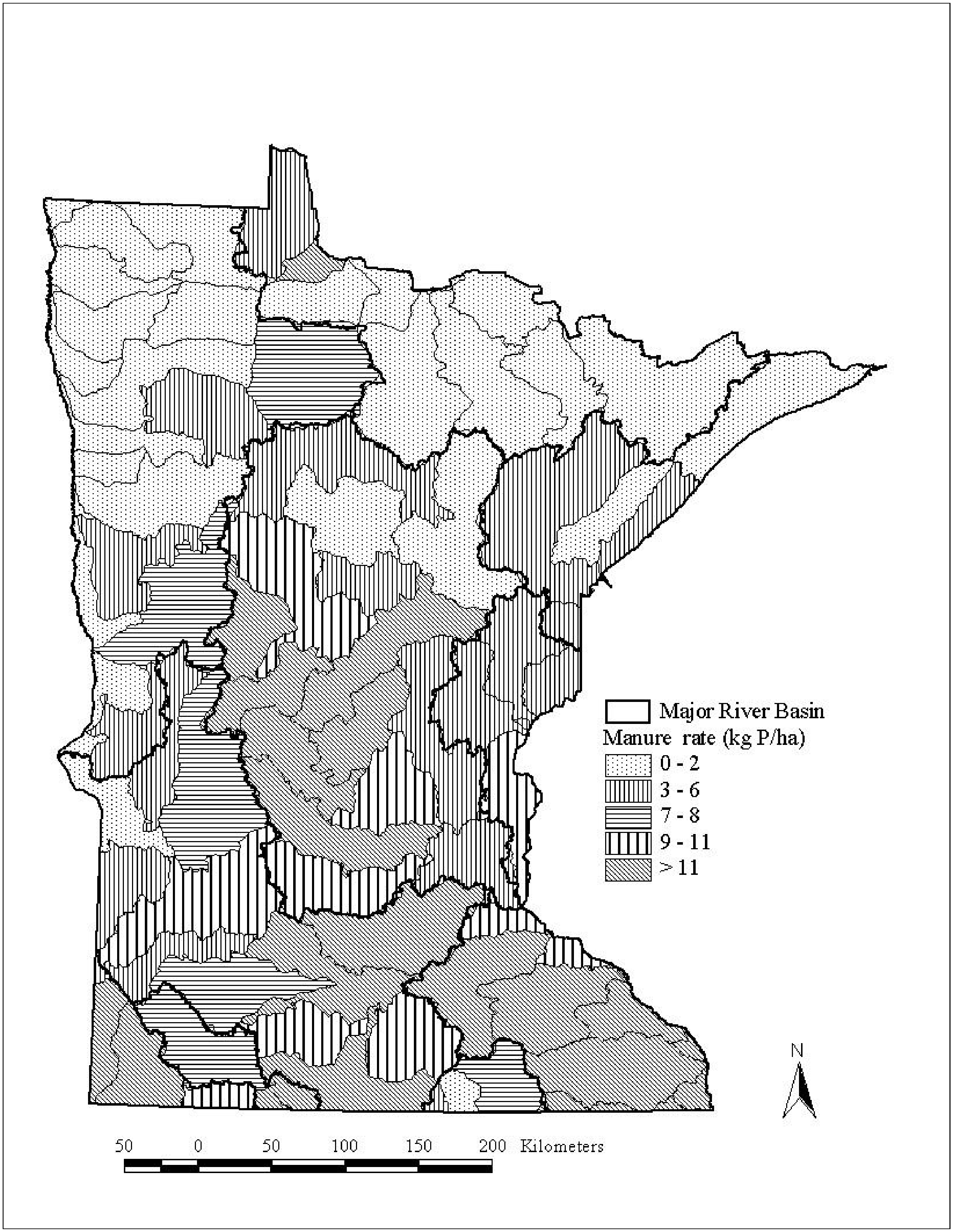

Fig. 16a: Average rates of manure phosphorus application to cropland for watersheds of Minnesota.

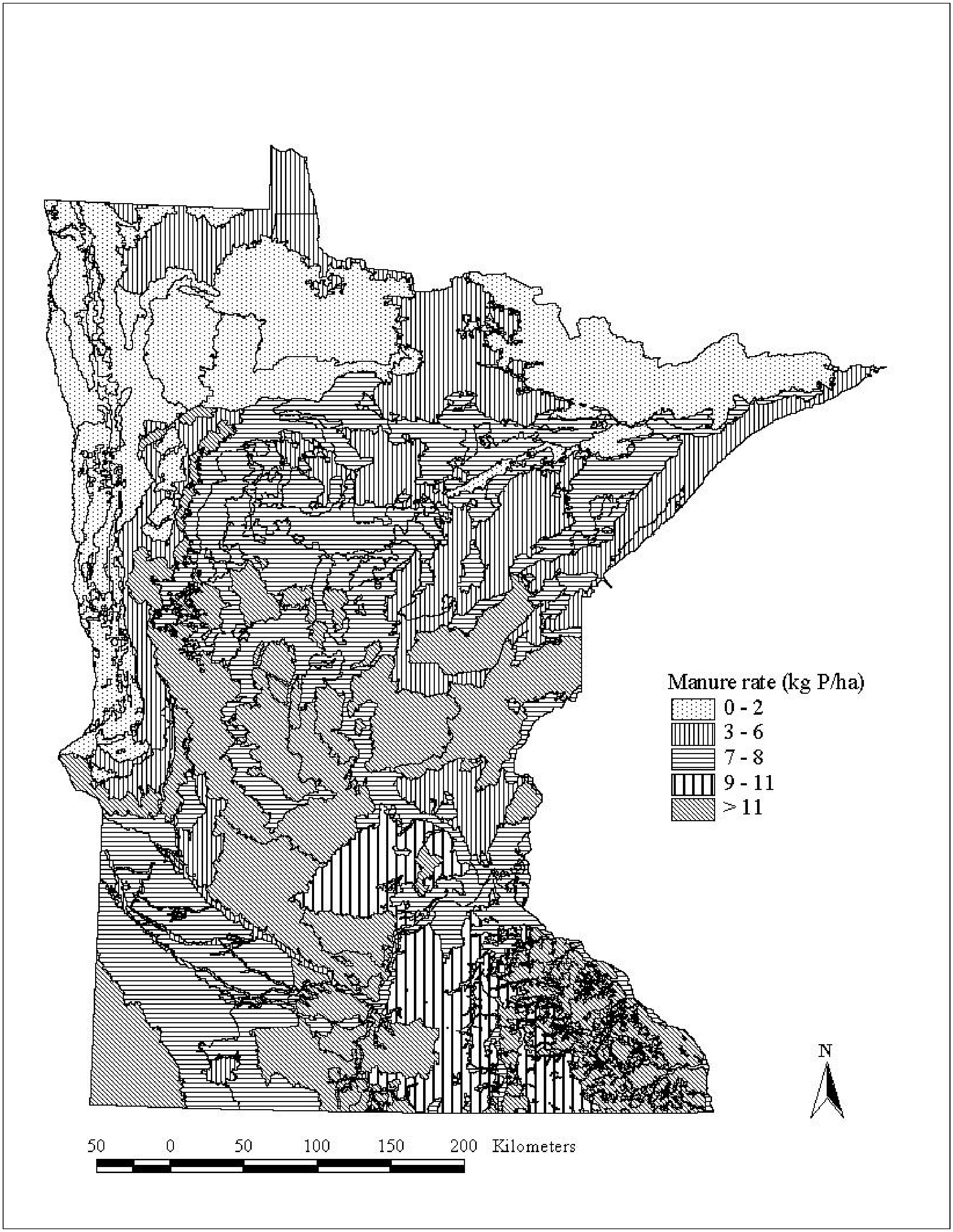

Fig. 16b: Average rates of manure phosphorus application to cropland for agroecoregions of Minnesota.

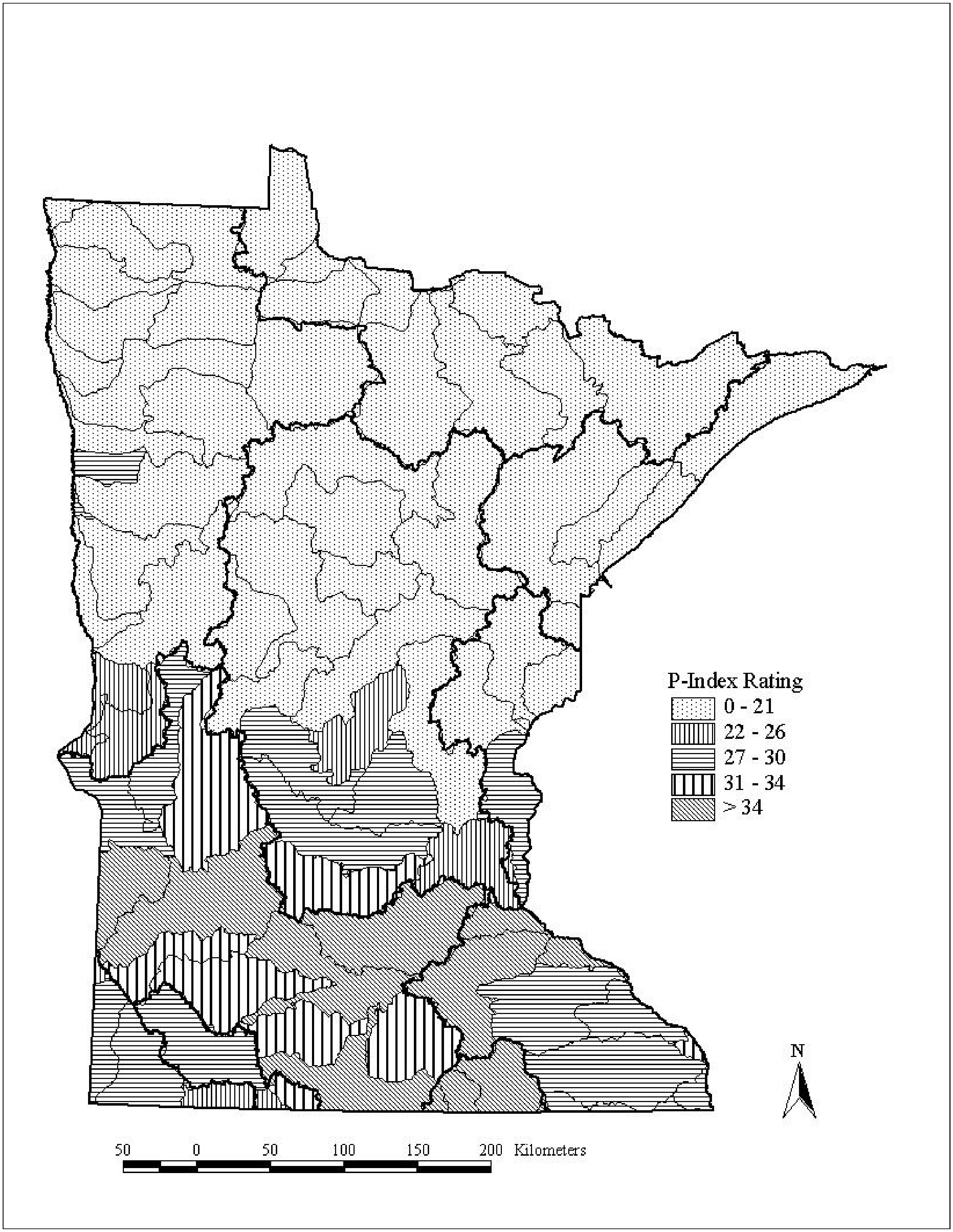

Fig. 17a: Phosphorus index values based on average hydrologic runoff volume, average rainfall runoff erosivity, a 300 ft buffer around perennial streams and ditches, and poor crop residue cover management conditions for watersheds of Minnesota.

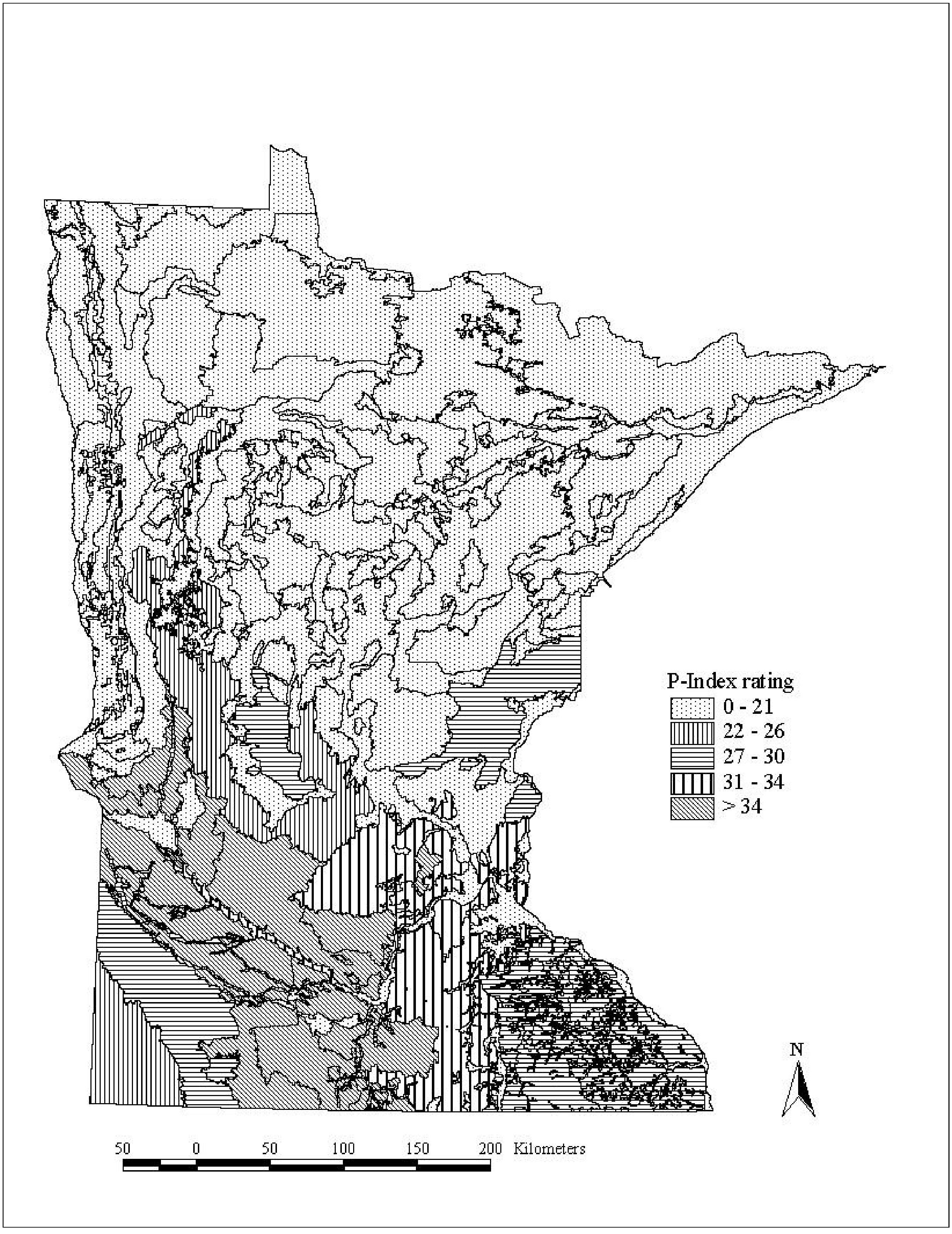

Fig. 17b: Phosphorus index values based on average hydrologic runoff volume, average rainfall runoff erosivity, a 300 ft buffer around perennial streams and ditches, and poor crop residue cover management conditions for agroecoregions of Minnesota.

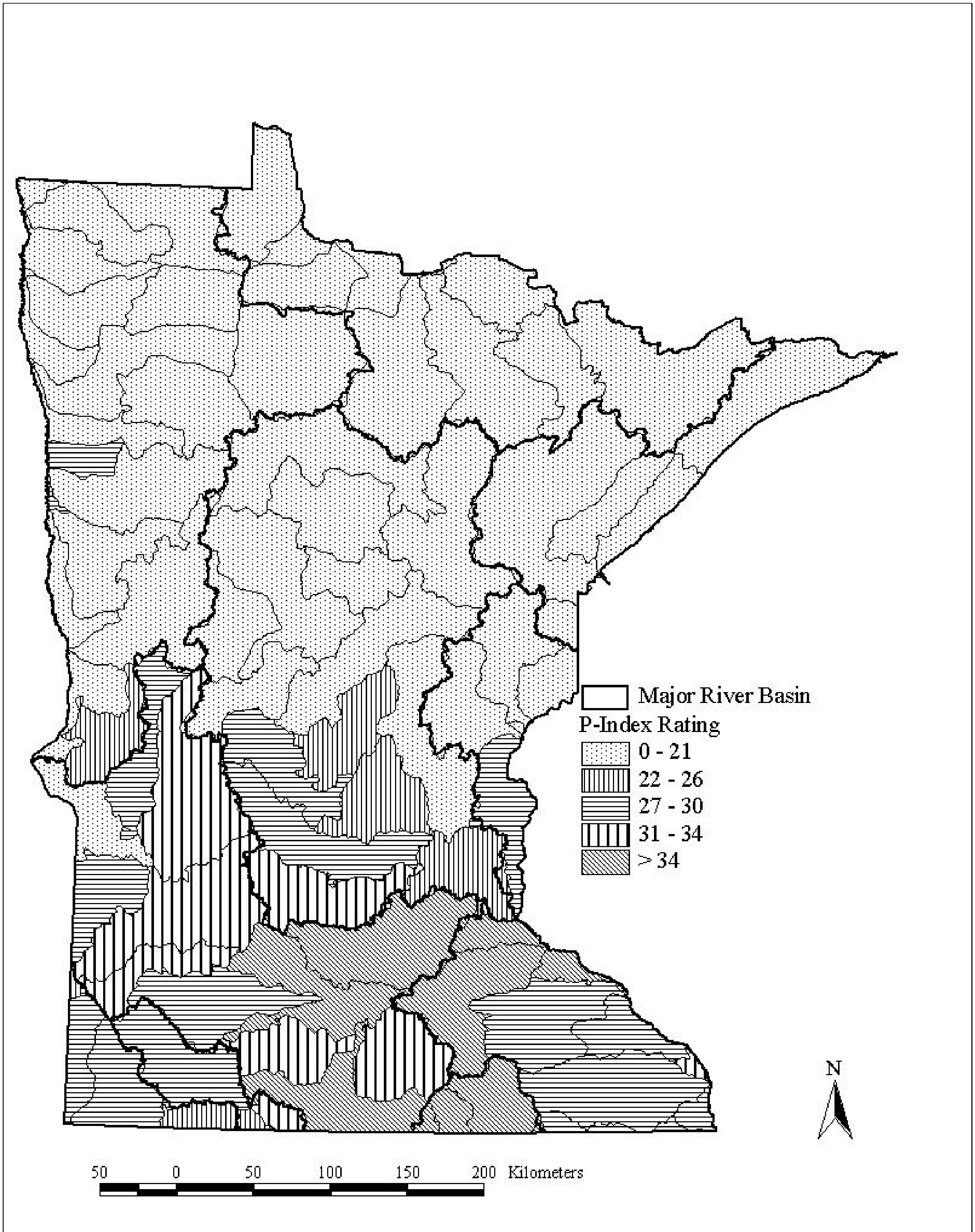

Fig. 18a: Phosphorus index values based on average hydrologic runoff volume, average rainfall runoff erosivity, a 300 ft buffer around perennial streams and ditches, and average crop residue cover management conditions for watersheds of Minnesota.

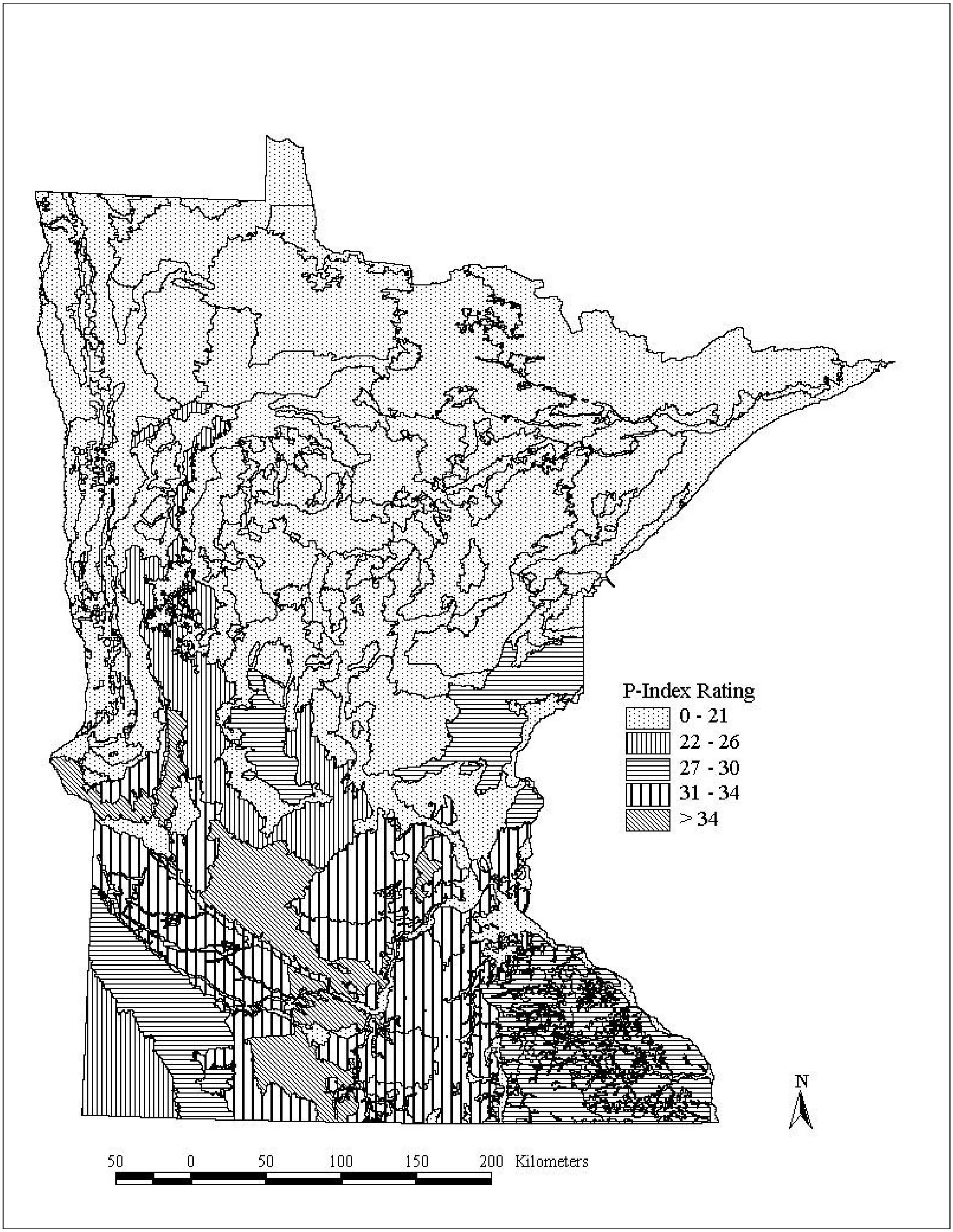

Fig. 18b: Phosphorus index values based on average hydrologic runoff volume, average rainfall runoff erosivity, a 300 ft buffer around perennial streams and ditches, and average crop residue cover management conditions for agroecoregions of Minnesota.

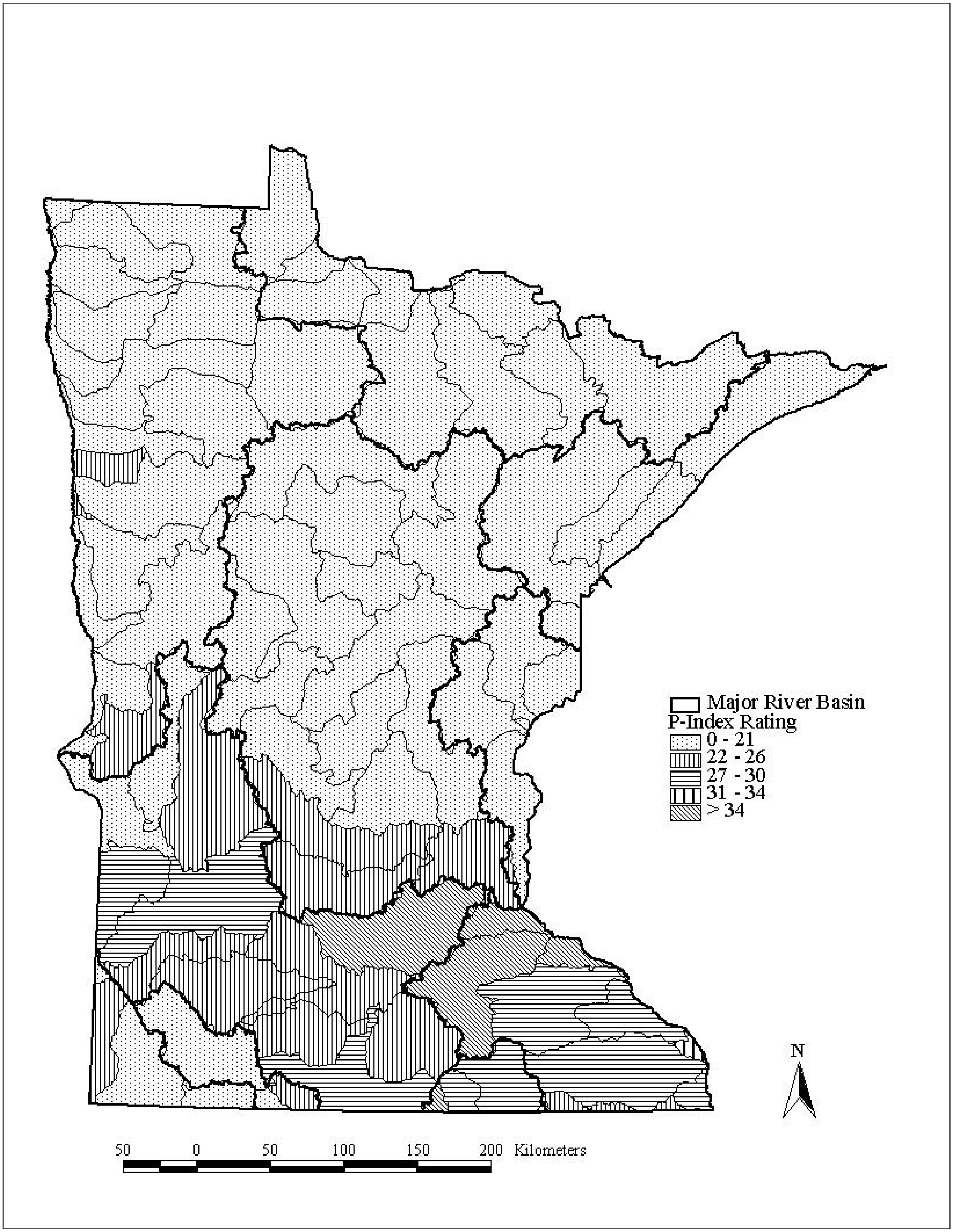

Fig. 19a: Phosphorus index values based on average hydrologic runoff volume, average rainfall runoff erosivity, a 300 ft buffer around perennial streams and ditches, and best crop residue cover management conditions for watersheds of Minnesota.

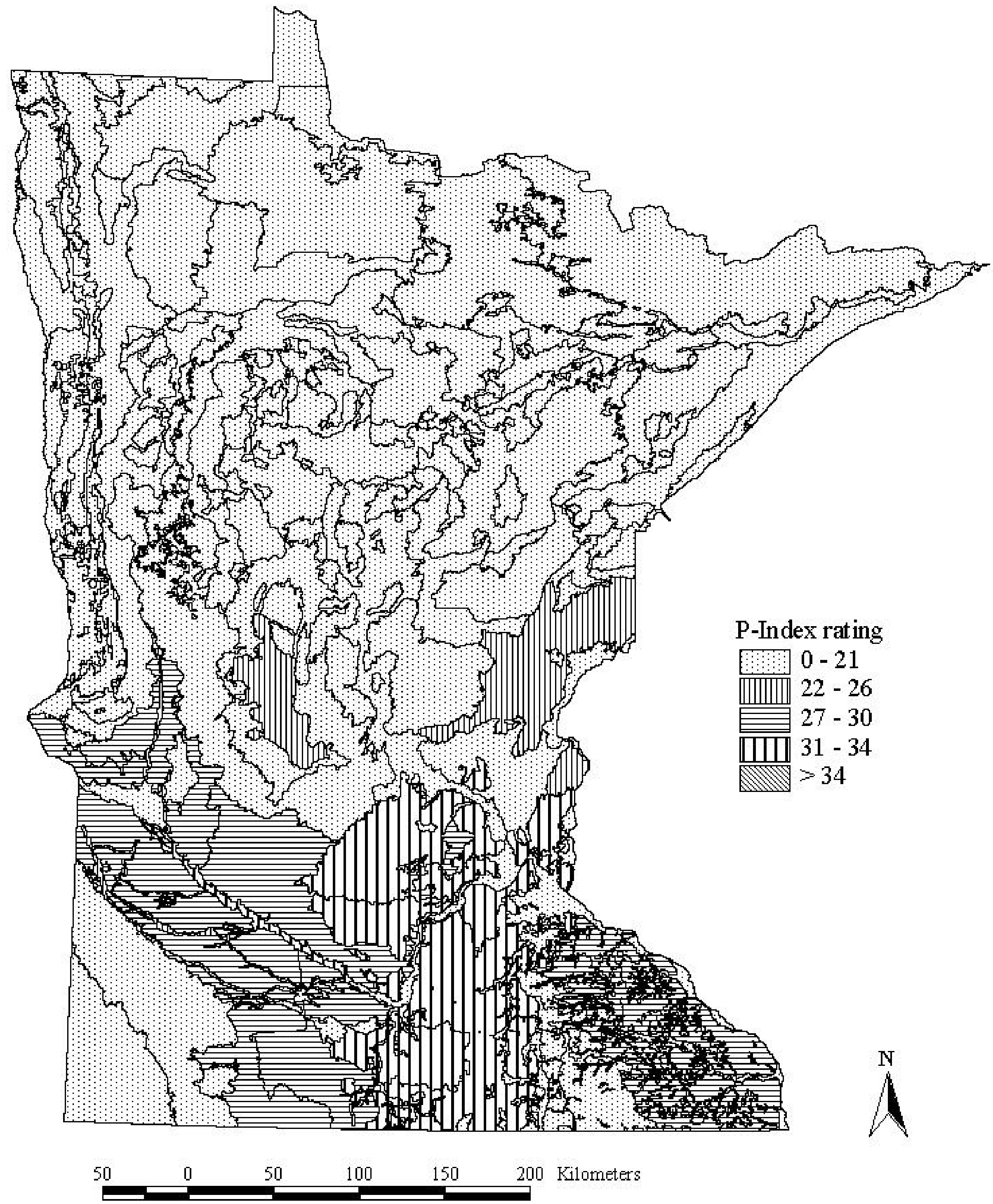

Fig. 19b: Phosphorus index values based on average hydrologic runoff volume, average rainfall runoff erosivity, a 300 ft buffer around perennial streams and ditches, and best crop residue cover management conditions for agroecoregions of Minnesota.

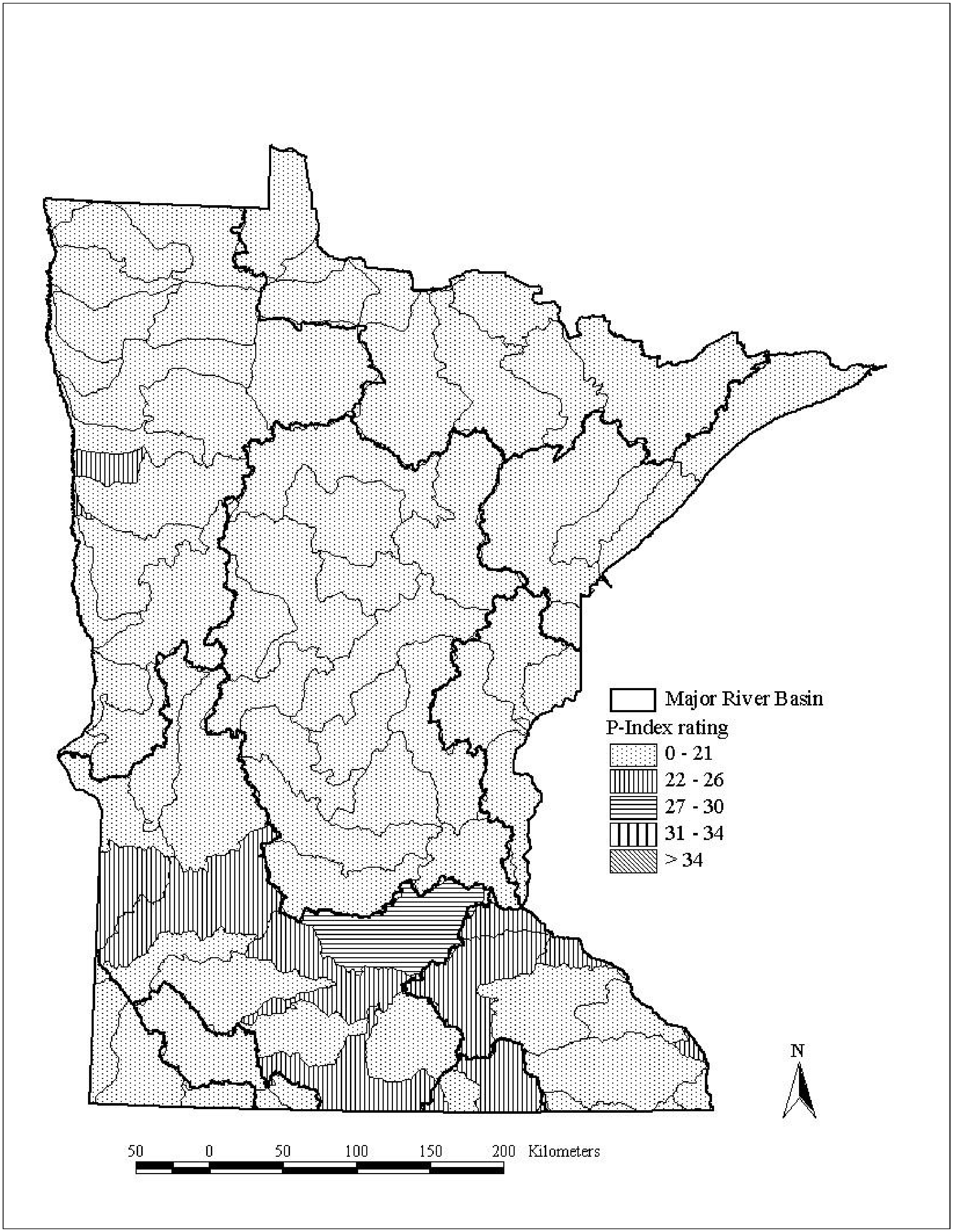

Fig. 20a: Phosphorus index values based on low hydrologic runoff volume, low rainfall runoff erosivity, a 300 ft buffer around perennial streams and ditches, and best crop residue cover management conditions for watersheds of Minnesota.

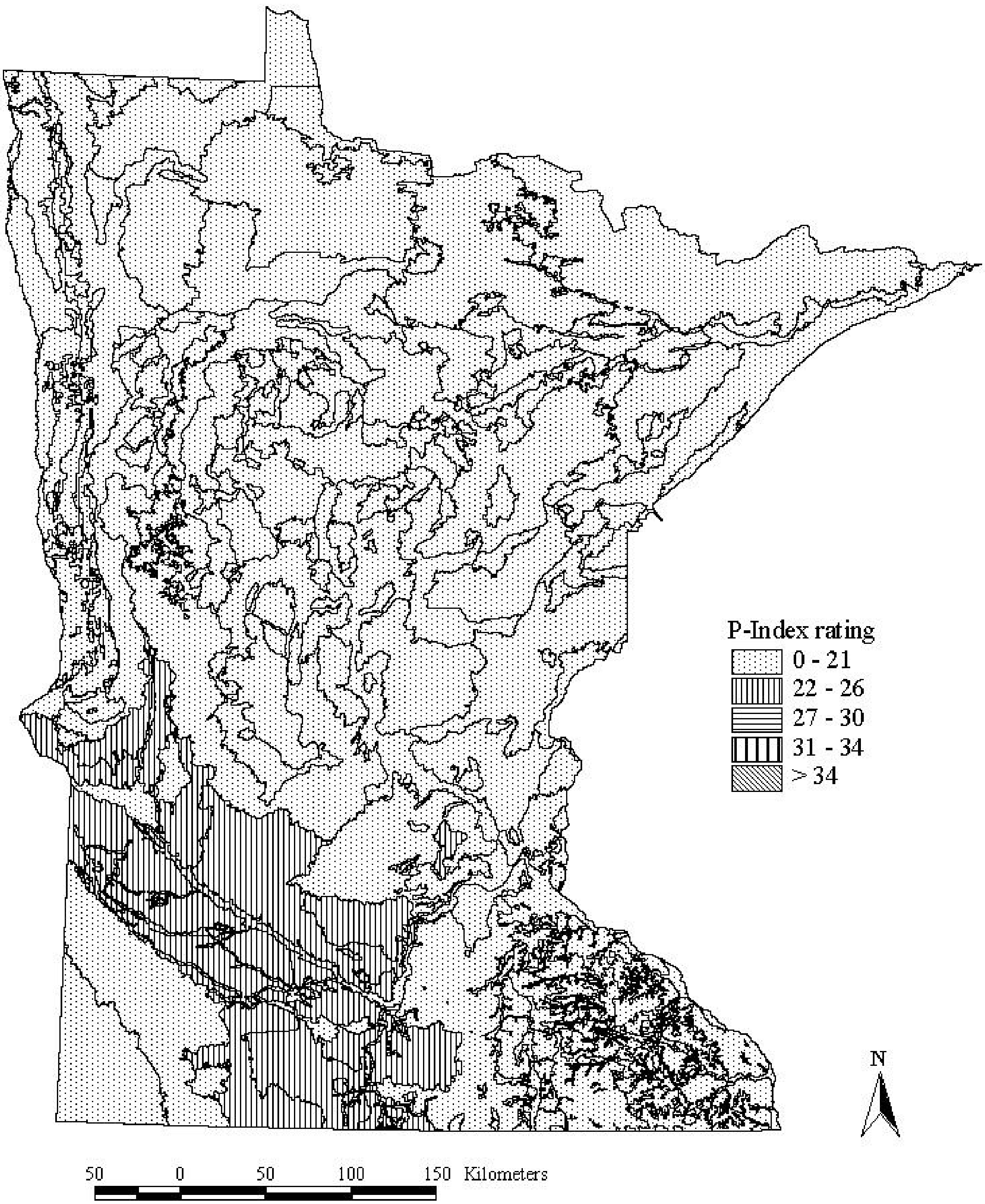

Fig. 20b: Phosphorus index values based on low hydrologic runoff volume, low rainfall runoff erosivity, a 300 ft buffer around perennial streams and ditches, and best crop residue cover management conditions for agroecoregions of Minnesota.

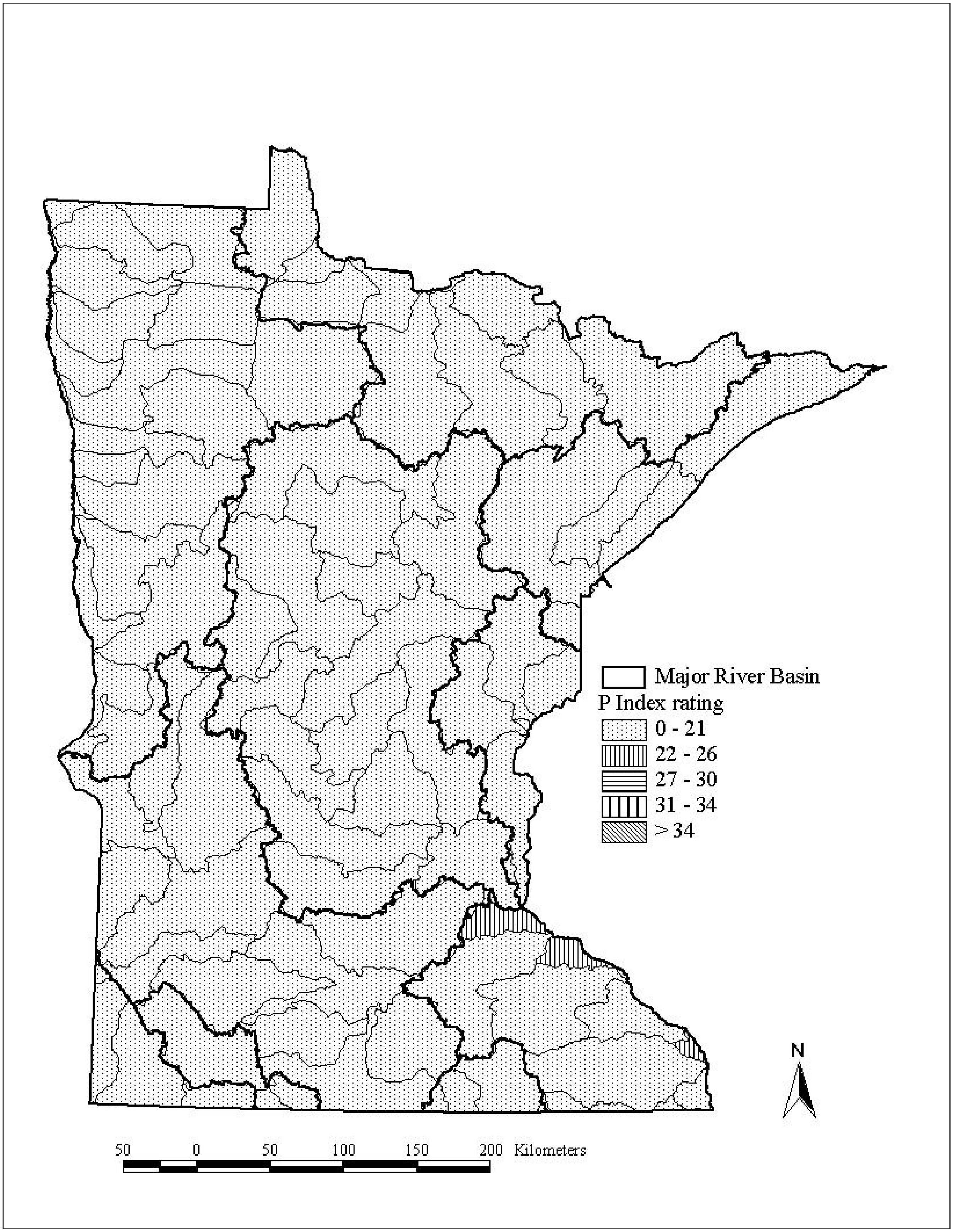

Fig. 21a: Phosphorus index values based on low hydrologic runoff volume, low rainfall runoff erosivity, a 300 ft buffer around perennial streams, and best crop residue cover management conditions for watersheds of Minnesota.

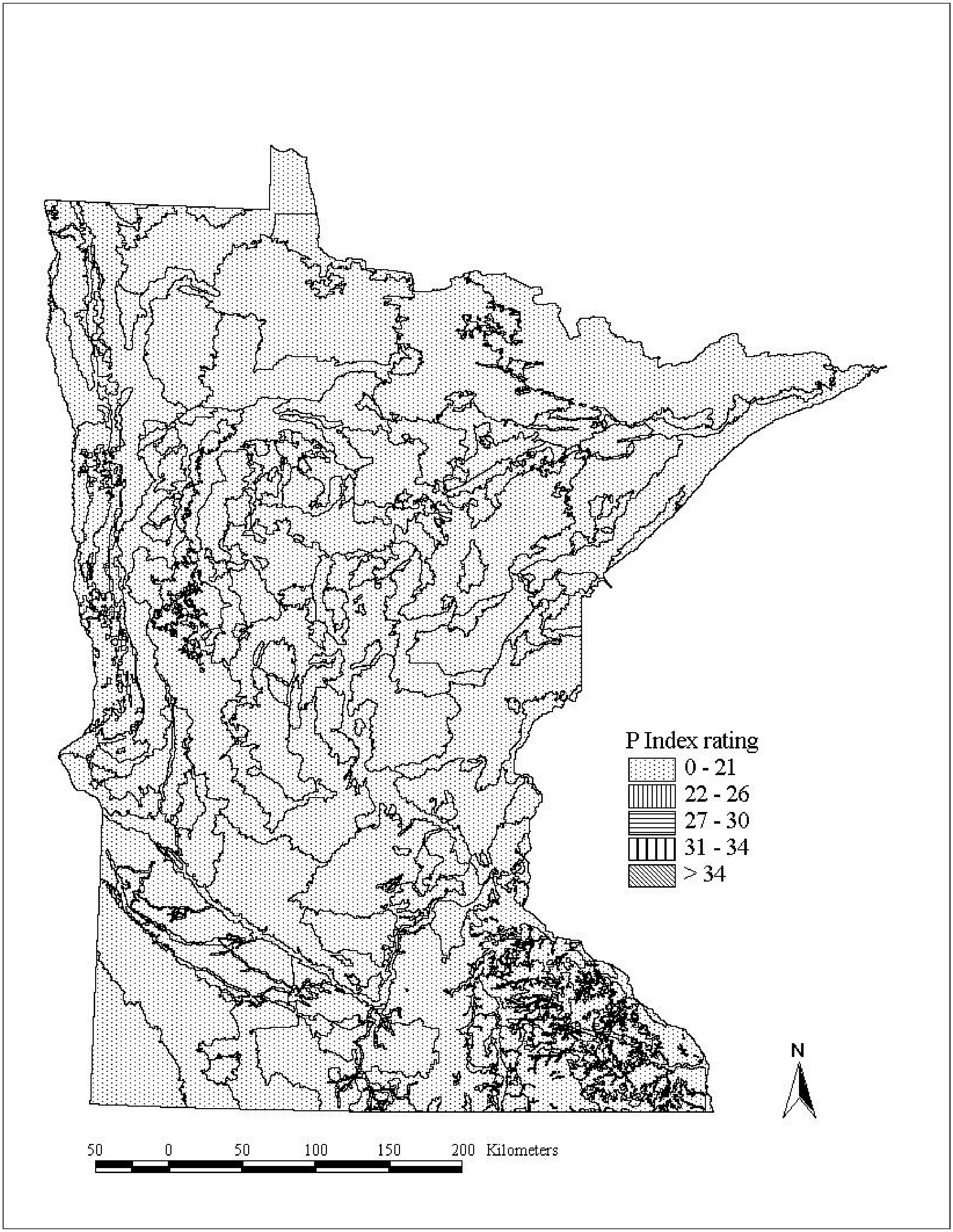

Fig. 21b: Phosphorus index values based on low hydrologic runoff volume, low rainfall runoff erosivity, a 300 ft buffer around perennial streams, and best crop residue cover management conditions for agroecoregions of Minnesota.

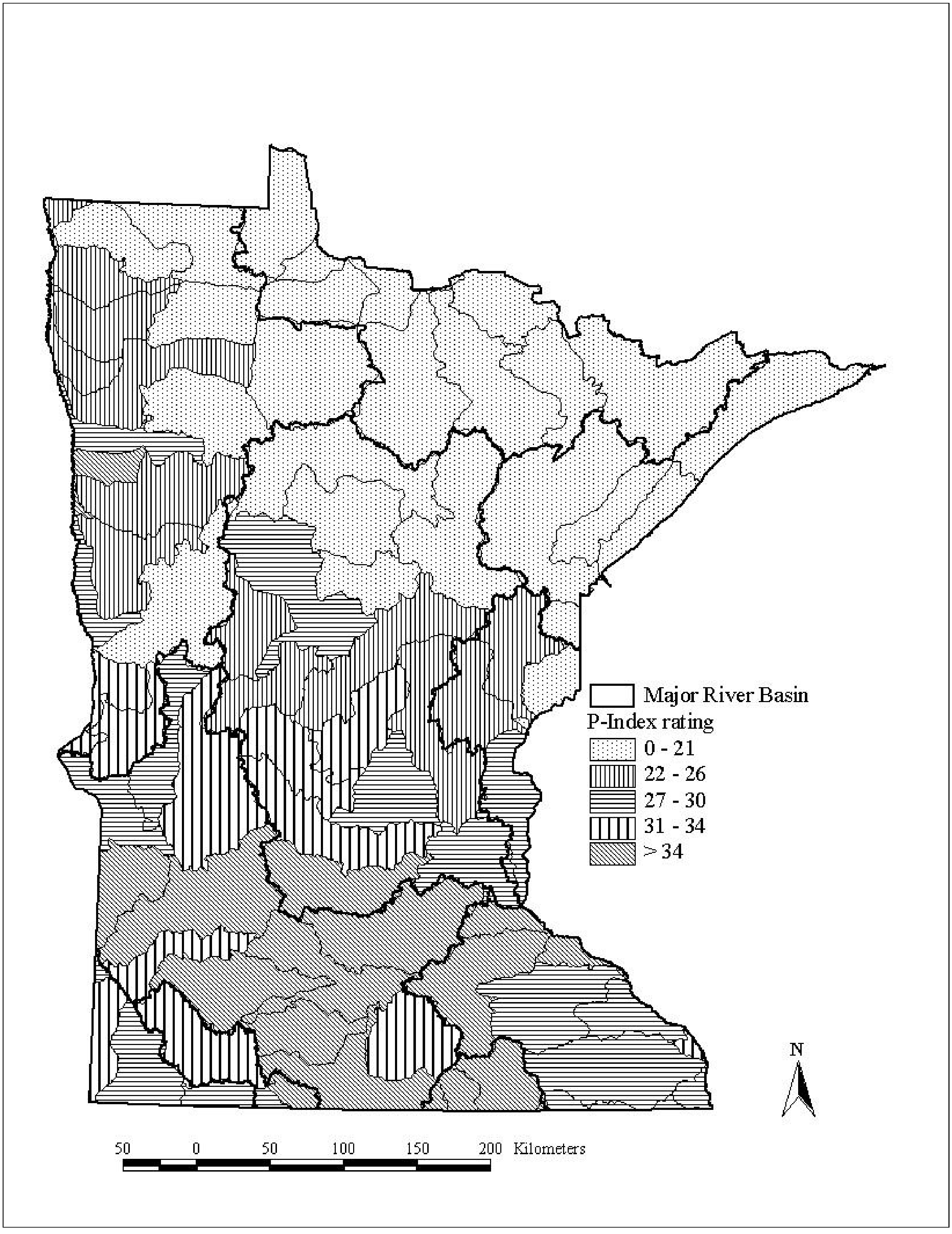

Fig. 22a: Phosphorus index values based on high hydrologic runoff volume, high rainfall runoff erosivity, a 300 ft buffer around perennial streams and ditches, and best crop residue cover management conditions for watersheds of Minnesota.

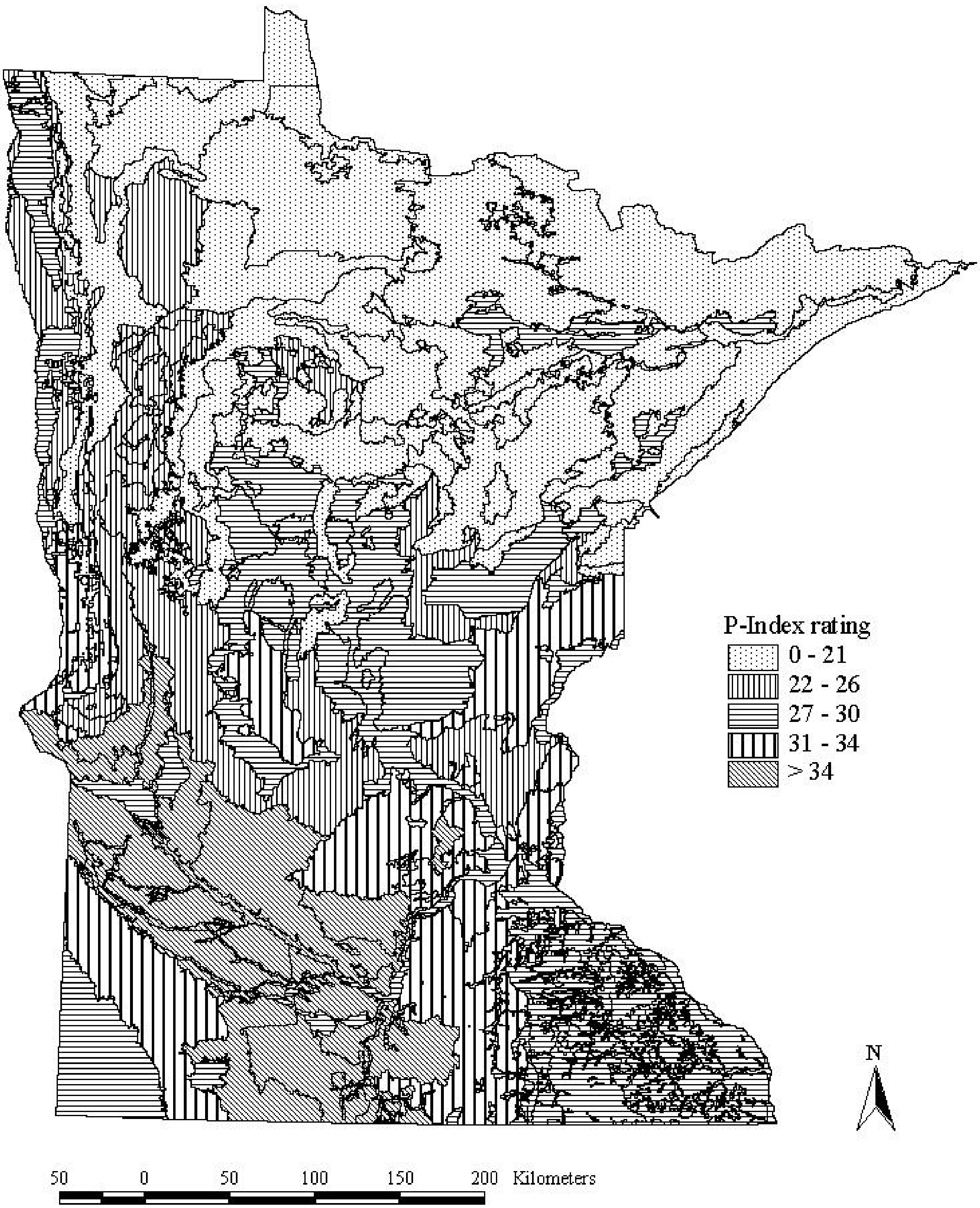

Fig. 22b: Phosphorus index values based on high hydrologic runoff volume, high rainfall runoff erosivity, a 300 ft buffer around perennial streams and ditches, and best crop residue cover management conditions for agroecoregions of Minnesota.

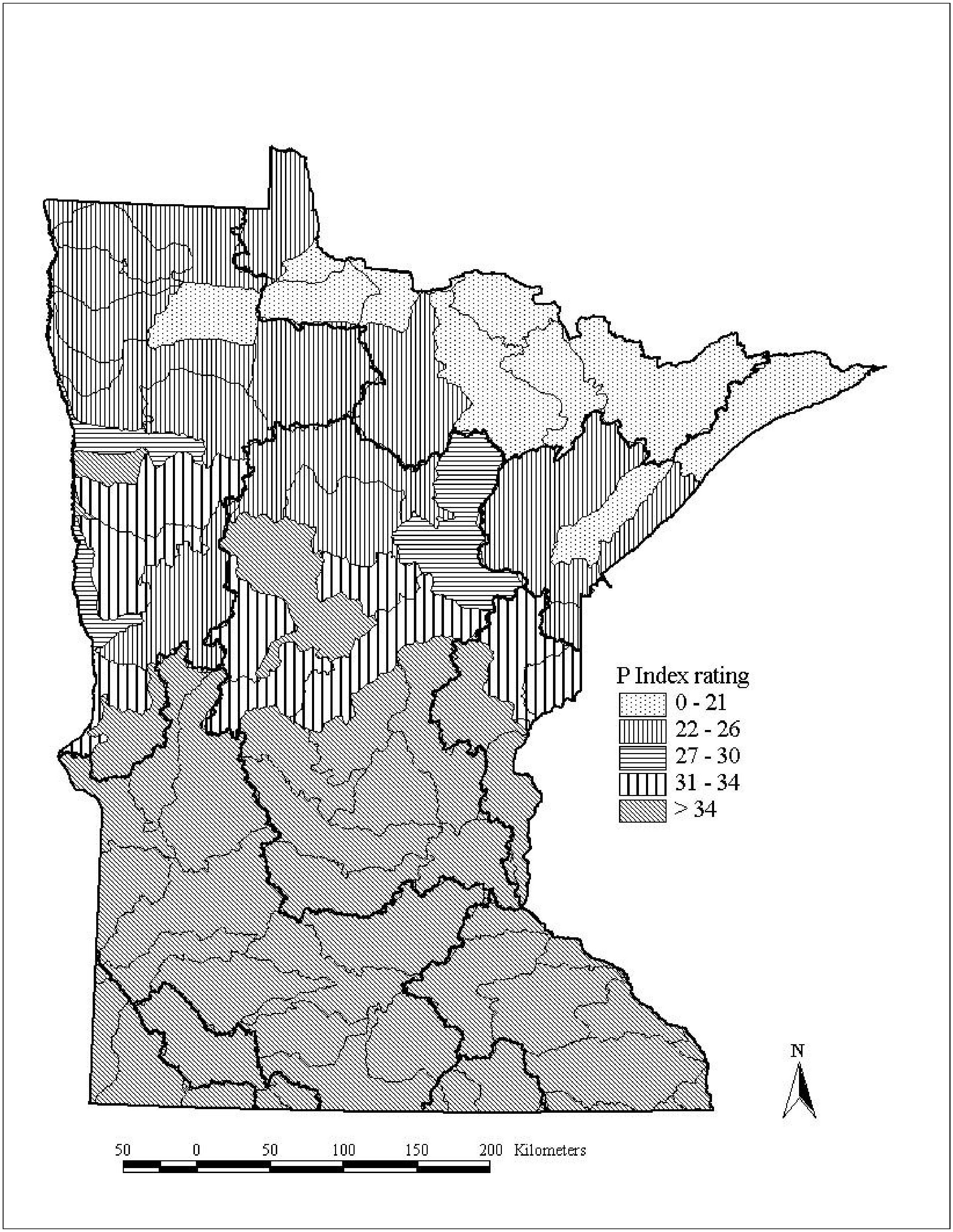

Fig. 23a: Phosphorus index values based on high hydrologic runoff volume, high rainfall runoff erosivity, a 300 ft buffer around all perennial and intermittent streams and ditches, and best crop residue cover management conditions for watersheds of Minnesota.

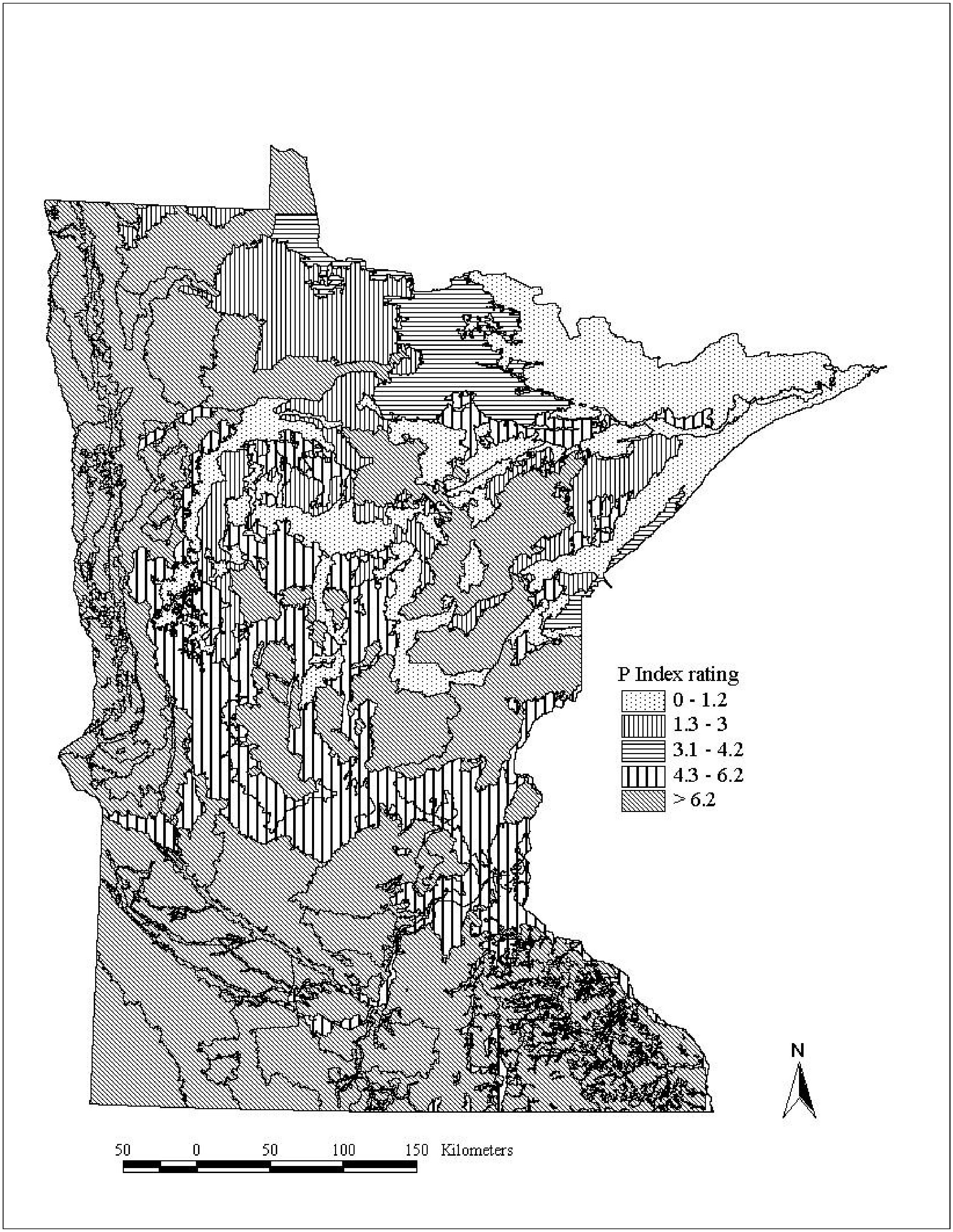

Fig. 23b: Phosphorus index values based on high hydrologic runoff volume, high rainfall runoff erosivity, a 300 ft buffer around all perennial and intermittent streams and ditches, and best crop residue cover management conditions for agroecoregions of Minnesota.

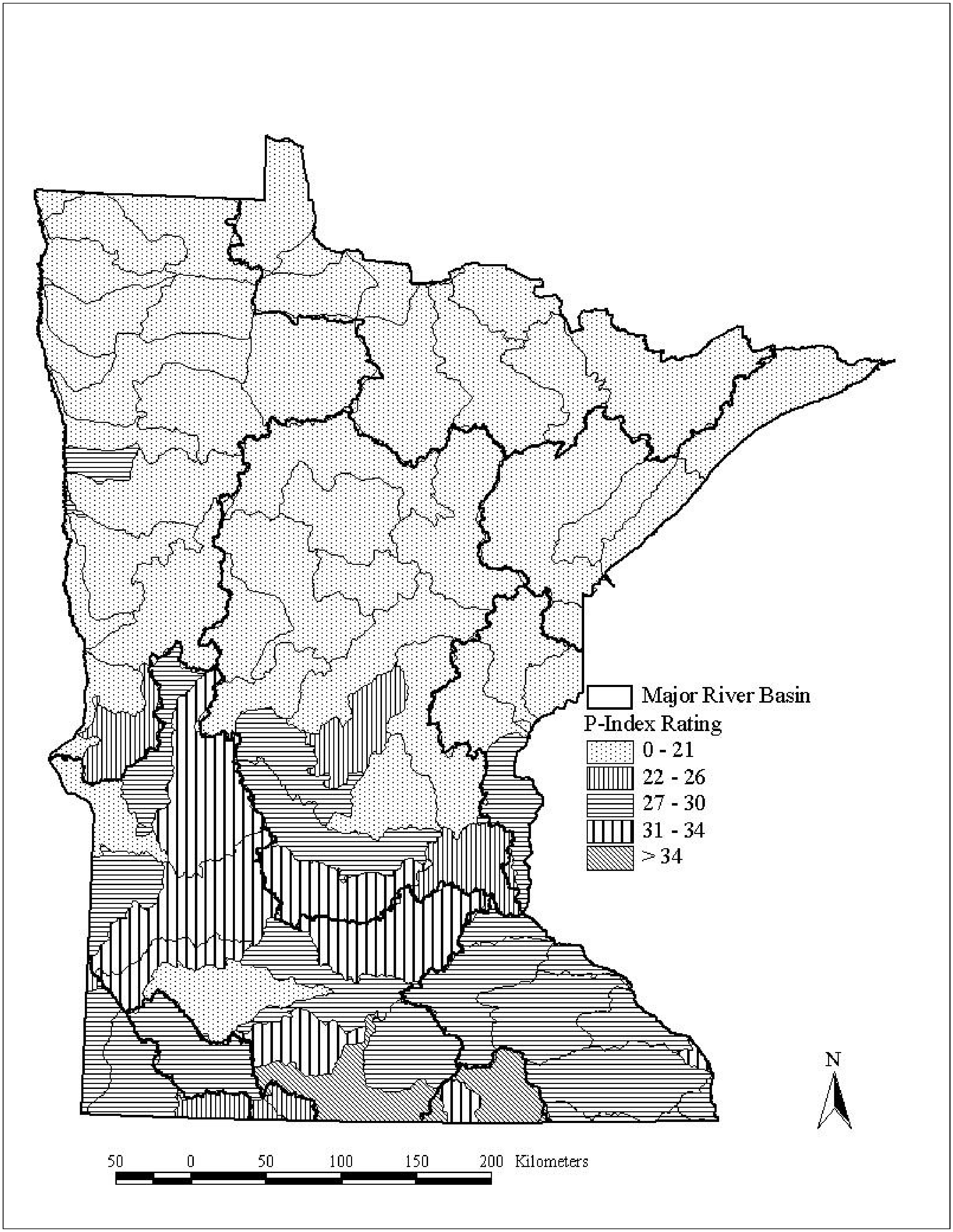

Fig. 24a: Phosphorus index values based on average hydrologic runoff volume, average rainfall runoff erosivity, a 300 ft buffer around perennial streams and ditches, average crop residue cover management conditions, and reduced rates of fertilizer phosphorus applications for watersheds of Minnesota.

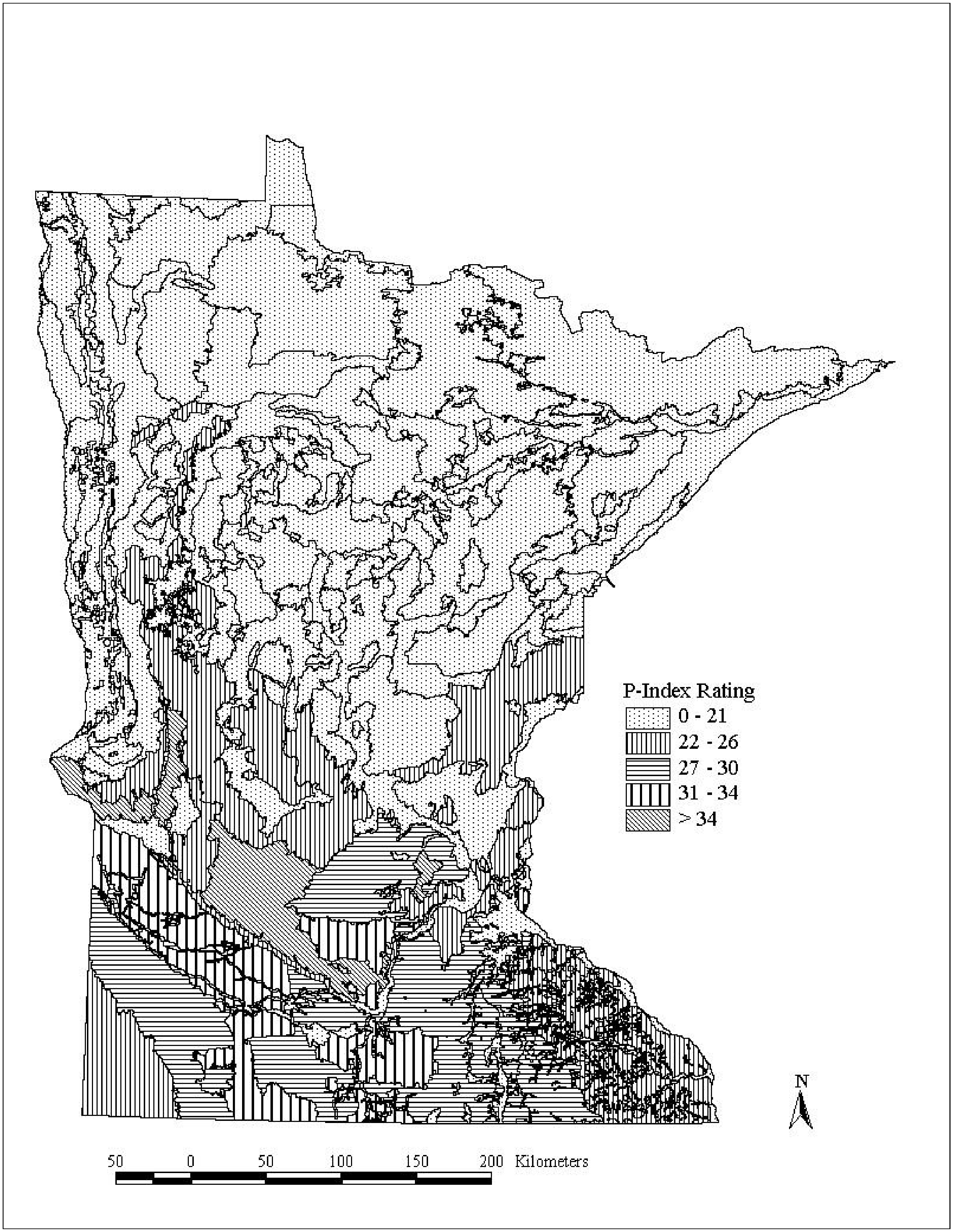

Fig. 24b: Phosphorus index values based on average hydrologic runoff volume, average rainfall runoff erosivity, a 300 ft buffer around perennial streams and ditches, average crop residue cover management conditions, and reduced rates of fertilizer phosphorus applications for agroecoregions of Minnesota.

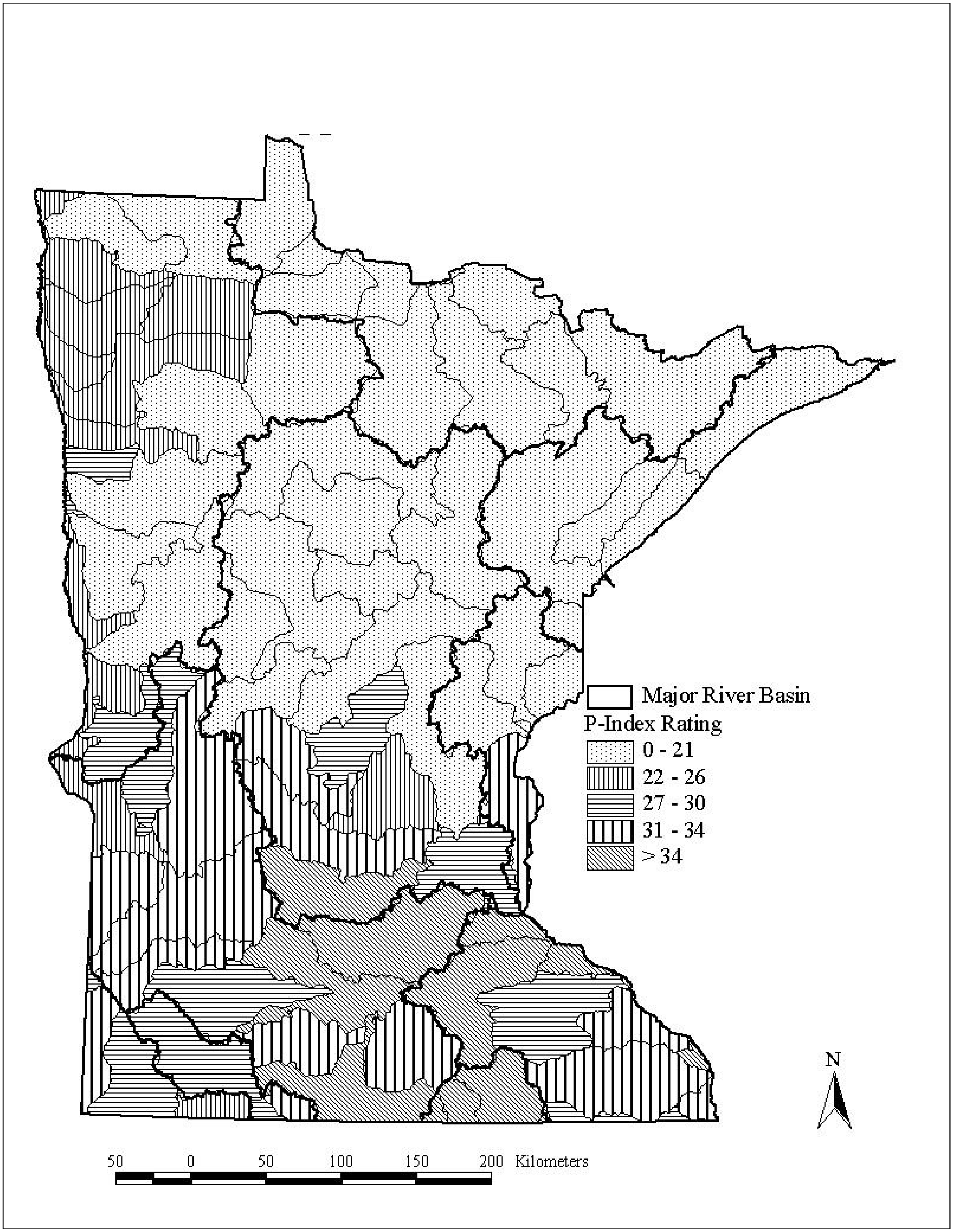

Fig. 25a: Phosphorus index values based on average hydrologic runoff volume, average rainfall runoff erosivity, a 300 ft buffer around perennial streams and ditches, average crop residue cover management conditions, and variable methods of manure phosphorus applications for watersheds of Minnesota.

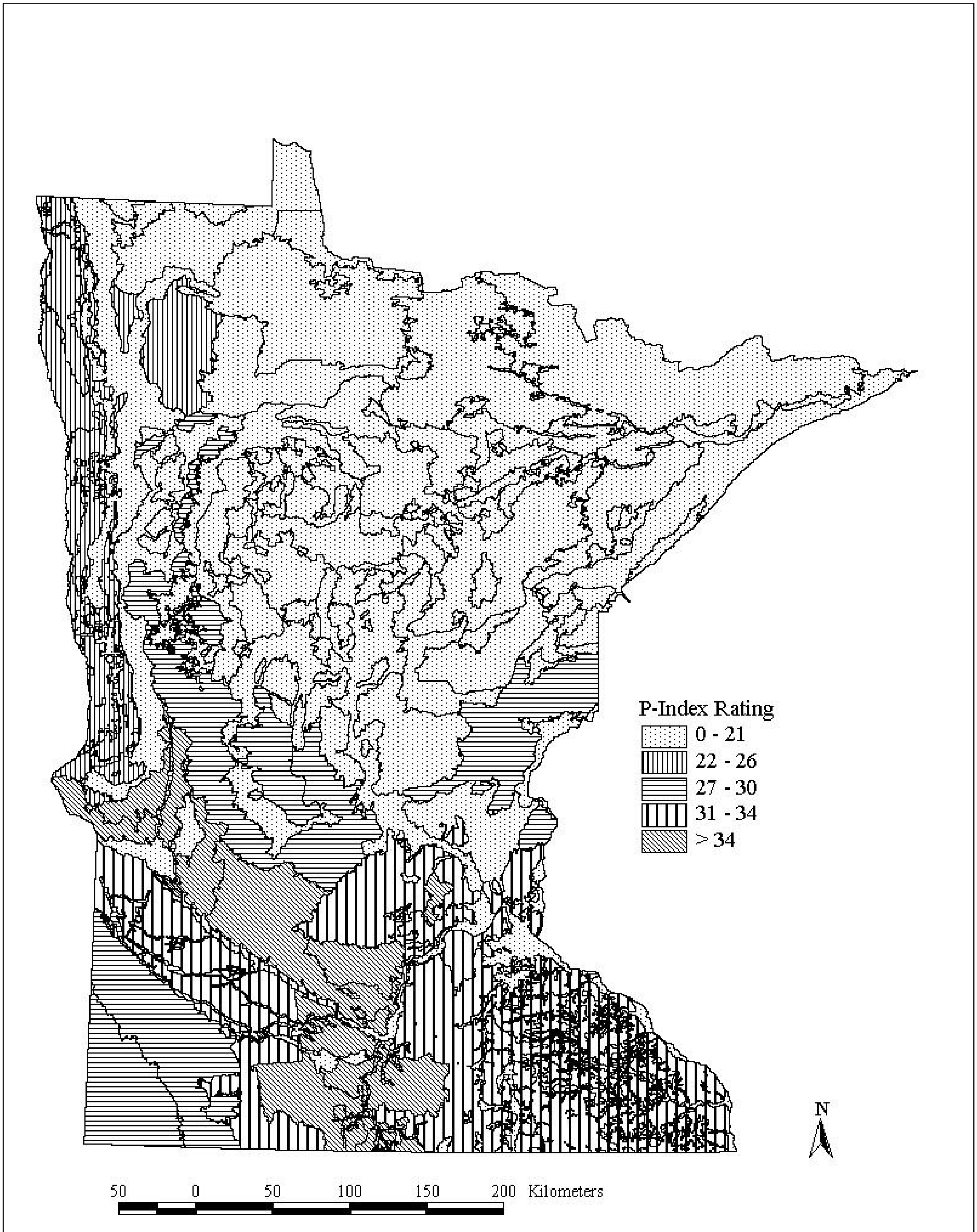

Fig. 25b: Phosphorus index values based on average hydrologic runoff volume, average rainfall runoff erosivity, a 300 ft buffer around perennial streams and ditches, average crop residue cover management conditions, and variable methods of manure phosphorus applications for agroecoregions of Minnesota.

Technical Memorandum

To: Marvin Hora, Minnesota Pollution Control Agency
Doug Hall, Minnesota Pollution Control Agency
Mark Tomasek, Minnesota Pollution Control Agency

From: Greg Wilson and Dave Wall

Subject: Final—Detailed Assessment of Phosphorus Sources to Minnesota Watersheds—Feedlot Runoff

Date: December 31, 2003

Project: 23/62-853 AGRI 008

c: Henry Runke

Overview and Introduction to Feedlot Runoff as a Source of Phosphorus

The primary way that feedlots contribute phosphorus to surface waters, apart from land application of manure, is through open lot runoff during precipitation and snowmelt events. Livestock manure accumulates on outdoor feedlots and is susceptible to runoff before being scraped from the feedlot and applied to cropland. Even after scraping for stockpiling or land application, a thin coating of manure remains on the feedlot surface and a fraction of this manure will wash off during precipitation or snowmelt events.

Overall, a small fraction of the total manure phosphorus generated at feedlots enters waters during precipitation and snowmelt events. Many feedlots do not have an open lot because they keep animals inside the barn most or all of the time, especially poultry, swine and large dairy facilities. Many of those with outdoor open lots collect runoff in impoundments or treat the runoff as it passes through downslope vegetation. Yet many feedlots still maintain open lot runoff that is out of compliance with state feedlot rules, and runoff from these feedlots contributes some phosphorus to waters. Under MN Rules 7020 control of runoff from these feedlots is phased in through October, 2010.

Results of Literature Search and Review of Available Monitoring Data

Typical amounts of phosphorus generated by livestock are described in Midwest Plan Service (2000). The daily P2O5 phosphorus generated per animal is reported as: Beef cattle 0.21 lbs.; Dairy cows 0.42 lbs.; and Swine 0.05 lbs. Most of this manure phosphorus (P) generated will be applied to cropland. However, a fraction of the manure P can be lost in feedlot runoff during precipitation or snowmelt events. Manure nutrients and organic matter (oxygen demand) is often retained in vegetation that is downslope of the feedlot. However, runoff from many feedlots enters flow channels (waterways, road ditches, drainage ditches, intermittent streams or streams) before sufficient phosphorus retention by vegetation can occur. In order to be compliant with MPCA rules, Chs. 7020 and 7050, monthly average discharges must be less than 25 mg/l biochemical oxygen demand (BOD) and less than 1 mg/l phosphorus if discharging into or affecting a lake or reservoir. Feedlots that meet the 25 mg/l BOD standard have phosphorus concentrations that are typically slightly greater than cropland runoff.

Based on a survey of county Soil and Water Conservation District Offices and Environmental offices, the Minnesota Department of Agriculture (MDA) estimates that roughly 34 percent of feedlots need upgrades to meet state regulations (MDA, 2003). In the same report, MDA estimates that approximately four out of every five (79%) of the feedlots needing upgrades need open lot upgrades and the other 21% have other problems not associated with open lot runoff (e.g. unlined manure storage structures). Most feedlots with open lot runoff are from smaller beef, dairy and swine feedlots, with much fewer instances of non-compliance observed for moderate and large sized feedlots (Mulla et al., 2001).

Phosphorus runoff loading from open lot feedlots can be estimated with a feedlot evaluation model developed in Minnesota (Young et al., 1982). The model (FLEval) has been used for many years in Minnesota to evaluate compliance with Minnesota Feedlot runoff rules and to estimate reduced oxygen demand and phosphorus loadings resulting from feedlot improvements. The model was developed to estimate pollutant loadings at the feedlot edge and to account for any contaminant retention/treatment that occurs in downslope vegetation and cropland. The model was developed to predict loading from individual storm events. However, the Board of Water and Soil Resources developed an equation to estimate annual loadings and annual runoff.

Watershed Basin Characteristics

Runoff characteristics of each major watershed basin in the state were developed to simplify and provide a surrogate of the annual amount of phosphorus that leaves the feedlots in that basin due to surface runoff. For example, wet condition runoff is 15.6 inches per year in the Lower Mississippi Basin and 6.1 inches per year in the Red River Basin (see the Basin Hydrology Technical Memorandum). Computer modeling using the Feedlot Evaluation model (FLEval) estimated that 2 percent of the annual phosphorus generated at non-compliant feedlots leaves the feedlot edge in runoff in the Lower Mississippi River Basin during wet years (assuming 15.6 inches of annual runoff at feedlots); whereas only 0.8 percent of the phosphorus leaves the feedlot edge in the Red River Basin (assuming 6.1 inches of annual runoff at feedlots). The annual runoff model inputs for low, average and high flow years were consistent with the runoff amounts used for assessing other phosphorus sources in this project (based on the Basin Hydrology Technical Memorandum).

Approach and Methodology for Phosphorus Loading Computations

Described below is a summary of the steps taken to develop estimates of P loading to waters from open lot runoff:

Step 1. Determine the number of beef, dairy and swine animal units found at all feedlots with open lots (excluding feedlots with 1000 or more animal units).

Step 2. Multiply the results in step 1 by the annual manure P generated by each type of livestock. This provides P generated by livestock in all open lots.

Step 3. Multiply the results in step 2 by the estimated percentage of open lot feedlots that contribute phosphorus during certain storm events. This provides P generated by livestock at feedlots that contribute P to waters.

Step 4. Multiply the results in step 3 by the typical fraction of P that is lost to surface waters during low, average and high flow years. This provides the estimated P loading to surface waters from open lots.

The spreadsheet used to make the calculations for the 4 steps is shown in Table 1. Each of the four steps is described further in the following pages.

Table 1
Estimated Annual Phosphorus Loadings for Outdoor Open Lot Feedlot Runoff to Surface Waters

Major Basin	Animal	P Produced per Animal Unit	Open Lot Animal Units	Manure P Produced from All Open Lots	Assumed Open Lots Contributing P to Waters	Manure P Produced from P Contributing Feedlots	Fraction of P Generated Entering Surface Waters from Non-Compliant Lots by Flow Condition (from FLEVAL)			Estimated TP from Feedlot Runoff by Flow Condition		
		lbs/yr	AU	lbs	fraction	lbs P/yr	fraction Low	fraction Average	fraction High	kg P/yr Low	kg P/yr Average	kg P/yr High
Cedar	Beef	33.5	6,809	228,102	0.35	79,836	0.0036	0.0062	0.0112	130	225	406
	Dairy	47.8	2,529	120,886	0.35	42,310	0.0033	0.0057	0.0102	63	109	196
	Hogs	26.6	9,759	259,589	0.35	90,856	0.0033	0.0057	0.0102	136	235	420
									Basin Total	**330**	**569**	**1,022**
Des Moines	Beef	33.5	48,639	1,629,407	0.35	570,292	0.0009	0.0036	0.0085	233	931	2,199
	Dairy	47.8	3,945	188,571	0.35	66,000	0.0008	0.0033	0.0077	24	99	231
	Hogs	26.6	48,122	1,280,045	0.35	448,016	0.0008	0.0033	0.0077	163	671	1,565
									Basin Total	**419**	**1,701**	**3,994**
Lake Superior	Beef	33.5	3,074	102,979	0.35	36,043	0.005	0.008	0.0107	82	131	175
	Dairy	47.8	3,203	153,103	0.35	53,586	0.0045	0.0073	0.0097	109	177	236
	Hogs	26.6	92	2,447	0.35	857	0.0045	0.0073	0.0097	2	3	4
									Basin Total	**193**	**311**	**414**
Lower	Beef	33.5	238,216	7,980,236	0.35	2,793,083	0.0045	0.0065	0.0099	5,701	8,235	12,543
	Dairy	47.8	200,040	9,561,912	0.35	3,346,669	0.0041	0.0059	0.009	6,224	8,956	13,662
	Hogs	26.6	79,301	2,109,407	0.35	738,292	0.0041	0.0059	0.009	1,373	1,976	3,014
									Basin Total	**13,298**	**19,167**	**29,219**
Minnesota	Beef	33.5	358,579	12,012,397	0.35	4,204,339	0.0012	0.0036	0.0071	2,288	6,865	13,540
	Dairy	47.8	158,480	7,575,344	0.35	2,651,370	0.0011	0.0033	0.0064	1,323	3,969	7,697
	Hogs	26.6	271,561	7,223,523	0.35	2,528,233	0.0011	0.0033	0.0064	1,261	3,784	7,339
									Basin Total	**4,873**	**14,619**	**28,576**
Missouri	Beef	33.5	132,679	4,444,747	0.35	1,555,661	0.0006	0.0033	0.008	423	2,329	5,645
	Dairy	47.8	27,219	1,301,068	0.35	455,374	0.0005	0.003	0.0072	103	620	1,487
	Hogs	26.6	81,589	2,170,267	0.35	759,594	0.0005	0.003	0.0072	172	1,034	2,481
									Basin Total	**699**	**3,982**	**9,613**
Rainy	Beef	33.5	8,993	301,266	0.35	105,443	0.003	0.005	0.0075	143	239	359
	Dairy	47.8	1,668	79,730	0.35	27,906	0.0027	0.0045	0.0068	34	57	86
	Hogs	26.6	116	3,086	0.35	1,080	0.0027	0.0045	0.0068	1	2	3
									Basin Total	**179**	**298**	**448**
Red	Beef	33.5	142,375	4,769,563	0.35	1,669,347	0.0006	0.0022	0.0039	454	1,666	2,953
	Dairy	47.8	54,886	2,623,551	0.35	918,243	0.0005	0.002	0.0036	208	833	1,499
	Hogs	26.6	9,740	259,084	0.35	90,679	0.0005	0.002	0.0036	21	82	148
									Basin Total	**683**	**2,581**	**4,601**
St. Croix	Beef	33.5	28,985	970,998	0.35	339,849	0.0036	0.0062	0.0091	555	956	1,403
	Dairy	47.8	36,362	1,738,104	0.35	608,336	0.0033	0.0056	0.0082	911	1,545	2,263
	Hogs	26.6	1,744	46,390	0.35	16,237	0.0033	0.0056	0.0082	24	41	60
									Basin Total	**1,490**	**2,542**	**3,726**
Upper	Beef	33.5	256,585	8,595,598	0.35	3,008,459	0.0023	0.0044	0.0066	3,139	6,004	9,006
	Dairy	47.8	391,607	18,718,815	0.35	6,551,585	0.0021	0.004	0.006	6,241	11,887	17,830
	Hogs	26.6	53,454	1,421,876	0.35	497,657	0.0021	0.004	0.006	474	903	1,354
									Basin Total	**9,853**	**18,794**	**28,191**
									Statewide Total	**32,017**	**64,564**	**109,804**

Step 1. Beef, Dairy and Swine animal units at open lot feedlots

MPCA's registered feedlot database was used to determine which feedlots had open lots. Of the 29,122 feedlots in this data base 14,367 feedlots indicated that they had an open lot and 3,181 indicated no open lot. Another 11,574 feedlots had a question mark under the open lot heading (or flag). The following five combinations of answers in the data base were considered to be feedlots likely to have an open lot.

1. Open Lot flag = Y and <1000 A.U.s
2. Open Lot flag = ? and Confinement Building flag = N and Total A.U.s < 300
3. Open Lot flag = ? and Confinement Building flag = Y and Manure Storage flag = N and Total A.U.s < 300
4. Open Lot flag = ? and Confinement Building flag = ? and Total A.U.s < 300
5. Open Lot flag = ? and Manure Storage flag = ? and Total A.U.s < 300

All feedlots with more than 1000 animal units were excluded, since discharge to waters is not allowed at these feedlots and they are routinely inspected to ensure compliance with the no discharge standard.

Based on the combinations outlined above, a total of 22,387 feedlots were assumed to have open lots. The distribution of these open lots, along with the remaining feedlot locations from the MPCA's registered feedlot database, is shown in Figure 1. The beef, dairy and swine animal units from these feedlots were tallied to determine the livestock animal units found at feedlots with open lots. This was determined separately for each basin.

Step 2: Manure P generated by livestock

Phosphorus generated for each animal unit of dairy, beef and swine was determined based on information from Midwest Plan Service (2000). By taking the daily P2O5 generation described in that publication, and converting to annual P generated per animal unit (au), the following estimates of annual P generation were developed: Beef cattle 33.5 lbs/au; Dairy cows 47.8 lbs/au; and Swine 26.6 lbs/au. Multiplying these numbers by the number of animal units in each basin provided the annual total P produced by livestock at open lot feedlots in each basin.

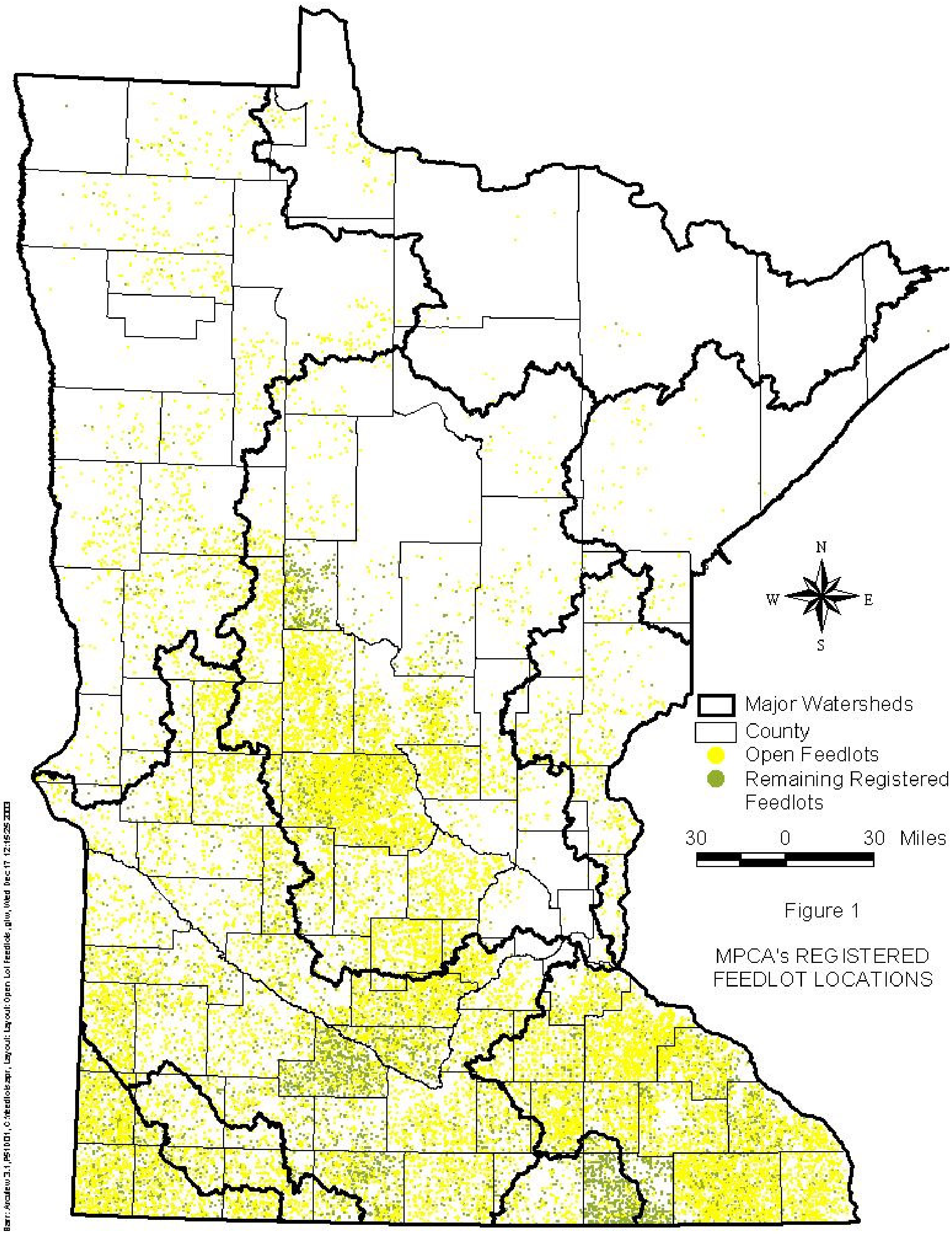

Figure 1

MPCA's REGISTERED FEEDLOT LOCATIONS

Step 3. Percentage of feedlots contributing P in runoff

We assumed that feedlots that are in compliance with Minnesota rules have negligible P runoff. Based on rough MDA estimates (MDA, 2003), we assumed that 27 percent of all feedlots contribute P to surface waters due to open lot runoff. Twenty-seven percent of all 29,122 registered feedlots is 7863 feedlots needing open lot runoff control improvements. With an estimated 22,387 feedlots with open lots in the data base used for this study, the percent of open lots contributing P in runoff is 35 percent (7863/22,387). While this fraction is expected to vary significantly across the state (see discussion of uncertainties and variability), a more detailed geographic-based analysis was not feasible at this time with the readily available information. Therefore, we assumed that 35 percent of open lot feedlots contributed P to surface waters in each of the basins. This fraction is expected to decrease significantly by October 2010, the deadline set in Minn. Rules ch. 7020 for those feedlots in open lot agreements.

We assumed that each animal unit in feedlots with open lot P runoff contributes to open lot runoff in the modeling exercise.

Step 4. Fraction of manure that reaches surface waters

The fraction of manure that reaches surface waters was calculated by dividing expected phosphorus runoff to waters by the total amount of manure that was generated at the feedlots with open lot P runoff.

We used the FLEval model to determine the amount of manure that is expected to leave the feedlot and enter waters at non-compliant feedlots. The following assumptions were made in the FLEval modeling exercise: animal stocking density of 200 square feet per animal; all of the soil in the lot had at least some manure covering the ground; no upslope runoff waters washed through the lot; and downslope vegetation reduced the phosphorus loads found at the feedlot edge by half (typical for less than 50 feet of grassed buffer). With these assumptions, the amount of P expected to reach the discharge point (channelized flow) during wet years ranged from 0.39 to 1.12 percent of the total manure P generated at the feedlots (varying by basin). During dry years the P loading at the discharge point was 0.1 to 0.5 percent across the different basins. While the total amount of P loading increased with increasing animal numbers in the feedlot, the fraction of P lost to the discharge point was independent of animal numbers. The other 99+

percent of manure P that does not runoff is applied to cropland, with a small amount remaining in the feedlot soils or picked up by wind.

Results of Phosphorus Loading Computations and Assessments

Table 1 presents the results of the phosphorus loading computations for runoff from noncompliant open feedlots during low, average and high flow conditions within each of the major basins of the state. The results show that the Lower Mississippi River produces the most phosphorus in feedlot runoff, with similar loadings estimated for the Upper Mississippi and Minnesota River basins. These three basins account for 88, 81, and 78 percent of the total statewide phosphorus loadings from feedlot runoff under low, average and high flow conditions, respectively. On a statewide basis, the total phosphorus loading during an average year is twice as high as the loading during a low flow year, while the high flow loading estimate is approximately 1.7 times higher than the estimate for average flow conditions. Table 1 shows that dairy in the Upper Mississippi River produces the largest amount of manure phosphorus generated from all open lots, followed by beef in the Minnesota River basin.

Due to uncertainties, variability and unaccounted sources described below, the feedlot runoff loading results could be significantly higher or lower in some basins than the results show.

Phosphorus Loading Variability and Uncertainty

Not all potential avenues of phosphorus transport to waters from feedlots were included in this analysis. This analysis did not include runoff from:

- Manure application sites (i.e. from spreading onto cropland) and pastures. This is handled in the report under the category agricultural field runoff;
- Silage leachate runoff, which has high concentrations of phosphorus, but relatively low volumes that add significantly to basin-wide phosphorus budgets;
- Milkhouse wastewater discharges;
- Open lots that are not included in the MPCA feedlots data base, including those feedlots that have not yet registered or those feedlots that are too small to require registration (i.e. under

50 animal units outside of shoreland). This would include many small farms with horses and livestock.

- Feedlots that do not have open lots; incidental runoff from total confinement operations is considered negligible.
- Poultry facilities and field stockpiles associated with poultry operations. Most poultry are raised in total confinement, and the relatively small amount raised outside or from stockpiles was considered negligible for basin-wide analysis.
- Runoff from pasturing animals, including animals with direct access to surface waters.

Several areas of uncertainty and variability exist in the analysis.

Uncertainties about animal units at open lots - The data base used to obtain the information is incomplete. While 29,122 feedlots exist in the data base, incomplete information is available from several counties, and also many smaller feedlots were not required to register. It is possible that the actual number of all feedlots could be several thousand more than indicated in the data base. Additionally, information about the presence of open lots at 11,574 was not available. Information about confinement buildings, manure storage and feedlot size were used to roughly determine which of those were likely to have open lots. Since the missing feedlots are mostly small lots, the added phosphorus loading would not be expected to be more than 25% greater than our current estimates.

Uncertainties about manure P generation – The amount of phosphorus generated by each animal type was provided from average values based on research in the Midwest. The actual P generated is increasingly being reduced through dietary measures. However, this source of variability and uncertainty is considered to be relatively minor.

Uncertainties about the fraction of feedlots that contribute P to surface waters – The percent of open lot feedlots that contribute P to waters varies from basin to basin within the state. Areas with steeper slopes and a more pronounced drainage system will have a higher percentage of open lots with runoff problems. Unpublished county-specific information used to develop the statewide average (MDA, 2003), indicates that the percentage of open lots that may contribute runoff P to surface waters in the Lower Mississippi basin could be much greater than the statewide average, whereas, in the Missouri and Des Moines river basins the fraction of feedlots with open lot runoff problems may be less than half of the statewide average. This variability was not accounted for in the analysis. The 35 percent of open lots contributing runoff P that was used for all basins in this study is likely to be too low for basins like the Lower Mississippi and too high for other basins. However, due to a lack of basin-specific information, we decided to use the 35 percent figure statewide.

It is likely that some phosphorus is delivered to waters from feedlots that are in compliance with state feedlots rules. No feedlot runoff was accounted from feedlots that were considered to be in compliance with state feedlot rules.

We assumed that all of the animals in feedlots with open lots contribute manure to the open lot. This is not valid at all feedlots, since some of the animals where open lots are found are in total confinement 100 percent of the time. For example, a feedlot may have 100 animal units that use an open lot and may have another 100 animal units kept in total confinement. We did not have information that would allow us to differentiate which animals used the open lot and which were kept in total confinement.

Uncertainties about phosphorus delivery – The FLEval model used to estimate the fraction of phosphorus delivery to waters is currently being upgraded by the University of Minnesota to improve estimates of annual phosphorus loading. We do not know if these upgrades will increase or decrease annual P loading estimates. Several assumptions were made for the FLEval modeling exercise that affected the estimated loading. The P loading results could be either half as much or twice as much as the study results, depending on modeling assumptions about the feedlot size (square feet per animal unit), the effect of downslope vegetation and cropland, and other model inputs.

Another uncertainty is the effect that holding animals in the barns or pastures will have on reducing the fraction of P delivery to waters. Where animals are held in barns or pasture for a long enough time during the day so that less than 100 percent feedlot of the feedlot area has manure on the surface, then the phosphorus loadings would be reduced. In the model we assumed that each animal unit contributed to 200 square feet of feedlot surface that was covered 100 percent manure. Both of these assumptions are variable and affect the modeling results, causing an overestimate of P loading for this part of the loading calculation.

Net effect of the uncertainties

If we look at the primary uncertainties in this exercise we see that some are expected to result in overestimates of phosphorus loading from feedlots and others contributed to underestimates of phosphorus loadings from feedlots. Included below is a summary of these uncertainties:

1. ***Incomplete feedlot data base*, resulting in underestimates by roughly 10 to 25 percent;**
2. ***Not including milkhouse wastewater, silage leachate and spills*, resulting in underestimates of P loading by roughly 5 to 20 percent;**
3. ***Not including P from feedlots in compliance with feedlot runoff regulations*, resulting in underestimates of roughly 1 to 10 percent;**
4. ***Uncertainties in percent of open lots that contribute P to surface waters*, potentially resulting in the Lower Mississippi basin underestimates by as much as 100 percent and overestimates in the Missouri, Des Moines basins by roughly 100 percent, with other basins being closer to statewide averages.**
5. ***Uncertainties about FLEval modeling of annual loading*, with unknown effects; and**
6. ***Uncertainties about how much time the livestock at feedlots with open lots spent in the barn or on pasture*, resulting in overestimates of roughly 10 to 30 percent.**

Recommendations for Future Refinements

Future refinements can be made when the MPCA data base is improved to more clearly indicate whether an open lot exists at each feedlot and when better basin-specific information can be provided about how many feedlots are out of compliance with state feedlot runoff rules and regulations. Additionally, the results can be refined after the FLEval model upgrades are completed by the University of Minnesota and when better information is available about average downslope buffer conditions at non-compliant feedlots. Also, future analyses should incorporate estimates of how livestock time in barns or pastures may reduce the overall fraction of manure P that is delivered to waters.

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Technical Memorandum

To: Marvin Hora, Minnesota Pollution Control Agency
Doug Hall, Minnesota Pollution Control Agency
Mark Tomasek, Minnesota Pollution Control Agency

From: Cliff Twaroski and Ron Reding

Subject: Detailed Assessment of Phosphorus Sources to Minnesota Watersheds - Atmospheric Deposition

Date: November 25, 2003

Project: 23/62-853 ATMO 010

c: Greg Wilson
Henry Runke

The purpose of this memorandum is to provide a discussion about Atmospheric Deposition as a source of phosphorus to Minnesota watersheds. This discussion is based on a review of the available literature, consideration of monitoring data and other available support data, and the results of phosphorus loading computations done for each of Minnesota's ten major watershed basins as part of this study. This memorandum is intended to:

- Provide an overview and introduction to this source of phosphorus
- Describe the results of the literature search and review of available monitoring data
- Discuss the characteristics of each watershed basin as it pertains to this source of phosphorus
- Describe the methodology used to complete the phosphorus loading computations and assessments for this study
- Discuss the results of the phosphorus loading computations and assessments
- Discuss the uncertainty of the phosphorus loading computations and assessment
- Provide recommendations for future refinements to phosphorus loading estimates and methods for reducing error terms
- Provide recommendations for lowering phosphorus export from this source

Overview and Introduction to Atmospheric Source(s) of Phosphorus

The importance of nutrient contributions to Minnesota's ecosystems have been recognized for some time (Verry and Timmons, 1977; Axler et al., 1994). Phosphorus in the atmosphere can be derived from a number of sources, including natural sources such as pollen, soil (from wind erosion) and forest fires, as well as anthropogenic sources such as fertilizer application and oil and coal combustion. Agricultural activities (pre-planting field preparations, harvesting) can increase the amount of soil-derived phosphorus in the atmosphere. Phosphorus can also be released into the atmosphere in vapor form from various materials (sewage sludge, landfills) by microbial reduction processes (Brunner and Bachofen, 2000).

The atmosphere contributes phosphorus and phosphorus-containing material to terrestrial and aquatic ecosystems by wet (precipitation in various forms such as rain, sleet or snow) and dry (very small particles) deposition. Previous work by Pratt et al. (1996) indicates that dry deposition of particles is important to Minnesota ecosystems. Federal agencies have also recognized the importance of dry deposition to ecosystem health (NOAA-ARL, 2003). Subsequently, considerable effort has gone into deriving estimates of dry deposited phosphorus for this project.

Results of Literature Search and Review of Available Monitoring Data

A. Literature Review

Some previous estimates of phosphorus deposition for Minnesota and Wisconsin are provided in Table 1 below, ranging from a low of 0.05 kilograms per hectare per year (kg ha^{-1} yr^{-1}) in northern Wisconsin (Rose, 1993; Robertson, 1996) to 0.48 kg ha^{-1} yr^{-1} for north central Minnesota (Verry and Timmons, 1977).

A cursory check on the availability of phosphorus deposition information and data was made for other states. Information on phosphorus Total Maximum Daily Load (TMDL) was reviewed for Lake Champlain (Vermont Agency of Natural Resources and New York State Department of Environmental Conservation, 2002) and for four watersheds in Kansas (Mau and Christensen, 2001). Deposition data for Florida were also reviewed (Dixon et al., 1998). However, due to these states being distant from Minnesota, it was uncertain as to the applicability of the data to Minnesota's watersheds. Therefore, for the purpose of estimating phosphorus deposition to Minnesota river basins and watersheds within basins, data from other states was not considered applicable.

Table 1. Estimates of phosphorus deposition in Minnesota and Wisconsin.

Deposition Estimate ($kg\ ha^{-1}\ yr^{-1}$)	Description	Reference
0.48	Annual precipitation input of total phosphorus for a precipitation year representative of the western Great Lakes region (data collected in north central Minnesota).	Verry and Timmons, 1977 (Table 5)
0.15	Estimated total atmospheric phosphorus in the northern Minnesota; input data for the Minnesota Pollution Control Agency's (MPCA) watershed modeling.	Wilson, 2003
0.3 – 0.4	Estimated total atmospheric phosphorus in the southern and western part of Minnesota; input data for the MPCA's watershed modeling.	Wilson, 2003
0.05	Total atmospheric phosphorus deposition in northern Wisconsin's forest region.	Rose, 1993 (northwest WI) Robertson, 1996 (northeast WI)
0.05	Precipitation total phosphorus loading to Lake Michigan.	Miller et al., 2000
0.2	Estimated total atmospheric phosphorus deposition in southeast Wisconsin's agricultural areas.	Robertson, 1996

Specific estimates of dry deposited phosphorus in Minnesota were not found in the literature review.

The literature review indicates that limited data are available from Minnesota sources to estimate phosphorus deposition to the state's river basins. The previous best source of information for precipitation input (wet deposition) of phosphorus to Minnesota watersheds is Verry and Timmons (1977). As noted above, no data on dry deposition of phosphorus in Minnesota was identified.

The MPCA's goal for this project is to provide an updated estimate of wet phosphorus deposition using more recent data and an initial estimate of dry deposited phosphorus for surface waters and wetland areas in Minnesota. The following section discusses the data considered to be the best available at this time for providing estimates of atmospheric phosphorus inputs to Minnesota's river basins and watersheds.

B. Available Data

The specific data used to provide an updated estimate of wet phosphorus deposition and an initial estimate of dry phosphorus deposition for Minnesota's major river basins are described below.

MPCA:

1. Nutrient (including phosphorus) and metal concentrations in precipitation from a special study conducted from August 1999 to September 2001 at four monitoring sites in Minnesota
2. PM10 air concentrations determined from particulate filters and elemental speciation of the PM10 mass by X-ray Fluorescence (XRF) analysis for the 30 sites included in the Statewide Air Toxics Monitoring Study (1996-2001).

National Atmospheric Deposition Program (NADP):

1. Annual volume weighted calcium concentrations in precipitation for the period of record from NADP sites located in, and adjacent to, Minnesota (Table 2).
2. Monthly volume weighted calcium concentrations for four sites (Fernberg, Marcell, Camp Ripley, Lamberton) for use in establishing the relationship between phosphorus and calcium in precipitation for NADP sites.

Table 2. Annual volume-weighted calcium data obtained from National Atmospheric Deposition Program (NADP) sites for Minnesota's phosphorus assessment project.

Iowa	Michigan	Minnesota	North Dakota	Wisconsin
Big Springs Fish Hatchery	Isle Royale Nat. Pk.	Camp Ripley	Icelandic St. Pk	Lac Courte Oreilles Res.
		Cedar Creek		Spooner
		Fond du Lac Res.		Wildcat Mountain St. Pk.
		Fernberg (Ely)		
		Grindstone Lake		
		Hovland		
		Lamberton		
		Marcell Exp. Forest		
		Wolf Ridge (Finland)		
		Voyageurs Nat. Park		

Additional details on the MPCA and NADP datasets are described in more detail in the next subsection.

Minnesota Department of Natural Resources, State Climatology Office. Annual normal precipitation amount for each river basin basis was obtained from the State Climatology Office. The State Climatology Office provides a full QA/QC program for precipitation data; therefore no additional QA/QC was conducted on the precipitation data for the atmospheric component of this project. The derivation of the annual normal precipitation amount for each basin, and the dataset used by the State Climatology Office, is discussed in the Basin Hydrology Technical Memorandum for this project.

C. Additional Discussion of the MPCA and NADP Data

Nutrient and metal concentrations in precipitation

1. Phosphorus in Precipitation Study.

   A special two-year study (August 1999 – September 2001) was conducted by the St. Croix Watershed Research Station of the Science Museum of Minnesota to determine nutrient and metal concentrations in precipitation in Minnesota. Precipitation sampling equipment was collocated at four National Atmospheric Deposition Program (NADP) monitoring sites in Minnesota: Fernberg Road (Ely), Marcell, Camp Ripley, and Lamberton (Engstrom et al., 2003). Samples were collected on a 4-week basis, acidified with a small amount of acid, and analyzed for various chemical components, including total calcium and total phosphorus. Appendix A provides additional details regarding sample collection, sample analysis, and quality assurance/quality control (QA/QC) for the phosphorus in precipitation project. The St. Croix Watershed Research Station provided a full QA/QC program for sample collection and sample analysis and data reporting, therefore no additional QA/QC was conducted on the data.

   It is noted here that a limited amount of editing occurred in the special phosphorus in precipitation study dataset to remove specific samples from the statistical analysis because the precipitation volume for that sampling event did not match with the precipitation volume collected at the collocated NADP sampler or NADP rain gauge. Following this data editing, the phosphorus concentrations from the special study, along with NADP calcium data, were used to derive the relationship between phosphorus and calcium in precipitation for the four NADP monitoring sites. The relationship between phosphorus and calcium in precipitation at these four NADP sites was then applied to the entire state. Additional details on deriving the relationship between phosphorus and calcium in precipitation and applying this relationship to the entire state are discussed in a later section of this technical memorandum.

2. NADP calcium concentrations in precipitation.
    a. Annual volume-weighted calcium concentrations were downloaded electronically from the NADP website for the monitoring locations listed in Table 2. A separate data file was downloaded for each monitoring site. These data files were then merged together for ease of data manipulation and calculations. The NADP provides a full QA/QC program for sample collection and sample analysis and data reporting. No additional QA/QC on the NADP data was conducted for this project.
    b. Monthly volume-weighted calcium concentrations from four sites (Fernberg, Marcell, Camp Ripley, Lamberton) were downloaded electronically from the NADP website for the 1999 – 2001 time period. The four NADP monitoring sites correspond to the same sites where the special phosphorus in precipitation study was conducted by the St. Croix Watershed Research Station. Separate data files were downloaded for each monitoring site, then merged with the data from the special phosphors in precipitation study. The NADP provides a full QA/QC program for sample collection, sample analysis and data reporting; therefore no additional QA/QC on the NADP data was conducted for this project.

Particulate (PM10) and elemental concentrations

Data files for PM10 air concentrations and elemental speciation of the PM10 mass by XRF analysis were obtained from the MPCA for the 30 sites included in the Statewide Air Toxics Monitoring Study (1996-2001) (Table 3). In any one year of the study, six sites were in operation. A specific site was in operation for only one year. For each site in operation during a given year, particulate filter samples were collected for a 24-hour period every sixth day and submitted to the MPCA's Air Quality Laboratory for analysis by XRF. The MPCA staff provided QA/QC for sample collection, sample analysis and data reporting. No additional QA/QC on the MPCA's PM10 filter data was conducted for this project.

A data file was received for each monitoring site. The 30 data files were then merged into a master data file containing all sites for ease of manipulation and calculations.

Table 3. List of randomly selected Minor Civil Divisions to be sampled in the Minnesota Pollution Control Agency's Statewide Air Toxics Monitoring Study

	SAMPLE YEAR				
MPCA REGION	**1. 1996-1997**	**2. 1997-1998**	**3. 1998-1999**	**4. 1999-2000**	**5. 2000-2001**
REGION 1 DULUTH	Wagner Township; Aitkin County Tier 5	Hibbing; St. Louis County Tier 3	Duluth; St. Louis County Tier 1	Virginia; St. Louis County Tier 4	Duluth; St. Louis County Tier 1
REGION 2 BRAINERD	Little Falls; Morrison County Tier 3	Elk River; Sherburne County Tier 2	St. Cloud; Stearns County Tier 1	St. Michael; Wright County Tier 4	Fort Ripley; Crow Wing County Tier 5
REGION 3 DETROIT LAKES	Alexandria; Douglas County Tier 3	Fergus Falls; Otter Tail County Tier 2	Brandon Township; Douglas County Tier 5	Perham; Otter Tail County Tier 4	Moorhead; Clay County Tier 1
REGION 4 MARSHALL	Pipestone; Pipestone County Tier 3	Granite Falls; Yellow Medicine County Tier 4	Holloway; Swift County Tier 5	Hutchinson; McLeod County Tier 2	Willmar; Kandiyohi County Tier 1
REGION 5 ROCHESTER	Leon Township; Goodhue County Tier 5	Rochester; Olmsted County Tier 1	Winona; Winona County Tier 2	Albert Lea; Freeborn County Tier 3	North Mankato; Nicollet County Tier 4
REGION 6 TWIN CITIES	Plymouth; Hennepin County Tier 3	Minneapolis; Hennepin County Tier 1	West Lakeland Township; Washington County Tier 5	St. Paul; Ramsey County Tier 2	Apple Valley; Dakota County Tier 4
ADDITIONAL SITES	International Falls; Koochiching County	Warroad; Roseau County	Bemidji; Beltrami County	Silver Bay; Lake County	Grand Rapids; Itasca County

Note: Minor Civil Divisions within a region were segregated into 5 tiers based on population densities. Sites were then selected randomly from within a tier.

The two key parameters to be obtained from the particulate filters were calcium and phosphorus concentrations. Calcium concentrations were typically available for each sampling period. However, upon review of the individual site data files, phosphorus concentrations were not available. Prior to this data review it was assumed phosphorus concentrations would be available from the particulate filters. Phosphorus concentration data is normally obtained from XRF analysis of particulate filters (Brook et al., 1997). Some of the particulate filters are being re-analyzed by MPCA using a different method that may provide phosphorus concentration data from the particle filters. Data from the re-analysis of the filters should be available in 2004. In the meantime, an alternative method for deriving phosphorus concentrations for the particle filters was employed for this project. This alternative method assumes that the relationship between phosphorus and calcium in precipitation is transferable to the particulate filter data (i.e., the same material being washed out in the precipitation is the same material being dry deposited and collected on the particulate filters). The critical assumptions and the details of calculating phosphorus air concentrations from the particulate filter data is described later in this memorandum.

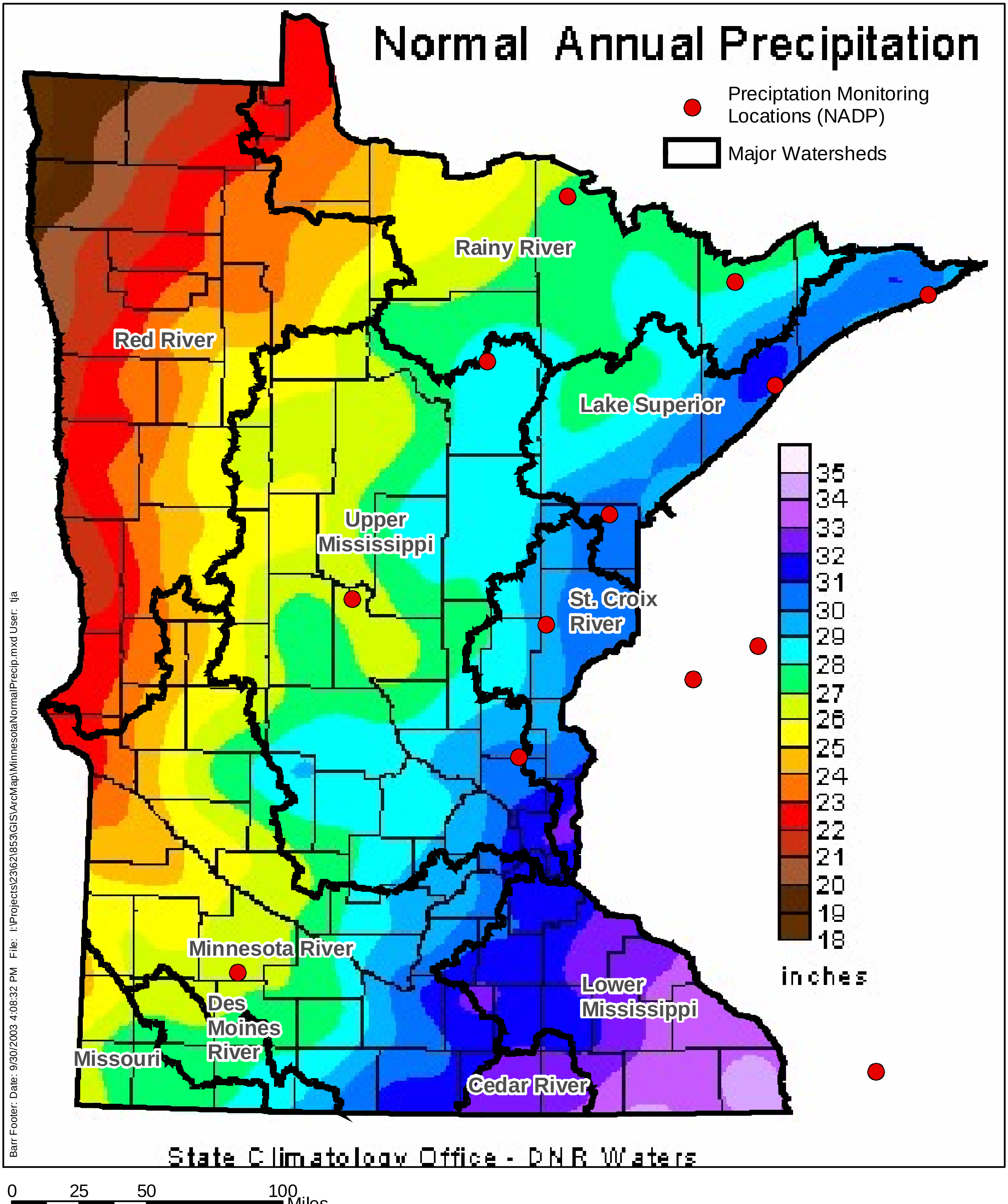
Watershed Basin Characteristics

Atmospheric inputs of nutrients to watersheds is highly dependent upon precipitation amounts. Typically for sulfur and nitrogen, precipitation accounts for a majority (50-80%) of total inputs, while dry deposition typically accounts for the balance of total inputs (Pratt et al., 1996). It is currently assumed that precipitation inputs of phosphorus are important, but the limited data for phosphorus does not yet provide a clear picture of the relationship between precipitation inputs versus dry deposition inputs.

Figure 1 provides a precipitation map of Minnesota, with normal annual precipitation isopleths overlain on the river basins and with NADP monitoring sites identified. In general, the eastern one quarter of the state receives 30+ inches of precipitation while the western half of the state receives less than 25 inches of precipitation. The most dramatic change in precipitation is from southeast to northwest, where precipitation amount can range from 33 to 34 inches in the southeast corner to less than 20 inches in the northwest corner of the state, respectively. Given the assumption that precipitation is the predominant source of atmospheric phosphorus for a river basin or specific watershed, the difference in precipitation amount can have a significant effect on phosphorus wet deposition estimates.

Figure 1 shows that significant gradients in precipitation amount exist for the following basins:

- Minnesota River: precipitation amount ranges from ~ 21 inches in the western tip (Big Stone County) to ~ 31 in the southeast part of the basin (Faribault and Waseca Counties).



Annual Precipitation Average
1971 - 2000
Data sources include National Weather Service, DNR Forestry,
Soil and Water Conservation Districts, and others
300 to 1400 precipitation observers gathered data over 30 year period (seasonally varying)
10 KM grids of monthly precipitation totals created for month-year using "Surfer"
State Climatology Office, DNR-Waters

FIGURE 1
Normal Annual Precipitation
Amounts for Minnesota

- Mississippi River – upper: precipitation amount ranges from ~ 25 inches in the northwest portion (Hubbard-Wadena-Cass Counties) to ~ 33 inches in the southeast corner in the Twin Cities metropolitan area.
- Red River: precipitation amount ranges from ~ 18 inches in the northwest corner of the basin (Kittson County) to ~ 25 inches in the eastern protrusion in Koochiching and Beltrami Counties.
- Rainy River: precipitation amount ranges from ~ 22 inches in the northwest corner (Lake of the Woods County) to ~ 30 inches in the eastern edge along the Lake Superior Highlands (Lake County).

The other river basins do not exhibit the notable difference in precipitation amount that is exhibited by the basins listed above.

Due to the notable difference in precipitation amount in the basins listed above, estimates of wet phosphorus deposition can be significantly different depending upon the precipitation data used for the estimate. For precipitation monitoring, an individual monitoring site can provide representative data for the surrounding region if the site is adequately selected (NOAA-ARL, 2003). However, precipitation amount within a basin, as well as from year-to-year, will influence the estimate of wet phosphorus deposition. This project uses an annual average precipitation amount for a basin. Given the gradient in precipitation amount across the state (Figure 1), a different estimate of wet phosphorus deposition can be obtained for various part of a basin that will be different from the deposition estimate using this annual average precipitation for the basin. It is expected that the use of a dry year (90th percentile) and a wet year (10th percentile) in estimating wet deposition will encompass the range of potential deposition amounts and address the within basin and site-to-site variability that is known to exist.

Dry deposition is more dependent upon local site conditions; therefore, an individual monitoring site may not be representative of the surrounding region because the controlling factors for dry deposition are typically surface driven and may not be regionally representative (NOAA-ARL, 2003). For total nitrogen, Pratt et al. (1996) estimated dry deposition to range from 9-17% of total N deposition, depending upon location in the state and sampling year. Other researchers (Likens et al., 1990; Lindberg et al., 1986) have identified dry deposition of nitrogen to account for as much as 40-60% of total deposition. In addition, Lindberg et al. (1986) identified coarse particles contributing 83 times more nitrogen than fine particles on an absolute basis. This earlier data on the importance of coarse particles for dry deposition of nutrients is confirmed by Meyers (2003) based on work in Florida where large particles greater than 10 microns in size accounted for only 15% of the particle mass but a more significant amount of the phosphorus deposition. Based on the above discussion, it could reasonably be expected that river basins dominated by agriculture will have more phosphorus being dry deposited (e.g., Red River, Cedar River, Minnesota River) while those river basins with little agriculture would be expected to have less phosphorus being dry deposited (e.g., Rainy River, Lake Superior). However, as noted by Verry and Timmons (1977), river basins with little agriculture may still receive a notable input of particulate phosphorus due to large regional precipitation or dust storm events. Therefore, it may be possible that regional events may limit the importance of local site influence for dry deposition inputs for a river basin.

Approach and Methodology for Phosphorus Loading Computations

The MPCA's intent for this project is to provide an updated estimate of phosphorus deposition for each river basin using the best available information from Minnesota.

A. Critical assumptions

Prior to initiating deposition calculations, a number of assumptions were agreed upon to assist in developing the approach and methodology for wet and dry phosphorus deposition calculations. These critical assumptions are listed below.

1. Deposition estimates are for surface waters only. Deposition estimates to terrestrial areas are not needed since the phosphorus loading will already be accounted for in the landform and soils (runoff) estimates.
2. Deposition estimates are to be provided for three moisture regimes: low precipitation year, average precipitation year, high precipitation year.
3. Calcium (Ca) is a marker for soil contributions. All of the Ca found in precipitation or on the PM10 filters is due to soil.
4. Phosphorus (P) is to be normalized to Ca; the P:Ca ratio found in precipitation is the same ratio for particles; since all of the Ca is assumed to be due to soil, all of the P is due to soil.

5. Particles washed out in precipitation are the same size and type of particles being dry deposited.
6. PM10 monitoring at a site was conducted for one year, therefore the average annual concentration of Ca and P are to be used; therefore, seasonality in dry deposition is addressed through the use of annual average concentrations.
7. Data from a monitoring site (precipitation or particulate) is representative of other areas within a river basin.
8. Precipitation and PM10 filter samples were collected under "normal or typical" conditions with regard to meteorology (average or typical year with regard to precipitation, no frequent large or severe storm events, etc.).

B. Wet Deposition

1. Establishing the relationship between phosphorus and calcium in precipitation.
   a. NADP routinely analyzes rain samples for pH, alkalinity, major cations (including calcium and potassium) and major anions (including sulfate, nitrate). Since calcium concentrations are available for all samples that were analyzed, and calcium is a signature for soil contributions, the relationship between phosphorus and calcium would need to be established. The use of NADP data also provides some consistency in the data used for estimating wet phosphorus deposition.
   b. The best source of phosphorus in precipitation data is the special study conducted by the St. Croix Watershed Research Station. The total phosphorus concentrations (hereafter denoted as total [P]) in precipitation data) determined from August 1991 – September 2001 at 4 sites: Fernberg (Ely), Marcell, Camp Ripley, Lamberton; referred to as "reference sites". The special study also provided measurements on total [Ca] in precipitation.
   c. An initial analysis identified that the total [Ca] from the special study was approximately two times greater than the [Ca] reported by NADP for the same time period. The NADP does not acidify samples; therefore the NADP reports dissolved [Ca]. To compensate for NADP reporting dissolved [Ca], and to provide the best estimate of [P] in precipitation from the auxiliary (NADP) sites, it was determined that the relationship between [P] and [Ca] in precipitation should be determined by using the total [P] concentrations from the

special study conducted by the St. Croix Watershed Research Station and the dissolved [Ca] reported by NADP for these same "reference" sites.

d. The volume-weighted relationship on a sample-by-sample basis between total [P] in precipitation and dissolved [Ca] in precipitation from NADP at these same reference sites (collocated sampling occurred) was established by MPCA staff (Dr. Ed Swain, 2003) through regression analysis:

$$y = 0.0671x - 0.4586 \quad (R^2 = 0.47)$$

Where: y = Total phosphorus in micrograms per liter (µg/L)
x = NADP calcium (dissolved) in µg/L.

2. Extrapolating the relationship of [P] and [Ca] in precipitation to other locations.
   a. The regression analysis based on total [P] and dissolved [Ca] concentrations for the reference sites was then used to estimate [P] in precipitation at other NADP monitoring sites (referred to as "auxiliary sites"). Annual volume-weighted [Ca] in precipitation data (annual volume weighted average) were obtained for the auxiliary sites from NADP and the regression equation from above was then used to estimate total [P] in precipitation for each auxiliary site.
   b. The auxiliary monitoring sites will supplement the information from the reference sites in calculating wet phosphorus deposition to specific basins.

3. Calculating wet phosphorus deposition
   a. Monitoring sites locations were mapped with respect to basin boundaries and assignments to watershed made based on site locations (spatial distribution of sites provided in Figure 2):

      Cedar River: Lamberton
      Des Moines River: Lamberton
      Lake Superior: Hovland, Wolf Ridge, Fond du Lac
      Minnesota River: Lamberton
      Mississippi (Upper): Marcell, Camp Ripley, Cedar Creek
      Mississippi (Lower): Wildcat Mountain
      Missouri River: Lamberton

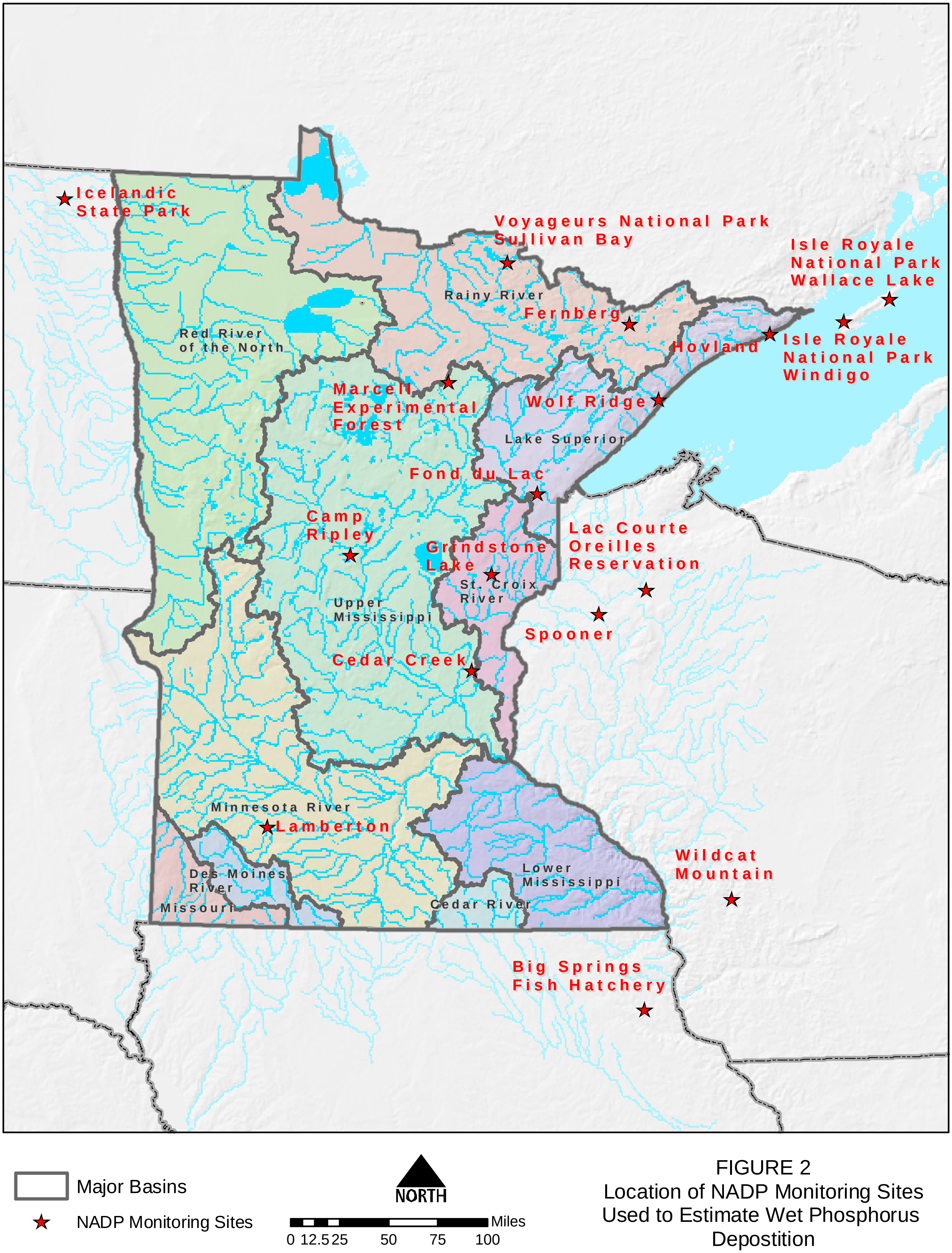


FIGURE 2
Location of NADP Monitoring Sites Used to Estimate Wet Phosphorus Depostition

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Rainy River: Voyageurs Nat. Park, Marcell, Fernberg

Red River: Icelandic State Park

St. Croix River: Grindstone Lake, Cedar Creek

b. Calculation components for phosphorus deposition in a basin:
   - Annual average precipitation for the basin (obtained from State Climatology Office)
   - [P] in precipitation (annual, volume weighted average; measured at one of the reference sites or estimated for one of the auxiliary sites; if more than one site assigned to a basin then the average [P] in precipitation used in the deposition calculation)
   - Area estimate (hectares or acres) of open surface water (surface water + wetland as designated in GIS) in a basin.

C. Dry Deposition

1. Establishing the relationship between phosphorus and calcium on particle filters.
   a. The relationship of phosphorus and calcium on the particle filters is assumed to be the same as the relationship of phosphorus and calcium in precipitation; the soil dust being washed out in precipitation is the same dust being dry deposited and collected on the PM10 filters.
   b. The best source of phosphorus and calcium in precipitation data is the special study conducted by the St. Croix Watershed Research Station. The total phosphorus and calcium concentrations (hereafter denoted as total [P]) and total [Ca] in precipitation data) determined from August 1991 – September 2001 at 4 sites: Fernberg (Ely), Marcell, Camp Ripley, Lamberton; referred to as “reference sites”.
   c. The relationship on a sample-by-sample basis (milligrams per square meter; mg/m^2) between total [P] and total [Ca] in precipitation at the 4 reference sites was established through regression analysis:

$$y = 0.0289x \quad \text{(through zero)} \quad (R^2 = 0.42)$$

Where: y = Total phosphorus in micrograms per square meter ($\mu g/m^2$)
x = Total calcium in $\mu g/m^2$.

2. Extrapolating the relationship of [P] and [Ca] from precipitation to the particulate filters.
    a. Since the regression equation for [P] and [Ca] in precipitation goes through zero, this regression equation can be applied to data from other media under the assumption that the ratio is the same (i.e., particulate filter data) without having to convert units. Essentially forcing the regression equation through zero creates a ratio of [P] to [Ca] that can be applied to other data.
    b. In this regard, the regression equation from above can be modified as follows for application to the particle filter data:

$$y = 0.0289x \quad \text{(through zero)} \quad (R^2 = 0.42)$$

Where: y = Total phosphorus in micrograms per square meter cubic meter ($\mu g/m^3$)
x = Total calcium in $\mu g/m^3$.

3. Estimating [P] in air at the MPCA's air monitoring locations.
    a. The regression equation from 2.b. was then used to estimate [P] in ambient air at the MPCA air monitoring sites. Annual [Ca] concentrations in micrograms per cubic meter were calculated for each monitoring site (Table 3) based on the individual sample [Ca] concentrations. The annual average [Ca] in air is then used in the regression equation to derive an estimate of annual average [P] in air.

4. Calculating dry phosphorus deposition
    a. Monitoring sites locations were mapped with respect to basin boundaries (spatial distribution of sites provided in Figure 3):
    Cedar River: Albert Lea
    Des Moines River: Pipestone
    Lake Superior: Virginia (2 sites), Duluth (2), Silver Bay, Hibbing
    Minnesota River: North Mankato, Brandon Township, Granite Falls, Willmar, Swift County
    Mississippi (Upper): St. Paul (3), Minneapolis (3), Bemidji, Elk River, Fort Ripley, Alexandria, Hutchinson, St. Cloud, St. Michael, Grand Rapids, Little Falls

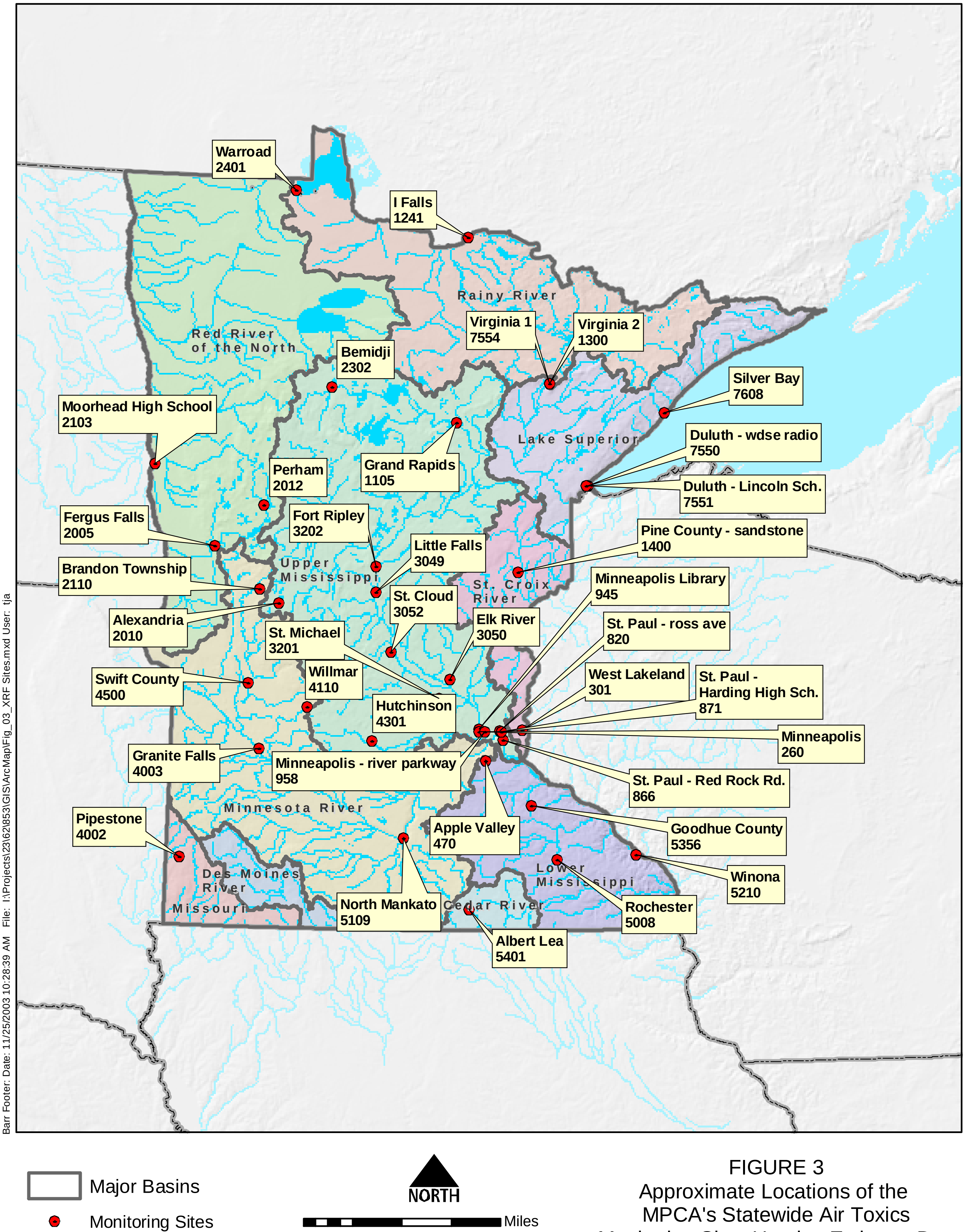

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FIGURE 3
Approximate Locations of the MPCA's Statewide Air Toxics Monitoring Sites Used to Estimate Dry Phosphorus Deposition

Mississippi (Lower): Rochester, Goodhue County, Apple Valley, Winona

Missouri River: Pipestone

Rainy River: Warroad, International Falls

Red River: Fergus Falls, Moorhead, Perham

St. Croix River: West Lakeland, Pine County (Sandstone)

b. Calculation components for phosphorus deposition in a basin:
   - Estimated phosphorus air concentration; if more than one site assigned to a basin then the average phosphorus in air concentration used in the deposition calculation.
   - The estimated phosphorus air concentration (or the average phosphorus air concentration if more than one site is in a basin) is to be split into two size fractions based on MPCA collocated PM10 and PM2.5 samplers (average from 5 sites):

     42% fine fraction (< 2.5 microns)

     58% coarse fraction

     [Note: The fine:coarse ratios found in the MPCA PM10/PM2.5 data are similar to those found by Brook et al. (1997) across all Canadian sites, rural and urban. A critical assumption for this data is that the PM2.5/PM10 ratios for urban sites is the same as for rural sites.]
   - A deposition velocity for each particle size fraction was estimated based on the information from Meyers (2003):

     Fine fraction deposition velocity = 0.5 centimeters per second (cm/s);

     Coarse fraction deposition velocity = 3 cm/s.
   - The coarse and fine particle deposition is summed together to provide a "total" particle deposition estimate.
   - Conversion factors: convert seconds to years, cm to meters, and $\mu g/m^3$ to kg/ha.

The reader should note that for the dry deposition estimate, 1) no adjustments were made in the estimation of dry deposition in a dry or a wet year; data are not available at this time to derive estimates of dry deposition during different precipitation regimes. 2) Seasonality is incorporated into the deposition estimates through the use of approximately one year of data from each monitoring site; however, seasonal deposition is not specifically calculated for this project due to the emphasis on providing annual average deposition values for each river basin.

Results of Phosphorus Loading Computations and Assessments

Wet Deposition

Estimates of average wet phosphorus deposition (average precipitation) range from ~ 0.069 kg ha^{-1} yr^{-1} in the Red River basin to 0.212 kg ha^{-1} yr^{-1} in the Cedar River basin (Table 4). When factoring in dry/wet years, the range in potential wet phosphorus deposition is from approximately 0.059 kg ha^{-1} yr^{-1} in the Red River basin (dry year) to 0.273 kg ha^{-1} yr^{-1} in the Cedar River basin (wet year) (Table 4).

Table 4 also provides estimates of average phosphorus deposition (average precipitation) for the respective basins, which ranges from ~ 2,100 kg/yr for the Cedar River to ~ 155,850 kg/yr for the Upper Mississippi.

As identified in Table 4, the estimate of phosphorus deposition for each basin is based on the area identified as "water" or "wetland" in the GIS database.

Dry Deposition

Estimates of average dry phosphorus deposition (assuming average precipitation year) range from ~ 0.028 kg ha^{-1} yr^{-1} in the St. Croix River basin to ~ 0.241 kg ha^{-1} yr^{-1} in the Cedar River basin (Table 5).

The reader should note that no adjustments were made in the estimation of dry deposition in a dry or a wet year. Data are not available at this time to derive estimates of dry deposition during different precipitation regimes.

Table 4
Estimated Wet Phosphorus Deposition to Minnesota Basins

Basin	NADP Station [1]	Total Ca conc. [2] (ug/L)	Total P conc. [3] (ug/L)	Low Precipitation Volume [4] (inches/yr)	Average Precipitation Volume [4] (inches/yr)	High Precipitation Volume [4] (inches/yr)	Basin Waters and Wetland Area [5a] (acres)	Basin Waters and Wetland Area [5b] (hectares)	% of Total Basin Land Area	Low Precipitation Phosphorus Deposition [6] ($kg\ ha^{-1}\ yr^{-1}$)	Average Precipitation Phosphorus Deposition [6] ($kg\ ha^{-1}\ yr^{-1}$)	High Precipitation Phosphorus Deposition [6] ($kg\ ha^{-1}\ yr^{-1}$)	Average Phosphorus Deposition to Waters and Wetlands (kg/yr)	Average Phosphorus Deposition to Waters and Wetlands (lb/yr)
Cedar River	Lamberton (MN)	348.75	25.98	27.50	32.10	41.30	24,523	9,924	3.7	0.181	0.212	0.273	2,102	4,635
Des Moines River	Lamberton (MN)	348.75	25.98	22.00	28.00	36.80	53,771	21,761	5.5	0.145	0.185	0.243	4,020	8,865
Lake Superior	Hovland (MN)	200.00	12.95											
	Wolf Ridge (MN)	183.33	11.83											
	Fond du Lac (MN)	165.71	10.65											
	Average	183.02	11.81	25.50	29.10	35.10	1,312,101	531,000	33.3	0.077	0.087	0.105	46,364	102,233
Minnesota River	Lamberton (MN)	348.75	25.98	22.10	28.10	34.80	742,441	300,462	7.8	0.146	0.185	0.230	55,709	122,838
Mississippi, Lower [7]	Wildcat Mountain (WI)	279.29	18.27	27.00	33.30	39.80	204,450	82,740	5.1	0.125	0.155	0.185	12,785	28,190
Mississippi, Upper [8]	Marcell (MN)	199.20	11.34											
	Camp Ripley (MN)	212.00	11.07											
	Cedar Creek (MN)	303.33	19.88											
	Average	238.18	14.10	22.60	28.10	34.30	3,826,925	1,548,735	29.7	0.081	0.101	0.123	155,847	343,642
Missouri River	Lamberton (MN)	348.75	25.98	21.10	27.20	35.60	29,691	12,016	2.6	0.139	0.179	0.235	2,156	4,755
Rainy River	Voyageurs National Park (MN)	163.33	10.49											
	Fernberg (MN)	182.17	9.28											
	Marcell (MN)	199.20	11.34											
	Average	181.57	10.37	22.40	26.20	32.10	3,770,048	1,525,718	52.4	0.059	0.069	0.085	105,303	232,194
Red River	Icelandic State Park (ND)	252.50	16.47	18.60	23.30	28.90	2,698,658	1,092,132	23.8	0.078	0.097	0.121	106,467	234,760
St. Croix River	Fond du Lac (MN)	165.71	10.65											
	Grindstone Lake (MN)	248.33	16.19											
	Cedar Creek (MN)	303.33	19.88											
	Average	239.13	15.58	23.70	30.60	37.60	680,145	275,251	30.1	0.094	0.121	0.149	33,322	73,474
TOTAL							13,342,753	5,399,738		1.125	1.391	1.747	524,075	1,155,586
	All Sites Average	276.87	19.05											

Note:
[1] National Atmospheric Deposition Program (NADP) monitoring sites that were used to derive estimates of phosphorus deposition for the basin.
[2] Average volume weighted calcium concentration for the monitoring station's period of record; volume-weighted averages calculated by NADP.
[3] For reference sites (special study conducted at the Fernberg, Marcell, Camp Ripley, and Lamberton sites): phosphorus concentration used directly from the special study.
For auxiliary sites: the phosphorus concentration in rainfall is calculated per the following regression equation derived from the reference sites: $y = 0.0671x - 0.4586$ (y is Total Phosphorus in ug/L and x is NADP calcium in ug/L)
If more than one monitoring site is applied to a basin, then the average [P] in rainfall is used to derive the estimate of P deposition.
[4] Dry, average and wet year precipitation volume data based on the 1979-2002 period (using water years october-september). The dry period is defined as the 10th percentile frequency value, the average is the 50th percentile and the wet is the 90th percentile. Derived by the State of Minnesota, State Climatology Office, Dept. of Natural Resources-Waters (2003).
[5a] Basin area is that part of the basin within the state's borders designated as "Water" or "Wetland" in the GIS database.
[5b] Hectares = acres / 2.471 [1 ha = 2.471 acres]
[6] Deposition calculation
[P] in rainfall x rainfall amount x basin area x unit conversion factors = P deposition (kg/yr) over basin
[P] deposition (kg/yr) over basin x (1/basin area) = P deposition kg/ha/yr

[7] Lower Mississippi is that part of the Mississippi downstream of where the St.Croix River merges with the Mississippi.
[8] Upper Mississippi is that part of the Mississippi upstream of where the St.Croix River merges with the Mississippi.

Table 5
Estimated Dry Phosphorus Deposition to Minnesota Basins

Basin	XRF Station [1]	Total Ca conc. [2] (ug/m3)	Total P conc. [3] (ug/m3)	Course Deposition Velocity [4] (cm/sec)	Fine Deposition Velocity [4] (cm/sec)	Course Deposition Rate [5] ($kg\ ha^{-1}\ yr^{-1}$)	Fine Deposition Rate [5] ($kg\ ha^{-1}\ yr^{-1}$)	Total Phosphorus Deposition [6] ($kg\ ha^{-1}\ yr^{-1}$)	Basin Waters and Wetland Area [7a] (acres)	Basin Waters and Wetland Area [7b] (hectares)	% of Total Basin Land Area	Phosphorus Deposition to Waters and Wetlands (kg/yr)	Phosphorus Deposition to Waters and Wetlands (lb/yr)
Cedar River	Albert Lea	1.355	0.039	3.0	0.5	0.215	0.026	0.241	24,523	9,924	3.7	2,390	5,270
Des Moines River	Pipestone	0.386	0.011	3.0	0.5	0.061	0.007	0.069	53,771	21,761	5.5	1,493	3,293
Lake Superior	Virginia (Site 7554)	0.603	0.017	3.0	0.5	0.096	0.012						
	Duluth - Lincoln Sch.	0.249	0.007	3.0	0.5	0.040	0.005						
	Silver Bay	0.241	0.007	3.0	0.5	0.038	0.005						
	Virginia (Site 1300)	0.216	0.006	3.0	0.5	0.034	0.004						
	Duluth - wdse radio	0.115	0.003	3.0	0.5	0.018	0.002						
	Hibbing	0.086	0.002	3.0	0.5	0.014	0.002						
	Average	0.252	0.007			0.040	0.005	0.045	1,312,101	531,000	33.3	23,753	52,376
Minnesota River	North Mankato	0.740	0.021	3.0	0.5	0.117	0.014						
	Brandon Township	0.430	0.012	3.0	0.5	0.068	0.008						
	Granite Falls	0.395	0.011	3.0	0.5	0.063	0.008						
	Willmar	0.291	0.008	3.0	0.5	0.046	0.006						
	Swift County	0.284	0.008	3.0	0.5	0.045	0.005						
	Average	0.428	0.012			0.068	0.008	0.076	742,441	300,462	7.8	22,858	50,402
Mississippi, Lower [8]	Rochester	0.659	0.019	3.0	0.5	0.105	0.013						
	Goodhue County	0.633	0.018	3.0	0.5	0.100	0.012						
	Apple Valley	0.445	0.013	3.0	0.5	0.071	0.009						
	Winona	0.344	0.010	3.0	0.5	0.055	0.007						
	Average	0.520	0.015			0.083	0.010	0.092	204,450	82,740	29.7	7,650	16,868
Mississippi, Upper [9]	St. Paul - Red Rock Rd.	1.324	0.038	3.0	0.5	0.210	0.025						
	Minneapolis Library	0.729	0.021	3.0	0.5	0.116	0.014						
	St. Paul - ross ave	0.577	0.017	3.0	0.5	0.092	0.011						
	Bemidji	0.394	0.011	3.0	0.5	0.062	0.008						
	Minneapolis - river parkway	0.350	0.010	3.0	0.5	0.056	0.007						
	St. Paul - Harding High Sch.	0.346	0.010	3.0	0.5	0.055	0.007						
	Minneapolis	0.308	0.009	3.0	0.5	0.049	0.006						
	Elk River	0.298	0.009	3.0	0.5	0.047	0.006						
	Fort Ripley	0.272	0.008	3.0	0.5	0.043	0.005						
	Alexandria	0.254	0.007	3.0	0.5	0.040	0.005						
	Hutchinson	0.243	0.007	3.0	0.5	0.039	0.005						
	St. Cloud	0.239	0.007	3.0	0.5	0.038	0.005						
	St. Michael	0.236	0.007	3.0	0.5	0.037	0.005						
	Grand Rapids	0.201	0.006	3.0	0.5	0.032	0.004						
	Little Falls	0.160	0.005	3.0	0.5	0.025	0.003						
	Average	0.395	0.011			0.063	0.008	0.070	3,826,925	1,548,735	5.1	108,811	239,928
Missouri	Pipestone	0.386	0.011	3.0	0.5	0.061	0.007	0.069	29,691	12,016	2.6	825	1,818
Rainy River	Warroad	0.382	0.011	3.0	0.5	0.061	0.007						
	I Falls	0.103	0.003	3.0	0.5	0.016	0.002						
	Average	0.243	0.007			0.038	0.005	0.043	3,770,048	1,525,718	52.4	65,761	145,003
Red River	Fergus Falls	0.683	0.020	3.0	0.5	0.108	0.013						
	Moorhead High School	0.678	0.020	3.0	0.5	0.107	0.013						
	Perham	0.499	0.014	3.0	0.5	0.079	0.010						
	Average	0.620	0.018			0.098	0.012	0.110	2,698,658	1,092,132	23.8	120,376	265,430
St. Croix River	West Lakeland	0.204	0.006	3.0	0.5	0.032	0.004						
	Pine County - sandstone	0.111	0.003	3.0	0.5	0.018	0.002						
	Average	0.158	0.005			0.025	0.003	0.028	680,145	275,251	30.1	7,711	17,002
TOTAL								0.843	13,342,753	5,399,738		361,629	797,391

Note:
[1] MPCA's Statewide Air Toxics Monitoring Study (XRF) monitoring sites that were used to derive estimates of phosphorus deposition for the basin.
[2] Average calcium concentration for the monitoring station's period of study (1996 to 2001).
[3] Phosphorus concentrations were calculated using the calcium to phosphorus correlation in wet deposition from the special study conducted at the Fernberg, Marcell, Camp Ripley, and Lamberton sites.
Dry deposition was assumed to contain the same chemical composition as wet deposition. The phosphorus concentrations were calculated per the following regression equation y = (0.0289x)
If more than one monitoring site is applied to a basin, then the average [P]concentration for all of the sites in the basin is used to derive the estimated P concentration.
[4] The deposition velocities are based on recent estimates for phosphorus deposition in Florida and personal communications with Tilden Meyers, NOAA, Oak Ridge National Laboratory.
[5] Course deposition calculation
[P] concentration x PM10 course size fraction in percent x course deposition velocity x unit conversion factors = Course P deposition (kg/ha/yr) over basin.
The PM10 course size fraction (>2.5) was calculated to be 58% of the total PM10. PM10 size fraction was calculated from the five monitoring site in Minesota that have co-located PM2.5 and PM10 monitors.
[5] Fine deposition calculation
[P] concentration x PM10 fine size fraction in percent x fine deposition velocity x unit conversion factors = Fine P deposition ($kg\ ha^{-1}\ yr^{-1}$) over basin.
The PM10 fine size fraction (<2.5) was calculated to be 42% of the total PM10. PM10 size fraction was calculated from the five monitoring site in Minesota that have co-located PM2.5 and PM10 monitors.
[6] Total deposition = sum of course deposition rate and fine deposition rate.
[7a] Basin area is that part of the basin within the state's borders designated as "Water" or "Wetland" in the GIS database.
[7b] Hectares = acres / 2.471 [1 ha = 2.471 acres]
[8] Lower Mississippi is that part of the Mississippi downstream of where the St.Croix River merges with the Mississippi.
[9] Upper Mississippi is that part of the Mississippi upstream of where the St.Croix River merges with the Mississippi.

TOTAL P Deposition

Estimates of average "total" (wet + dry) phosphorus deposition range from ~ 0.102 kg ha^{-1} yr^{-1} in the Rainy River basin (dry year) to 0.513 kg ha^{-1} yr^{-1} in the Cedar River basin (wet year) (Table 6). The largest phosphorus loading of ~ 299,044 kg/yr is found in the Upper Mississippi basin.

As noted in Table 6, dry deposition could only be estimated for an "average" year due to the lack of available data for estimating deposition during a wet or dry year. Therefore, total (wet + dry) estimates for the dry, average, and wet years for each basin in Table 6 use the same dry deposition value, which adds uncertainty to the deposition estimates and therefore the results from Table 6 should be used cautiously.

Table 6
Estimated Total Phosphorus Deposition to Minnesota Basins

Basin	Low Precipitation Phosphorus Deposition [1] (kg ha^{-1} yr^{-1})	Average Precipitation Phosphorus Deposition [1] (kg ha^{-1} yr^{-1})	High Precipitation Phosphorus Deposition [1] (kg ha^{-1} yr^{-1})	Dry Phosphorus Deposition [2] (kg ha^{-1} yr^{-1})	Dry Year Total (wet+dry) Phosphorus Deposition [3a] (kg ha^{-1} yr^{-1})	Average Year Total (wet+dry) Phosphorus Deposition [3b] (kg ha^{-1} yr^{-1})	Wet Year Total (wet+dry) Phosphorus Deposition 3[c] (kg ha^{-1} yr^{-1})	Basin Waters and Wetland Area [4a] (acres)	Basin Waters and Wetland Area [4b] (hectares)	% of Total Basin Land Area [5]	Waters and Wetland Basin Loading Estimate: Dry Year Total (wet+dry) Phosphorus Deposition [6a] (kg/yr)	[7] (lb/yr)	Average Year Total (wet+dry) Phosphorus Deposition [6b] (kg/yr)	[7] (lb/yr)	Wet Year Total (wet+dry) Phosphorus Deposition [6c] (kg/yr)	[7] (lb/yr)
Cedar River	0.1815	0.2118	0.2725	0.2408	0.4223	0.4526	0.5133	24,523	9,924	3.7	4,191	9,241	4,492	9,905	5,095	11,233
Des Moines River	0.1452	0.1848	0.2428	0.0686	0.2138	0.2534	0.3114	53,771	21,761	5.5	4,652	10,258	5,514	12,158	6,777	14,944
Lake Superior	0.0765	0.0873	0.1053	0.0447	0.1212	0.1320	0.1501	1,312,101	531,000	33.3	64,382	141,962	70,118	154,610	79,677	175,689
Minnesota River	0.1458	0.1854	0.2296	0.0761	0.2219	0.2615	0.3057	742,441	300,462	7.8	66,672	147,011	78,567	173,240	91,850	202,529
Mississippi, Lower [8]	0.1253	0.1545	0.1847	0.0925	0.2177	0.2470	0.2771	204,450	82,740	5.1	18,016	39,725	20,435	45,058	22,930	50,561
Mississippi, Upper [9]	0.0809	0.1006	0.1228	0.0703	0.1512	0.1709	0.1931	3,826,925	1,548,735	29.7	234,154	516,309	264,658	583,570	299,044	659,391
Missouri River	0.1392	0.1795	0.2349	0.0686	0.2079	0.2481	0.3035	29,691	12,016	2.6	2,497	5,507	2,981	6,573	3,647	8,042
Rainy River	0.0590	0.0690	0.0846	0.0431	0.1021	0.1121	0.1277	3,770,048	1,525,718	52.4	155,792	343,520	171,065	377,197	194,778	429,485
Red River	0.0778	0.0975	0.1209	0.1102	0.1880	0.2077	0.2311	2,698,658	1,092,132	23.8	205,367	452,835	226,843	500,190	252,432	556,613
St. Croix River	0.0938	0.1211	0.1488	0.0280	0.1218	0.1491	0.1768	680,145	275,251	30.1	33,518	73,908	41,032	90,476	48,655	107,284
State Wide Totals								13,342,753	5,399,738		789,241	1,740,277	885,704	1,952,977	1,004,885	2,215,770

Note:
[1] The phosphorus deposition rates from dry, average and wet precipitation volumes. Dry, average and wet year precipitation volume data based on the 1979-2002 period (using water years october-september). The dry period is defined as the 10th percentile frequency value, the average is the 50th percentile and the wet is the 90th percentile. Derived by the State of Minnesota, State Climatology Office, Dept. of Natural Resources-Waters (2003). See Table 4 for calculation methods.
[2] Includes course and fine dry deposition, See Table 5 for calculation methods. Calculations assumed to be for an "average" precipitation year. There is insufficient information to estimate deposition for a dry or wet year; therefore, dry deposition is only estimated for what is assumed to be an "average" year.
[3a] Total deposition = low precipitation phosphorus deposition + dry deposition
[3b] Total deposition = average precipitation deposition + dry deposition
[3c] Total deposition = high precipitation phosphorus deposition + dry deposition
[4a] Basin area is that part of the basin within the state's borders designated as "Water" or "Wetland" in the GIS database. Surface water included open water, woody wetlands and emergent herbaceous wetlands as defined by the USGS National Landcover database (~1992). This is a landsat based raster data set developed by the USGS with a minimum mapping unit of 30 meters.
[4b] Hectares = acres / 2.471 [1 ha = 2.471 acres]
[5] The percentage of the total land area within a river basin that is designated as water or wetland surface water.
[6a] The total phosphorus deposition rate to the basin water or wetland surface waters. The low precipitation deposition rate + dry depositon rate was used to calculate this total.
[6b] The total phosphorus deposition rate to the basin water or wetland surface waters. The average precipitation deposition rate + dry depositon rate was used to calculate this total.
[6c] The total phosphorus deposition rate to the basin water or wetland surface waters. The high precipitation deposition rate + dry depositon rate was used to calculate this total.
[7] Pounds = kilograms x 2.205 [1 kg = 2.205 lb]
[8] Lower Mississippi is that part of the Mississippi downstream of where the St.Croix River merges with the Mississippi.
[9] Upper Mississippi is that part of the Mississippi upstream of where the St.Croix River merges with the Mississippi.

Phosphorus Loading Variability and Uncertainty

Variability in the Data

Wet Deposition

- Annual average precipitation was used to estimate wet phosphorus deposition. Precipitation can vary significantly from year to year. The estimate of phosphorus deposition in any given year could be significantly different from the annual average wet phosphorus deposition calculated in this project for each river basin. Therefore, the results of this project should be used cautiously in other applications.

Dry Deposition

- No adjustments were made in the estimation of dry deposition in a dry or a wet year. Data are not available at this time to derive estimates of dry deposition during different precipitation regimes. Variability in the amount of dry deposited phosphorus due to different moisture regimes was assumed to remain constant for this project.

Uncertainty in the Data

Wet Deposition

- Establishing the relationship of [P] and [Ca] in precipitation from a limited number of sites (4 reference sites) for a limited time period (2 years) introduces some uncertainty into the wet deposition calculations. It is assumed the two years during which the data were collected are representative precipitation years and were not unduly influenced by unique large storm events. The inclusion of more monitoring sites, for a longer period of time, would likely improve the data to provide a better relationship of [P] and [Ca] in precipitation.
- An individual monitoring site can provide representative data for the surrounding region if the site is adequately selected (NOAA-ARL, 2003). The four "reference" NADP sites used for the phosphorus-in-precipitation study, and the auxiliary NADP sites, are assumed to be representative for the various basins where they have been assigned. However, there is some uncertainty as to the representativeness of some monitoring sites to specific basins. For example, the Lamberton monitoring site is assumed to be representative for all of southwest Minnesota, including the Minnesota River basin which encompasses a large area from the

western border to where it joins the Mississippi River near the Twin Cities. We believe the application of the Lamberton monitoring site data to most of southwestern Minnesota is appropriate, but it does introduce some uncertainty into the calculations due to the large area of the state that is represented by this one monitoring site.

- Wet phosphorus deposition may be underestimated for the Red River basin due to the use of [Ca] in precipitation data from Icelandic State Park, North Dakota, which is on the west side of the Red River Valley. A station on the east side of the Red River Valley may have higher [Ca] in precipitation concentrations than Icelandic State Park due to prevailing winds carrying more dust from the valley to a monitoring site on the east side of the valley. We are not sure this is the case, but the location of Icelandic State Park on the west edge of the Red River valley introduces some uncertainty into the estimate for this basin.

Dry Deposition

- An individual monitoring site is not considered to be necessarily representative of the surrounding region because the controlling factors for dry deposition are surface driven and are not regionally representative (NOAA-ARL, 2003). However, in this application, it was assumed that the MPCA's air toxics monitoring sites were representative of large areas (i.e., the basins in which they were located or to where they were assigned) because they provide an estimate of ambient air PM10 concentrations as opposed to actually measuring dry deposition. There is some uncertainty associated with this assumption because it is possible that the PM10 and Ca concentrations measured on the filters are due to unique local factors that may not occur on a wide scale or in other parts of a river basin. In this case dry deposition could be under-or -overestimated for a specific river basin. The estimates of dry phosphorus deposition may also be under-or-overestimated by applying data collected from population centers to rural areas. The working assumption is that the factors resulting in PM10 and Ca concentrations at the monitoring sites occur on a wide scale or in other parts of the river basin. Again, there is uncertainty in this assumption.
- The relationship of [P] and [Ca] found in precipitation was assumed to be applicable to the particle (PM10) data and the [P] and [Ca] on the filters would be in a similar ratio as found in the precipitation. Currently there are no data supporting this assumption and therefore this assumption adds to the uncertainty in the estimate of dry deposited phosphorus.

Recommendations for Future Refinements

The following recommendations are made to improve the estimates of atmospheric (wet and dry) phosphorus deposition:

1. Additional one to two years of monitoring for [P] and [Ca] in precipitation to improve the ability to extrapolate the findings from the research sites to other locations in the state.
2. Additional sites should be included in the wet deposition monitoring network, particularly in southwest and western Minnesota, to identify significant differences in the [P] and [Ca] relationship due to regional differences, and further improve the ability to extrapolate the findings to other locations in the state.
3. Assess the variability in annual dry deposition in relation to changes in annual precipitation to determine the significance of this project assuming dry deposition is constant for low, average, and high precipitation years.
4. Analysis of the collected PM10 filters using an appropriate analytical method to determine phosphorus concentrations and use this data to determine if the [P] and [Ca] relationship on the filters is similar to, or different from, the [P] and [Ca] relationship in precipitation.
5. Additional particulate monitoring (TSP, PM10) in other areas of the state should be conducted, with a particular emphasis on rural areas and determine whether extrapolation of the particulate filter data to larger regions or river basins is appropriate.
6. A source apportionment study, using chemical mass balance or similar approach, for phosphorus should be conducted to determine if sources other than soil are significant, or could be significant, for phosphorus deposition.

Recommendations for Lowering Phosphorus Export

Soil dust is assumed to be the largest source of atmospheric phosphorus. Therefore, reducing soil dust, particularly from agricultural fields, through the application of best management practices (shelterbelts, no till planting, use of cover crops, etc.) would seem to be a high priority. Another potential activity on a much smaller and local scale to reduce soil dust might include the periodic wetting of exposed soil at large construction sites during dry periods to minimize soil dust being entrained into the air due to wind erosion.

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Northern one-half to one-third of MN:	15 $kg/km^2 \cdot yr^{-1}$
Central:	30+ $kg/km^2 \cdot yr^{-1}$
Southern part of MN with wind erosion:	30 – 40 $kg/km^2 \cdot yr^{-1}$

Appendix A

Phosphorus in Precipitation Study

(Conducted by the St. Croix Watershed Research Station)

(Write-ups as received from the MPCA, September 2003)

INTRODUCTION

Four sites included4 sites (sample times, every 4 weeks), data logger to record precipitation data. MDN website. MDN program

SAMPLE HANDLING

One-liter Teflon sample bottle weights were etched onto bottle. Frontier Geosciences Inc. (Seattle, WA) were responsible for all acid washing of the Teflon sample bottles and sample trains (including inserts) using a perchloric-nitric acid cleaning procedure (claiming proprietary information on procedure). Sample bottles and trains were bagged and shipped by Frontier to each of the four sites. The 1-liter Teflon sample bottles were precharged with 20 (± 0.1) mL 10% v/v HCl preservative (final concentration of preservative = 1.13 N HCl) by Frontier Geosciences (high purity HCl was purchased from Seastar Chemicals cat. # BA-04-0500-certificate of analysis attached).

Sample operators at each of the four sites were responsible for changing the sample bottles at four-week intervals during the two-year study. However, at times, sample bottles were changed sooner due to sample overflow. Also, at times, sample bottles were changed later due to inclement weather, or replacement sample bottles were not available. In some instances, sample bottles were removed and a new sample bottle was not replaced until a later time resulting in missed precipitation collection. At each change out or sampling period, the site operator filled out a data sheet indicating start and stop times of each sample and any other notes that were appropriate.

When changed by the site operators, the one-liter Teflon sample bottles were shipped from each of the four sites to the St. Croix Watershed Research Station (SCWRS) via FedEx (next day). Upon arrival at SCWRS, data sheets were verified and filed, while samples were weighed and recorded. Sample bottle weights (etched into each bottle) were noted and used to calculate the normality of each sample (sample weight including preservative minus sample bottle weight). Samples were refrigerated at 4°C until analyzed. Usually received sample bottles were held until a batch of 40 samples could be run for nutrients and/or trace metals.

LABORATORY ANALYSIS

Samples received at the St. Croix Watershed Research Station were digested and analyzed for Total Phosphorus and Total Nitrogen (TP/TN). Samples were also digested for trace metals and sent to the University of Minnesota Geochemistry Lab (Department of Geology and Geophysics) for trace metal analysis.

Nutrient Dual Digestion

A sample dual digestion (modified from Ameel et. al. and Jones, ND Dept. of Health. unpublished) for both total phosphorus and total nitrogen (TP/TN, unfiltered) was performed in 60-mL high density polyethylene (HDPE) acid washed bottles. 20 g (± 0.5 g) were weighed into a preweighed HDPE digestion bottle on an analytical balance; weights were recorded. Five mL of digestion solution (sodium hydroxide and potassium persulfate) was added. Bottles were loosely capped and autoclaved at 121 °C and 16 psi for 15 min. Samples were removed from the autoclave and cooled in a freezer for 20-30 minutes. When cooled, 0.5 mL of 11 N H2SO4 was added to each bottle. Bottles were again placed back into the autoclave for an additional 30 minutes at 121 °C and 16 psi. Samples were again cooled in a freezer and weighed back. Dilutions were calculated based on sample weight, reagent added, and weight loss during digestion.

Phosphorus calibration standards were diluted from a 250 µg P/L working stock standard. The working stock standard was diluted from a 25 mg P/L stock standard made by dissolving 0.1099 g primary standard grade anhydrous potassium phosphate monobasic (KH_2PO_4) that has been dried for one hour at 105 °C in 1000 mL DIW. Nitrate calibration standards were diluted from a 200.0 mg N/L stock standard made by dissolving 1.444 g potassium nitrate (KNO_2) in 1000 mL DIW.

Mixed quality control check standards (QCSPEX-Nut, SPEX CertiPrep, Inc., Metuchen, NJ) were purchased for both total phosphorus and total nitrogen and diluted to manufacture's specifications. A midrange and low check standard for total nitrogen was diluted to 10.0 and 0.30 mg N/L. Separate dilutions were made for total phosphorus check standards at 100, 25, and 5.0 µg P/L . Allowable recoveries for check standards were +/- 10% with some exceptions of the low TP check standard of 5.0 µg P/L. Since the detection limit of the Total Phosphorus method is close to 5.0 µg P/L, percent relative difference of this low check standard was allowed to be above 10 percent. Instrument blanks as well as procedural blanks were included during analysis and were required to be below 5.0 µg P/L. Over ten percent of the samples were run in duplicate (a duplicate sample is one which has a separate digestion from the original), and aside from a couple of samples, had a percent relative difference less than 10 (some duplicates were less than 5.0 µg P/L). Digestion efficiency standards for both nitrogen (glutamic acid, 1.00 and 8.00 mg N/L) and phosphorus (adenosine 5"-triphosphate disodium salt hydrate, 25 and 100 µg P/L) were included to verify complete conversion of organic species during digestion. Typically the Total Nitrogen efficiency standards were 20-30 percent more than expected (indicating a greater amount of conversion) and Total Phosphorus efficiency standards were usually at least 95% complete. Laboratory fortified samples and spikes were also included to verify no matrix interference and typically had a percent relative difference from the expected value of less than 10. All calibration and check standards as well as blanks, samples, and duplicates were digested in the same manner before analysis.

Total nitrogen analyses were determined on a QuickChem 8000 dual-channel nutrient autoanlayzer (Lachat Instruments, Milwaukee, WI). During the digestion, Organic-N and Ammonium-N are converted to nitrate+nitrite-N. This reduced nitrate plus the original nitrate+nitrite was determined using the cadmium reduction method (Lachat Instruments method 10-107-04-1-A). Nitrate is quantitatively reduced to nitrite by passage of the sample through a copperized cadmium column. The nitrite (reduced nitrate plus original nitrite) forms a magenta color which is read at 520 nm. Seven nitrate calibration standards (0.0, 0.20, 0.40, 1.00, 4.0, 8.0, 20.0 mg N/L) were used to generate a first-order polynomial which uses linear regression to calculate a best fit straight line for all the calibration points. The resulting first-order polynomial is then used for calculating concentration:

$$\text{Concentration} = C(1)\,Y + C(0) \qquad (5)$$

Where:

C(1) = calibration curve first-order coefficient (slope),

C(0) = calibration curve constant term (concentration axis intercept), and

Y = analyte response (peak area)

Direct chemistry was applied to all peaks formed from this method. Direct chemistry calculates only peaks that go positive from the baseline (peak area > 0). Peak base width and threshold values are assumed and then calculated to activate this chemistry. Calibration failure criteria were set for each calibration curve generated. The minimum correlation coefficient allowed (r value) was 0.9900, however, an r value of 1.0000 was usually observed. The detection limit for this method is 0.2 - 20.0 mg N/L as NO3- or NO2-.

Total Phosphorus

Total phosphorus was determined using a QuickChem 8000 dual-channel nutrient autoanalyzer (Lachat Instruments, Milwaukee WI). During the digestion, Organic-P is converted to orthophosphate. The orthophosphate ion (PO_4^{3-}) reacts to form a complex, which absorbs light at 880 nm. The absorbance is proportional to the concentration of orthophosphate in the sample. A modified Lachat manifold for orthophosphate (based on EPA method 365.1) was used to measure total phosphorus simultaneously with total nitrogen. The calibration range used for total phosphorus was 200, 100, 50, 25, 10, 5, 0 µg P/L. A second-order polynomial produced a more suitable calibration fit for the total phosphorus calibration curve. The resulting equation for a second-order polynomial is as follows:

$$\text{Concentration} = C(2)\, Y2 + C(1)\, Y + C(0) \qquad (6)$$

where:

C(2) = calibration curve second-order coefficient,

C(1) = calibration curve first-order coefficient,

C(0) = calibration curve constant term (concentration axis intercept), and

Y = analyte response (peak area)

A 0.231 *N* H_2SO_4 carrier was used on the phosphorus manifold to avoid sample/carrier mismatch.. A Bipolar chemistry was used when integrating the peaks. An r-value of 0.9900 was the minimum correlation coefficient, but typically r-values generated around 0.9995 or higher.

Trace Metals

A trace metal extraction was performed at the St. Croix Watershed Research Station on the received samples. Over ten percent of the samples were run in duplicate. Procedural blanks were included with each batch extracted. Twenty-five ml of sample were poured into a 60-mL Teflon bottle, sample weight was recorded. Depending on the normality of the sample (determined by sample weight and 20 ml preservative), either 2.5 N high purity HCl (Seastar, Baseline) or Type 1 reagent grade DI water was added to adjust each sample to 0.5 N. Samples were loosely capped and digested in an oven at 85oC for 30 min. When samples had cooled, weights were recorded and dilutions calculated. The digested samples were then sent to the University of Minnesota Geochemistry Lab (Department of Geology and Geophysics) to be analyzed on a Perkin Elmer Sciex Elan 5000 inductively coupled plasma mass spectrometer (ICP-MS) for Ni, Cu, Cd, Pb(206, 207, 208), Zn, Cr, Co, Se, Fe, Mn, Ca (and Ba in year 1).

Nickel, Chromium, Cobalt, Selenium, and to some extent Copper and Cadmium showed sample matrix interferences on the ICP-MS. Copper and Cadmium values are reported but should be viewed with caution. Nickel, Chromium, Cobalt, and Selenium values were not used. Barium was analyzed during the first year of the study, but was not analyzed during the second year. Lead isotopes were analyzed and a 206/207 ratio is reported for each year. See QA/QC output.

DATA REDUCTION/CALCULATION

Precipitation data was collected using a rain gauge at each of the four sites and recorded using a datalogger. This information was downloaded from the MDN website. Funnel cross sectional area was also determined and precipitation was calculated using this along with sample weight. This was then compared with the rain gauge data. It appears that the funnel area/sample weight calculation method seemed to underestimate the amount of precipitation that fell when compared to the rain gauge data. This may most likely be due to the inefficiency of the sample collectors (especially in winter when snow can blown in or out of the funnels). Because of this, the precipitation data used is from the rain gauges and is also the data reported on the web site. At certain sites during certain times throughout this two-year study, the data loggers would malfunction and not collect data during precipitation events. In these cases, the MDN web site precipitation manager was contacted and his estimates were given for this missing data (viewed as grayed area in spreadsheet).

During year one of the study, there were two samples that were analyzed for total nitrogen but not total phosphorus. A regression using total nitrogen as an indicator of total phosphorus was generated (Y = 84.5 + 16.2 * X, R2 = .56) and total phosphorus was predicted (highlighted in blue on the spreadsheet). This regression only used samples from year one of the study.

During sample intervals where no sample exists or where an analysis was not measured and a regression could not be used or where results seemed suspect, the averaged results of adjacent sample time periods (during that year or during the other year of the study) were used and then multiplied by the *actual* precipitation that fell during the interval in question. See Table 1 for samples that had averaged values reported and why (also see spread sheet for samples intervals used to average missing sample periods). Because sample intervals many times contained varying amount of days, an attempt was made to use intervals with close to the same number of days (i.e. this is why some missing sample intervals used a different amount of intervals for an average). Results highlighted in green on the spreadsheet are averages from other intervals (and can be found on bottom of spreadsheet). The averaged mass results were used and then back-calculated to determine (ug/L, mg/L, ng/g) .

Sample Collection Time Period	Reason Original Sample Was Not Used	Averaged Sample Time Periods Used To Calculate Result
Lamberton		
4	TP result suspect	Regression of TN samples from Year 1 of study
6	Too little sample for analysis of nutrients and trace metals	5, 7, 18, 19, 20
16	Original Cu result suspect	15, 17, 2, 3, 4
24	Too little sample for analysis of nutrients	23, 25, 10, 11, 12
26	Original nutrient results suspect	25, 14, 12, 13, 1
Camp Ripley		
5	TP result suspect	Regression of TN samples from Year 1 of study
18	Too little sample for analysis of nutrients and trace metals	17, 19, 4, 5, 6
20	Too little sample for analysis of nutrients and trace metals	19, 21, 6, 7, 8
28	Original nutrient results suspect	13, 12, 1, 14, 25, 26, 27
Marcell		
4	Original Cu result suspect	3, 2, 16, 17, 18, 19, 20, 6
5	Original Cu result suspect	19, 20, 6, 18, 17
14	No sample received	27, 13, 26, 1, 15
Fernberg		
2	No sample received	1, 17, 3, 18
4	No sample received	3, 18, 1, 17, 5, 6, 19
8	Original nutrient results suspect, Original Cu result suspect	21, 7, 20, 22,
9	Original Cu result suspect	22, 21, 10, 11, 23, 24
16	No sample received	15, 28, 1, 17
29	No sample received	28, 15, 17, 1

Phosphorus in Precipitation Study

SOP #1

Total P and Total N (TPTN) and/or Dissolved P and Dissolved N (DPDN) Digestion

(6/13/00 Kelly Thommes)

DIGESTION:

1. Samples will be analyzed on the Lachat autoanalyzer for both Total Phosphorus and Total Nitrogen (TPTN, unfiltered) and/or Dissolved Phosphorus and Dissolved Nitrogen (DPDN, filtered through a 0.45 µm filter). Forty-eight samples can be processed per batch (this includes QA/QC samples).

2. Print out sample names using the plastic labels and place on acid-washed 60-mL HDPE bottles. Include project initials, site #, type of water sample (SW or GW), TPTN or DPDN, site name, date, and time. Include calibration standards, check standards, blanks, digestion efficiency standards, duplicates, spikes, lab-fortified blanks, and samples. Ten percent blanks and duplicates should be included. If enough sample exists, use the same sample for the duplicate as for the spiked sample. Include one spiked-sample and one lab-fortified blank for phosphorus and one spiked-sample and one lab-fortified blank for nitrogen. Use Deionized (DI) water for the zero calibration standards, blanks, and lab-fortified blanks.

3. Using the spreadsheet generated for labels, record the weight of the labeled bottles (with cap) using the analytical balance connected to the laptop computer.

4. Remove cap, and tare the 60-mL HDPE bottle on the balance. Pour 20 g (+/- 0.5 g) calibration standard, check standard, efficiency standard, duplicate, blank, or sample into the 60-mL HDPE bottle. Remove the bottle and replace cap. Tare the balance and record weight of the bottle+sample with cap.

5. When pouring out the spiked-sample or lab-fortified blank, record the sample weight (20 g +/- 0.5 g). Using a calibrated auto pipette, add 3 mL of the 100 µg P/L calibration standard for the phosphorus spiked-sample and phosphorus lab-fortified blank. Add 3 mL of the 8.00

mg N/L calibration standard for the nitrogen spiked-sample and nitrogen lab-fortified blank. Record weights of spike added.

6. Using the calibrated 5-mL auto pipette, add 5 mL of digestion solution (made from the ND-SOP) to each bottle. Cap tightly and shake to mix. Place loosely capped sample bottles in autoclave and digest for 15 min at 121 ^oC and 16 psi. Remove samples from autoclave and cool in freezer for 20-30 min (keep caps loosened). When cool enough to handle, add 0.5 mL of 11 *N* H_2SO_4 to each bottle, cap tightly, and shake to mix. Place loosely capped bottles back into autoclave for an additional 30 min at 121 ^oC and 16 psi. Again, cool samples in freezer. When cool enough to handle, tightly cap and shake bottles. Dry bottles if wet and record bottle+sample weight.

7. Samples can now be run using the Lachat autoanalyzer. Samples should be run preferably the same day or no more than a couple of days after the digestion.

DIGESTION REAGENTS AND STANDARDS:

Digestion Solution

To a 1-L volumetric, dissolve 10.48 g of granular sodium hydroxide (NaOH) and 42 g of potassium persulfate ($K_2S_2O_8$) in approximately 900 mL of DI reagent grade water. When dissolved, bring to volume.

11 *N* Sulfuric Acid (H_2SO_4)

To a 1-L volumetric and in a fumehood, add 305 mL of concentrated sulfuric acid to about 600 mL of DI reagent grade water. The volumetric should be surrounded by an ice bath while at the same time swirled to reduce the heat. When cool, bring to volume.

Phosphorus Stock Standard 25 mg P/L

To a 1-L volumetric, dissolve 0.1099 g primary standard grade anhydrous potassium phosphate monobasic (KH_2PO_4) that has been dried for one hour or overnight at 105 ^oC in about 800 mL DI reagent grade water. Bring to volume and invert to mix.

Phosphorus Working Stock Standard 250 µg P/L

To a 1-L volumetric, dilute 10 mL Phosphorus Stock Standard to the mark with DI reagent grade water. Invert to mix.

Nitrogen Stock Standard 200.0 mg N/L as NO_3^-

To a 1-L volumetric, dissolve 1.444 g potassium nitrate (KNO_3) in about 600 mL DI reagent grade water. Dilute to mark and invert to mix.

Phosphorus Working Standards 0, 5, 10, 25, 50, 100, 200 µg P/L

5 µg P/L	5 mL of P Working Stock Standard (250 µg P/L) in a 250-mL volumetric
10 µg P/L	10 mL of P Working Stock Standard (250 µg P/L) in a 250-mL volumetric
25 µg P/L	0.25 mL of P Stock Standard (25 mg P/L) in a 250-mL volumetric
50 µg P/L	0.50 mL of P Stock Standard (25 mg P/L) in a 250-mL volumetric
100 µg P/L	1.00 mL of P Stock Standard (25 mg P/L) in a 250-mL volumetric
200 µg P/L	2.00 mL of P Stock Standard (25 mg P/L) in a 250-mL volumetric

Nitrogen Working Standards 0.00, 0.20, 0.40, 1.00, 4.0, 8.0, 20.0 mg N/L

0.20 mg N/L	0.25 mL of N Stock Standard (200.0 mg N/L) in a 250-mL volumetric
0.40 mg N/L	0.50 mL of N Stock Standard (200.0 mg N/L) in a 250-mL volumetric
1.00 mg N/L	1.25 mL of N Stock Standard (200.0 mg N/L) in a 250-mL volumetric
4.0 mg N/L	5.00 mL of N Stock Standard (200.0 mg N/L) in a 250-mL volumetric
8.0 mg N/L	10.0 mL of N Stock Standard (200.0 mg N/L) in a 250-mL volumetric
20.0 mg N/L	25.0 mL of N Stock Standard (200.0 mg N/L) in a 250-mL volumetric

Check Standards Amp 2 for TN and TP (Record Lot # on volumetric and bench sheet)

5 µg P/L, 25 µg P/L, 100 µg P/L with 0.30 mg N/L, 10 mg N/L

Stock Adenosine 5'-triphosphate disodium salt hydrate (Aldrich A26209) 99% pure, 50 mg P/L

To a 1-L volumetric, dissolve 0.2996 g Adenosine 5'-triphosphate disodium salt hydrate that has been dried for one hour or overnight at 105 °C in about 800 mL DI reagent grade water. Bring to volume and invert to mix.

Phosphorus Efficiency Standard 100 µg P/L

To a 250-mL volumetric, add 0.50 mL Stock Adenosine (50 mg P/L) and bring to volume.

Phosphorus Efficiency Standard 25 µg P/L

To a 250-mL volumetric, add 0.125 mL Stock Adenosine (50 mg P/L) and bring to volume.

Stock Glutamic Acid 100 mg N/L

To a 1-L volumetric, dissolve 1.3366 g glutamic acid that has been dried for one hour or overnight at 105 °C in about 800 mL DI reagent grade water. Bring to volume and invert to mix.

Nitrogen Efficiency Standard 8.00 mg N/L

To a 250-mL volumetric, add 20.0 mL Stock Glutamic Acid (100 mg N/L) and bring to volume.

Nitrogen Efficiency Standard 1.00 mg N/L

To a 250-mL volumetric, add 2.50 mL Stock Glutamic Acid (100 mg N/L) and bring to volume.

AUTOMATED COLORIMETRIC PROCEDURE ON THE LACHAT QUICHEM 8000 AUTOANALYZER

	Phosphorus	Nitrogen
Method	SCWRS Method	10-107-04-1-A
Sample Loop	133 cm	Microloop
Interference Filter	880 nm	520 nm
Chemistry	Bipolar	Direct
Inject to Peak Start		
Peak Base Width		
% Width Tolerance		
Threshold		
Method Cycle Period		
Probe in Sample		
Sample reaches 1st Valve		
Load Period		

LACHAT REAGENTS

PHOSPHORUS MANIFOLD

Stock Ammonium Molybdate Solution

To a 1-L volumetric, dissolve 40.0 g ammonium molybdate tetrahydrate [$(NH_4)_6Mo_7O_{24}$•$4H_2O$) in approximately 800 mL of DI reagent grade water. Dilute to mark and mix with a magnetic stirrer for at least four hours. Store in plastic and refrigerate.

Stock Antimony Potassium Tartrate Solution

To a 1-L volumetric, dissolve 3.0 g antimony potassium tartrate (potassium antimony tartrate hemihydrate $K(SbO)C_4H_4O_6$•$1/2H_2O$) in approximately 800 mL of DI reagent grade water. Dilute to mark and mix with a magnetic stirrer until dissolved. Store in a dark bottle and refrigerate.

Working Molybdate Color Reagent

To a 1-L volumetric, add approximately 500 mL DI reagent grade water and 20 mL concentrated H_2SO_4. Swirl until cool and add 213 mL of Stock Ammonium Molybdate Solution, then add 72 mL of Stock Antimony Potassium Tartrate Solution. Dilute to mark and invert to mix. Degas with helium.

Working Ascorbic Acid

To a 1-L volumetric, dissolve 60.0 g ascorbic acid in approximately 900 mL of DI reagent grade water. When dissolved, dilute to mark. Degas with helium. Add 1.0 g sodium dodecyl sulfate ($CH_3(CH_2)_{11}OSO_3Na$). Invert to mix. Prepare fresh weekly.

Phosphate Carrier 0.231 N H_2SO_4

Dilute 21 mL of 11 N Sulfuric Acid to 1-L volumetric with DI reagent grade water. Degas with helium.

Sodium Hydroxide-EDTA Rinse

To a 500-mL volumetric, dissolve 32.5 g sodium hydroxide (NaOH) and 3 g tetrasodium ethylenediamine tetraacetic acid (Na_4EDTA). Dilute to mark and invert to mix. Store at room temperature. Use this to clean phosphorus manifold lines. Pump reagent through for about five minutes followed by DI water for five minutes.

NITROGEN MANIFOLD

15 *N* Sodium Hydroxide (NaOH)

To a 500-mL volumetric, add 75 g NaOH very slowly to approximately 250 mL of DI reagent grade water. Caution: the solution will get very hot. Swirl until dissolved. Cool and store in a plastic bottle at room temperature.

Ammonium Chloride Buffer, pH 8.5

To a 1-L volumetric, dissolve 85.0 g ammonium chloride (NH_4Cl) and 1.0 g disodium ethylenediamine tetraacetic acid dihydrate ($Na_2EDTA \bullet 2H_2O$) in approximately 800 mL DI reagent grade water. Dilute to mark and invert to mix. Adjust pH to 8.5 with 15 N sodium hydroxide.

Sulfanilimide Color Reagent

To a 1-L volumetric, add approximately 800 mL DI reagent grade water. Add 100 mL 85% phosphoric acid (H_3PO_4), 40.0 g sulfanilimide, and 1.0 g N-(1-naphthyl)ethylenediamine dihydrochloride (NED). Shake until wetted and stir to dissolve for 30 min. Dilute to mark and invert to mix. Store in a dark bottle. This solution is stable for one month.

REFERENCES

Standard Operating Procedure For the Analysis of Total Phosphorus and Total Nitrogen in Water From an Alkaline Persulfate Digest, North Dakota Dept. of Health, Chemistry Div.

EPA (March 1983) Method 353.2 (colorimetric automated, cadmium reduction)

Lachat (Aug 1994) QuikChem Method 10-107-04-1-A (Nitrate/Nitrite)

Lachat (Feb 1996) QuickChem Method 10-115-01-1-B (Determination of Orthophosphate by FIA Colorimetry)

Phosphorus in Precipitation Study

SOP #2
Trace Metal Extraction for Precipitation Samples
(5/15/00 Kelly Thommes)

1. Make up 1 L of 2.5 N HCl. Use high purity acid from Seastar. Include lot # of acid on bench sheet. When making up acid, anything coming into contact with the acid must be *extremely* clean. Volumetric should be acid washed, triple rinsed with DI water, and rinsed with a small amount of the high purity acid before using. Use a final rinse of DI water.

2. Teflon sample bottles must be labeled with the special plastic lab labels. MPCA sample #'s should be printed on the labels using the laser printer.

3. We will be running 10% duplicates. After every 10^{th} sample, include a duplicate sample from that batch. Include 1 lab blank per batch and also run field blanks (acid preservative sent to us) as samples if available.

4. Record weight of Teflon bottle (including cap) on bench sheet (use laptop hooked to top-loading balance).

5. While wearing gloves, pour out 25 mL of sample into 60-mL Teflon bottle. Record sample weight on bench sheet.

6. Working from bench sheet , add 2.5 N HCl in calculated amount to adjust samples to 0.5 N. Use lab adjustable pipette that has been calibrated prior to each addition. Record weight (using balance) on bench sheet. Swirl sample to mix.

7. In some instances the sample will need to be diluted with DI-water to adjust the sample to 0.5 N. Use DI-water that has been recently taken from the *"point of use gun"* on the Millipore DI unit. Record weight of DI-water added.

8. Loosely cap bottles and digest in oven at 85 ^{o}C for 30 min. Include a PP bottle with DI and thermometer to determine when samples reach 85 ^{o}C (usually 1-1.5 hours) and then digest for 30 min. after samples have reached the appropriate temperature.

9. After digestion, cool completely in a refrigerator or freezer, cap tightly, and weigh bottle on balance. Record weight.

10. Calculate dilution and sample matrix.

11. Digested samples should be stored in refrigerator prior to sending to U of MN (Rick Knurr) for ICP-MS analysis. Send Rick approximately 100 ml of sample matrix for standards (i.e. 0.5 N HCl sample matrix-dilute 2.5 N HCl).

Trace metals of interest: Ni, Cu, Cd, Pb, Zn, Cr, Co, Se, Fe, Mn, Ca, Al

Technical Memorandum

To: Marvin Hora, Minnesota Pollution Control Agency
Mark Tomasek, Minnesota Pollution Control Agency
Doug Hall, Minnesota Pollution Control Agency

From: Jeffrey Lee

Subject: Detailed Assessment of Phosphorus Sources to Minnesota Watersheds – Deicing Agents

Date: December 17, 2003

Project: 23/62-853 DEIC 008

c: Greg Wilson
Henry Runke

The purpose of this memorandum is to provide a discussion on deicing agents as sources of phosphorus to Minnesota watersheds. This discussion is based on a review of the available literature, monitoring data and the results of phosphorus loading computations done for each of Minnesota's major watershed basins as part of this study. This memorandum is intended to:

- Provide an overview and introduction to deicing agents as a source of phosphorus
- Describe the results of the literature search and review of available monitoring data
- Discuss the characteristics of each watershed basin as it pertains to deicing agents as a source of phosphorus
- Describe the methodology used to complete the phosphorus loading computations and assessments for this study
- Discuss the results of the phosphorus loading computations and assessments
- Discuss the uncertainty of the phosphorus loading computations and assessment
- Provide recommendations for future refinements to phosphorus loading estimates and methods for reducing error terms
- Provide recommendations for lowering phosphorus export from deicing agents

Overview and Introduction to Deicing Agents as Source(s) of Phosphorus

The use of deicing chemicals has increased in the U.S. since the 1940s and 1950s to provide "bare pavement" for safe and efficient winter transportation. As more and more transportation agencies adopted the "bare pavement" policy, the use of salt, salt and sand mixtures, liquid brines and alternative deicers increased with the need to maintain this standard for pavement conditions during inclement weather. Sodium chloride (NaCl) is one of the most commonly used deicing chemicals. Concern about the effects of sodium chloride on the nation's environment and water quality has increased with this chemical's continued usage.

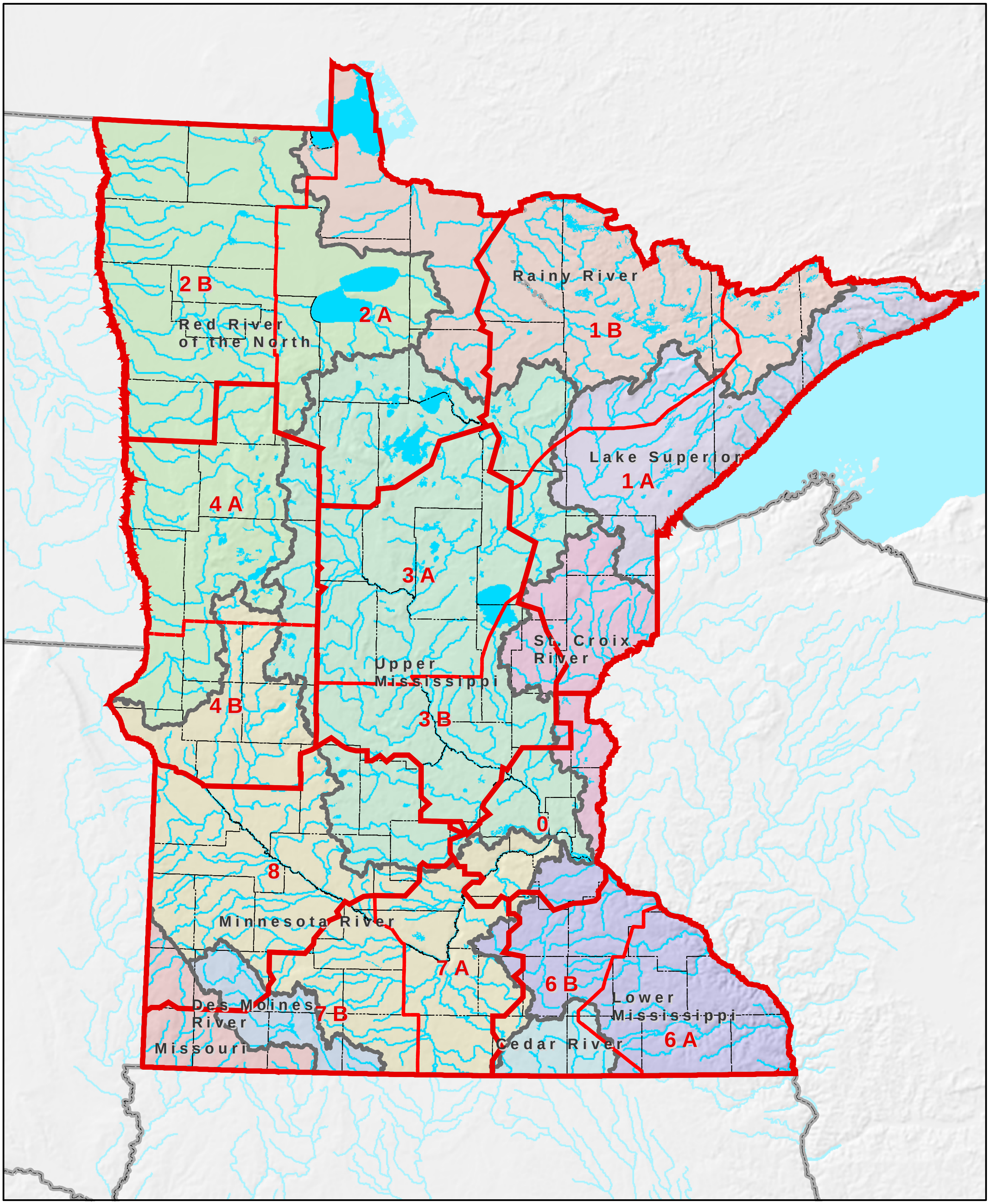
As environmental and associated impacts of salt usage became better documented, the Minnesota Department of Transportation (MnDOT) began implementing procedures to reduce the usage of salt and sand on the state maintained roadway system. In 1996 MnDOT conducted a pilot project – Salt Solutions – to develop tools for reducing their usage of deicing agents, while maintaining safe roadways (SRF Consulting Group, 1998). Following a successful pilot project in winter of 1996-97, the program was adopted state-wide. Other road agencies in Minnesota such as cities, townships and counties use deicing agents to maintain a similar standard for pavement conditions during inclement weather. Many of these agencies have less rigorous record keeping programs than MnDOT.

The search for alternatives to salt for road deicing has been prompted primarily due to the infrastructure corrosion concerns and the impacts of chloride on water quality and vegetation. Recent research in Colorado, New York, and British Columbia have documented water quality concerns related to phosphorus and other chemicals present in deicing agents, as well as the alternative compounds. Due to the recent nature of the work on phosphorus in road salt and alternative deicers, the amount of information present in the scientific literature is somewhat limited, scattered, and quite variable in quality.

Results of Literature Search and Review of Available Monitoring Data

Review of the existing scientific literature with regard to deicing agents as a phosphorus source was concerned with three major areas; 1) usage patterns of deicing agents in Minnesota and other states with regard to road types and road management agency, 2) the phosphorus content of deicing agents – salt, sand, and deicing alternatives, and 3) the impact of weather patterns on usage levels.

The data available for the usage patterns of deicing within the state of Minnesota available from MnDOT is extensive and detailed (MnDOT, 2003; MnDOT Office of Maintenance. 2003; MnDOT Office of Transportation Data & Analysis. 2002). MnDOT has undertaken extensive analyses of usage patterns with regard to road type, service levels and weather patterns. In 1996 MnDOT began a program to reduce the usage of deicers in District 1 and has subsequently expanded the program statewide (SRF Consulting Group, 1998). Figure 1 provides the MnDOT District boundaries in relation to the basin boundaries. The Minnesota Office of Legislative Auditor completed a report that identified some of the best techniques for snow and ice control in Minnesota with the purpose of



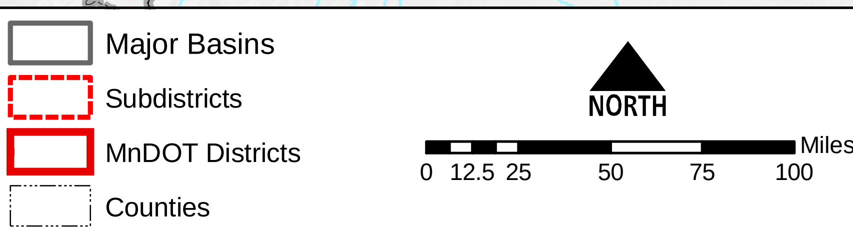


FIGURE 1
Major Basins with MnDOT
Subdistricts

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cataloging effective methods of snow and ice control and to encourage the adoption of practices as appropriate throughout the state (Minnesota Legislative Auditor, 1995). While this report attempted to identify practices, it provided little quantitative data on application rates and usage levels. Table 1 presents a summary of the local government salt to sand mix uses from this report.

The states of California, Colorado, Michigan and New Hampshire; as well as the province of British Columbia, Environment Canada and the U.S. Department of Transportation Federal Highway Administration have undertaken studies on the usage of deicing agents in an effort to document and reduce the environmental impacts of their use (Environment Canada and Health Canada, 2001; Fischel, 2001; Goldman, and Hoffman, 1975; Lewis, 1999; Public Sector Consultants, 1993; U.S. Department of Transportation Federal Highway Administration, 1996; Warrington, 1998; University of New Hampshire, 1996;) In nearly all cases, the various studies recommend that service levels be established to define acceptable road conditions and deicing guidelines that define the frequency of winter maintenance and service level needs based upon weather conditions. MnDOT and many other road agencies have developed and implemented sand and salt application guidelines to ensure safe roads and minimize the application of deicers. MnDOT has established targets for snow and ice removal based upon service levels:

Road Class	Avg. Annual Daily Traffic	Target Time to Bare Lane
Super Commuter	More than 30,000	1-3 hours
Urban Commuter	10,000-30,000	2-5 hours
Rural Commuter	2,000-10,000	4-9 hours
Primary	800-2,000	6-12 hours
Secondary	Under 800	9-36 hours

Attainment of the desired pavement conditions is dictated by several factors, including weather conditions and pavement temperature. Weather conditions, precipitation type and temperature determine the deicing mixture (ratio of sand to salt) or compound to be used, the rate of application (quantity per lane mile) and the frequency of application. The summary data for the state highway system and Twin Cities Metropolitan Area (TCMA) county roads in Tables 2 and 3 illustrates how the implementation of the maintenance guidelines is impacted by weather and the road service level needs across the state and TCMA counties.

Many local road agencies such as the City of Duluth and some out-state counties have adopted application guidelines similar to MnDOT guidelines, but a review of the literature yielded few examples of specific guidelines (Duluth Streams, 2003; SRF Consulting Group, 1998). Review of Minneapolis and St. Paul NPDES stormwater permit annual reports, various MnDOT reports and a database prepared by the Ramsey-Washington Metro Watershed District provided some information related to annual usage rates. In most cases the information in these reports did not provide detailed usage data that could be converted to lane mile usage levels. Lane mile usage levels were calculated or provided for the MnDOT data (City of Minneapolis and Minneapolis Park and Recreation Board, 2003; Weber, 2003; Watson, 2003; Ramsey-Washington Metro Watershed District. 1999; SRF Consulting Group, 1998;). SRF Consulting Group (1998) provided information on usage rates for the TCMA county road agencies for the winter of 1994 – 98. Information provided by Minnesota

Legislative Auditor (1995) indicates that many local units of government use higher ratios of sand to salt than does MnDOT. Some counties, such as Pine, St. Louis and Lake, report the use of sand only for winter road maintenance, while data for the eight TCMA counties indicates that the TCMA counties use a higher salt to sand ratio than what was indicated for other counties across the state (SRF Consulting Group, 1998). In many areas of the state MnDOT, some cities and counties now exclusively use salt without the use of sand for road deicing purposes.

Table 1. Percent of Local Governments Using Various Ratios of Sand to Salt in Mix (from: Minnesota Legislative Auditor, 1995)

Percent of Sand in Mix	Counties (n = 68)	Cities (n = 137)	Townships (n = 6)
99 to 90%	47%	28%	50%
89 to 80%	29%	39%	17%
79 to 70%	15%	10%	0
Less than 70%	3%	9%	16%
No Reply	6%	14%	17%

Table 2. MnDOT Sand & Salt Application Summary Analysis (Winter of 2002-2003)

Summary per District			
District	**Average Sand (Tons)/LM**	**Average Salt (Tons)/LM**	**Salt: Sand Ratio**
1	7.8	6.9	0.5
2	3.5	2.5	0.4
3	3.5	5.8	0.6
4	3.4	3.5	0.5
METRO	0.4	11.4	1.0
6	4.5	8.0	0.6
7	2.2	3.3	0.6
8	3.6	2.6	0.4
STATEWIDE	3.5	5.9	0.6
Summary per Service Level			
Service Level	**Average Sand (Tons)/LM**	**Average Salt (Tons)/LM**	**Salt: Sand Ratio**
Primary	3.6	3.5	0.5
Rural Commuter	4.3	5.0	0.5
Super Commuter	0.6	11.2	1.0
Secondary	3.6	3.1	0.5
Urban Commuter	3.6	9.0	0.7
ALL	3.5	5.9	0.6

Data based on MNDOT Report PS1A6 – "Sand, Salt, Brine Usage; Coverage Rates by Lane Miles Only" from 10/15/2002 to 4/20/2003

Table 3. TCMA County Road Agency Sand & Salt Application Summary (from: SRF Consulting Group, 1998).

Year	Sand Ap (tons/LM)	Salt Ap (tons/LM)	Sand + Salt Ap (tons/LM) *	% Salt
1994-95	10	5	15	33%
1995-96	15	7	22	32%
1996-97	16	8	24	33%
1997-98	12	7	19	37%
AVG	13.25	6.75	20	33.75%

*Calculated from data in SRF Consulting Group, 1998
Number of counties = 8

As a review of existing literature was undertaken it became obvious that the application rates and mixtures of deicers used are strongly predicated by weather conditions. Initially the concept of wet, dry and average year were proposed as the means of defining the average and extreme conditions. However a further examination of the MnDOT records indicated that the number of “events” per season appeared to be the driving factor in the quantities of material applied (MnDOT, 2003; MnDOT Office of Maintenance. 2003; MnDOT Office of Transportation Data & Analysis, 2002;). There was a limited amount of information as to how these vagaries in weather patterns impacted usage levels by counties and local units of government (SRF Consulting Group, 1998). The MnDOT application guidelines listed below in Table 4 provide some insight into this pattern.

Table 4. MnDOT Sand and Salt Application Guidelines (from: SRF Consulting Group, 1998)

Pavement Temperature	Weather Conditions	Pounds per Two Lane Mile	Operation
30+	Snow	200 - 400	As needed
	Freezing rain	200	Re-apply as necessary
25 - 30	Wet Snow	400 - 500	Re-apply as necessary
	Freezing rain	300	Initial
		200	Re-apply as necessary
20 - 25	Wet snow / sleet	1200 sand/salt	Repeat as necessary
	Freezing rain	1200 sand/salt	Repeat as necessary
15 - 20	Dry snow	1200 sand/salt	Sand hazardous areas 20:1 Sand/salt mixture (stockpile)
	Wet snow / sleet	1200 sand	Repeat as necessary
Below 15	Dry Snow	1200 - 1500	Sand hazardous areas 20:1 Sand/salt mixture (stockpile)

Based upon an assessment of the snow data and usage levels provided by MnDOT for the period of 1971 to 2003 the amount of winter snow was used as a surrogate for the number of events. The high variability in the number of events between regions of the state in any given year, as well the year-to-year variability in the number of events precluded the use of events in this analysis. The winter snow fall amount at MSP Airport was used to define average, dry (low snowfall – 90^{th} percentile) and wet (10^{th} percentile) conditions.

As the concern over and documentation of the environmental impacts of deicing agents has increased, a number of authors and agencies have attempted to document the concentrations of other elements or compounds of concern that are introduced into the environment through road deicing. Some of the earliest studies were in high quality water basins such as Lake Tahoe and the TCMA (Goldman and Hoffman, 1975; Oberts, 1986). Subsequent studies have furthered the analyses and widened the scope of study (Environment Canada and Health Canada, 2001; Fischel, 2001; Lewis, 1999; Public Sector Consultants, 1993; Levelton Engineering, 1998, 1999, and 2000; Tierney and Silver, 2002;). Recent concern over the environmental impacts of chloride has led to searches for alternatives to salt and also widened the concerns for other elements present in these substances. Much of the recent research shows that road salt still is the best alternative for road deicing (Ohrel, 2000). Mangold (2000) references several studies that express concern over the biological oxygen demand exerted on surface waters by the acetate based substitutes and the New York State Attorney

General Office's analysis of the phosphorus content of readily available deicers has heightened concerns for protection of the New York water supply (Tierney and Silver, 2002;). The results from New York and the Levelton Engineering reports (1998, 1999, and 2000) document a wide variety of substances present in deicers and the concern over elevated levels of phosphorus in the deicers derived from agricultural waste products. Table 5 summarizes results from these various analyses and shows the wide variation in phosphorus concentrations among deicers.

Table 5. Phosphorus Concentrations in Deicers

Company or Item	Product or Product Constituent Name	Description	Total Phosphorus (ppm*)
Magnesium Chloride Deicing Products	Sears Ecological Applications Co. $MgCl_2$ (30% solution)**	From Dead Sea	6.2 (1)
	Sears Ecological Applications Co. Magic-O: Laboratory measured value of product consisting of top two components	Ice B' Gone 1 (Spanish Cane) + $MgCl_2$-50:50***	164.8 (1)
	Sears Ecological Applications Co. Magic-O: Estimate calculated from ratio of above two components	Ice B' Gone 1 (Spanish Cane) + MgCl2-50:50	194.2 (1)
	Sears Ecological Applications Co. Magic-O	Ice B' Gone 1 (Venezuelan Cane) + $MgCl_2$-50:50	50.8 (1)
	Sears Ecological Applications Co. Magic-O	Ice B' Gone 1 (Sugar Beet) + $MgCl_2$ 50:50	108.7 (1)
	Sears Ecological Applications Co. Ice B' Gone 2	Synthetic product	0.81 (1)
	Natural Solutions Summit M	Corn Steep residue + $MgCl_2$- 50:50	2281.9 (1); 3692.4(1)#
	Natural Solutions Performance Plus M	Corn Steep residue + $MgCl_2$- 16:84	1556.1 (1); 2062.1(1)#
	Natural Solutions Ultra M	Corn-based product + $MgCl_2$	13.4 (1); 16.7 (1)#
	Natural Solutions $MgCl_2$ (30% solution)**	From Great Salt Lake	13.4 (1); 12.1 (1)#
	SWP Caliber M1000	Manufactured corn product + $MgCl_2$-10:90	109.4 (1)
	SWP Caliber M2000	Manufactured corn product + $MgCl_2$-20:80	249.6 (1)
	SWP $MgCl_2$ w/rust inhibitor		259.5 (1)

	SWP NC-3000	Carbohydrate, potassium carboxylates mix	90.6 (1); 50.5 (1)##
	Envirotech FreezGard Zero	$MgCl_2$	42 (5)
	FreezGard Zero (with 4% Ice Ban)	$MgCl_2$	230 (4)
	FreezGard Zero/TEA	MgCl2 + Triethanolamine Inhibitor (5% by weight)	13 (4)
	80% Freezgard + 20% Ice Ban	$MgCl_2$ + Ice Ban	800 (4)
	50% $MgCl_2$ + 50% Ice Ban		2,160 (4)
	Calibre M1000	MgCl2 + 10% Corn-based Inhibitor	76 (4)
Calcium Chloride Deicing Products	Natural Solutions Performance Plus C	Corn Steep residue + $CaCl_2$-50:50	2,133.4 (1)
	Natural Solutions Performance Plus C	Corn Steep residue + $CaCl_2$-16:84	863.2 (1)
	Liquidow $CaCl_2$ (Dow)	$CaCl_2$	30 (4)
	Inhibited $CaCl_2$ (Dow)	CaCl2 with 4% Dow organic inhibitor	53 (4)
	50% $CaCl_2$ + 50% Ice Ban		3,840 (4)
	70% $CaCl_2$ + 30% Ice Ban		2,600 (4)
	80% CaCl2 + 20% Ice Ban		230 (4)
	Calibre C1500	CaCl2 + 15% Corn-based Inhibitor	324 (4)
Other Deicing Products	Sears Ecological Applications Co. Ice B' Gone (concentrate)**	Spanish cane sugar byproduct	323.4 (1)
	Ice Ban	Byproduct from wet milling of corn and alcohol production	10,700 (4)
	Liquid CMA (25%)	Calcium Magnesium Acetate	24 (4)
	Liquid KA (50%)	Potassium Acetate	86 (4)
	Liquid CMAK	50% CMA + 50% KA	120 (4)
Salt	Westchester County salt		4 (1)
	Westchester County salt		1 (1)
	Delaware Co. NYSDOT salt		2 (1)
	Leslie Foods, Newark, California		0.213 (3)

	Utah Salt Co., Salt Lake City, Utah		0.231 (3)
	Southwest Salt Co., Los Angeles, California		25.696 (3)
	Morton Salt Co., Burlingame, California		0.872 (3)
	West Coast Salt & Milling Co., Bakersfield, California		14.312 (3)
	NaCl Brine 23%		<2 (4)
	23% NaCl Brine + 20%Ice Ban		1020 (4)
	NaCl plus 10% Calibre Inhibitor	NaCl + 10% Corn-based Inhibitor	559 (4)
	Minnesota Road Salt		4.6 (2)
	Hennepin County Hwy Dept Salt		1 (6)
Sand	Westchester County sand		53.4 (1)
	Westchester County sand		55 (1)
	Hennepin County Hwy Dept Sand		4.7 (6)
Salt:Sand	Delhi (10:90)		113.5 (1)
	Walton Village (10:90)		55 (1)
	Bloomville salt/sand (10:90)		163.5 (1)
	Colorado Salt/Sand (18:82)		1.91 (5)
	Colorado Salt/Sand (5:95)		3.23 (5)
	Colorado Salt/Sand (5:95)		2.47 (5)

Notes: * ppm = parts per million

** Product constituents = Ice B' Gone 1 concentrate and MgCl2 or magnesium chloride salt (30% solution)

*** 50:50 = A ratio consisting of 50% Ice B'Gone 1 and 50% MgCl2.

Sample re-analyzed

Product was analyzed twice with a duplicate analysis each time. Agreement between duplicates was poor and outside quality control limits. Results of the four analyses ranged from 14.9 to 112.8 ppm. Lab concluded that there was interference with this sample and the method.

Source: (1) Office of NY Sate Attorney General, 2002. Scientific Guidance on Lower-Phosphorus Roadway De-icers http://www.oag.state.ny.us/environment/deicer.html

(2) Biesboer and Jacobson, 1993.

(3) Goldman and Hoffman, 1975.

(4) Levelton Engineering Ltd. 1998.

(5) Lewis, 1999.

(6) Oberts, 1986.

Phosphorus Concentrations in Deicing Agents

Unfortunately much of the analysis done for phosphorus content have not been conducted under any type of standard testing protocol; as such much of the available data had to be converted to a standard measure of phosphorus concentration. For purposes of this analysis, all of the data was converted to concentration in parts per million (mg P/L or mg P/kg). The statistical summary data presented in Table 5 for salt, sand and salt/sand mixtures were the used for the phosphorus load calculations completed for the deicing agents for each of the basins.

Table 5a. Summary statistics for salt, sand and salt/sand mixtures; all values in ppm – phosphorus.

	Salt (NaCl)	Sand	Sand salt mixes
Mean	4.99	37.70	33.93
Std. Dev.	7.97	28.59	55.05
Number	11	3	13

Watershed Basin Characteristics

The literature review made it obvious that the application rates and mixtures of deicers used are strongly predicated by weather conditions that are not always closely related to total annual precipitation levels. An assessment was completed for the snow and deicer usage levels provided by MnDOT for the period of 1971 to 2003. The lack of long term data on number of events, coupled with the high variability in the number of events between regions of the state in any given year and the year-to-year variability in the number of events precluded the use of events in this analysis. Based upon this data the amount of winter snow was used as a surrogate for the number of events, as the number of events is the main determinant for the amount of sand used in a winter season. Based upon this data the winter snow fall amount at MSP Airport was used to define average, dry (low snowfall – 90^{th} percentile) and wet (10^{th} percentile) conditions. The amount of deicer usage (sand and salt) varied between road class service levels, as did the ratio of sand and salt. The variation in weather patterns that determine the deicer usage appear to be too complex to define accurately across all of the basins on a year-to-year basis, so weather variability based upon annual snow fall and ratios established between the districts was based upon the best data years (1994-98 and 2002-03). Table 8 provides a tabular summary of the weather pattern, usage variability and the conditions selected for average, wet and dry years.

The initial attempt to estimate salt usage for the three scenarios was based upon these same conditions and assumptions. A subsequent assessment of those results and the actual MnDOT usage levels proved those assumptions to be invalid. Conversations with MnDOT staff strongly suggested that another estimation alternative would be needed to accurately predict the salt usage over the different weather conditions. The total season usage levels of salt are more strongly influenced by the number of events than the amount of snow, so the assumptions for sand and snowfall do not apply to salt. Also, since the implementation of the Salt Solutions study, the use of sand has been reduced and the amount of salt used has become more stable from year-to-year (Vasek, 2003). The salt usage rates that were used in the overall basin loading estimates are constant from year-to-year, but are variable with regard to road type. These results were compared for accuracy and uncertainty to salt use data for the last sevens years – the time period that coincides with implementation of the Salt Solutions study.

MnDOT deicer usage data for the winters of 1994 – 1998 and the winter of 2002 – 2003 were also analyzed to determine the differences in application rates for the various portions of the state based upon the MnDOT Maintenance Districts and sub-district boundaries (SRF Consulting Group, 1998; MnDOT, 2003). This data shows that the Metro, Northeast and Southeast maintenance districts have the highest application rates for deicers (see Table 6). An analysis was completed for the state highway application rates for the Metro District and these were then adjusted based upon the variation for application rates with the individual districts to estimate lane miles applications rates for the three scenarios.

MnDOT databases and GIS were used to develop road miles for each county in the state and then the road miles were distributed by basin based upon area-weighting within county boundaries. Roads were categorized based upon the road type and lane miles as per Table 7.

Table 6. MnDOT Maintenance District Deicer Usage Rates Data – Comparison of Usage Rates for the Winter of 2002 – 2003

"Dry year" (Winter of 2002 – 2003) District	Service Level	Average Sand (Tons)/LM	Average Salt (Tons)/LM	Average Brine (Gals)/LM	Salt + Sand (Tons)/LM	Percent Salt+Sand Use – higher/lower than Metro	Total Miles Serviced
1	ALL	7.83	6.93	70.9	14.76	25%	3784
1A	ALL	6.6	7.01	48.15	13.61	15%	2010
1B	ALL	9.41	6.93	99.06	16.34	38%	1728
2	ALL	3.5	2.5	9.62	6	-49%	3904
3	ALL	3.52	5.75	62.12	9.27	-22%	3987
3A	ALL	5.1	5.46	40.3	10.56	-11%	1921
3B	ALL	1.96	5.77	80.75	7.73	-35%	2066
4	ALL	3.41	3.46	40.81	6.87	-42%	3588
METRO	ALL	0.4	11.43	8.63	11.83	0%	5333
6	ALL	4.52	7.95	62.42	12.47	5%	3691
6A	ALL	7.51	7.44	75.36	14.95	26%	1917
6B	ALL	1.28	8.5	48.44	9.78	-17%	1774
7	ALL	2.24	3.25	36.31	5.49	-54%	3217
7E	ALL	1.27	3.62	44.52	4.89	-59%	1631
7W	ALL	3.13	2.78	26.95	5.91	-50%	1639
8	ALL	3.62	2.61	42.57	6.23	-47%	2928
STATEWIDE	ALL	3.49	5.91	40.08	9.4	-21%	30386

Table 7. Total road lane miles by basin.

Road Type	Upper Mississippi River (Lane Miles)	St. Croix River (Lane Miles)	Red River of the North (Lane Miles)	Rainy River (Lane Miles)	Missouri River (Lane Miles)	Minnesota River (Lane Miles)	Lower Mississippi (Lane Miles)	Lake Superior (Lane Miles)	Des Moines River (Lane Miles)	Cedar River (Lane Miles)
Interstate Trunk Highway	2,558	890	497	0	497	1,175	1,224	290	191	550
U. S. Trunk Highway	3,718	71	2,237	368	134	2,143	1,852	726	155	159
Minnesota Trunk Highway	5,470	890	2,654	1,256	319	4,211	1,695	880	336	187
County State-aid Highway	16,640	2,705	11,779	2,456	1,761	14,768	6,652	2,871	1,538	1,207
Municipal State-aid Street	3,799	202	254	18	10	1,271	660	515	13	130
County Road	7,980	1,510	6,113	2,136	839	6,273	1,909	2,556	382	354
Township Road	26,665	4,185	27,859	1,210	3,713	28,613	11,425	1,801	3,285	2,035
Unorganized Township Road	554	68	578	1,686	0	0	0	379	0	0
Municipal Street	16,886	1,696	1,821	269	305	6,235	3,649	1,713	368	497
National Forest Development Road	831	0	0	816	0	0	0	1,000	0	0
Indian Reservation Road	83	0	633	94	0	0	0	0	0	0
State Forest Road	667	159	579	1,011	0	0	116	270	0	0
State Park Road	29	58	27	16	2	17	16	6	1	1
National Wildlife Refuge Road	0	0	0	0	0	10	0	0	0	0
Frontage Road	0	0	0	0	0	0	0	2	0	0
Ramp	331	31	30	2	11	155	72	26	4	27
Private Jurisdiction Road	17	3	0	0	0	35	0	0	0	0
Other	15	2	5	61	1	14	2	3	1	0
Total	86,240	12,469	55,066	11,399	7,592	64,919	29,271	13,038	6,275	5,147

Table 8. Summary statisatics for MnDOT deicing applications for winters 1971 - 2003 and 1996 - 2003.

1971 - 2003	Snowfall (inches)	Sand (Tons)	Sand Applied (Tons/LM)	Chemical Applied (Salt Tons)	Salt Applied (Tons/LM)	Sand+Salt Applied (Tons)	Sand+Salt Applied (Tons/LM)	Percent salt (tons/LM)
MAX =	99	397,798	13	251,159	8	620,448	20	75%
MIN =	17	106,478	4	56,295	2	224,634	7	34%
AVG =	58	279,765	9	154,956	5	434,721	14	64%
90th %ile	36	284,157	6	150,031	3	431,827	11	52%
Median	57	367,906	9	229,040	5	558,405	14	68%
10th %ile	76	174,393	12	95,325	8	326,804	18	72%
>90th %ile mean	24	177,818	6	117,483	4	295,301	10	60%
Mean	58	279,765	9	154,956	5	434,721	14	64%
<10th %ile mean	92	311,035	10	142,937	5	453,971	15	69%
1996 - 2003								
MAX =	76	369,289	12	251,159	8	620,448	20	59.5%
MIN =	35	106,478	4	171,087	6	287,039	9	33.6%
AVG =	55	220,529	7	215,445	7	435,974	14	48.6%
Median	57	229,263	8	222,894	7	441,526	15	51.9%
Median	57	229,263	8	222,894	7	441,526	15	51.9%

* Assumes 30,386 Total Miles Serviced Statewide (2002-03 MNDOT data) for 1971 - 2003 time period
** Within percentile values used for analysis based upon >10th %tile and <90 %tile, respectively for 1971 - 2003 only

Approach and Methodology for Phosphorus Loading Computations

Phosphorus loading computations were primarily based upon the MnDOT data sources as this was the most detailed data set and extended over the longest time period. Loading calculations for TCMA counties were from SRF Consulting Group (1998) and other road types were extrapolated using the MnDOT data trends, applications rates and deicing mixtures. The following discussion of loading rate calculations is organized around the application of deicing agents to the road classification based upon level of government maintaining the particular road type.

MnDOT Maintained Roads:

As has been previously mentioned, the MnDOT database was the most comprehensive and most useful in determining application rates across the range of conditions for wet, dry and average years. Table 8 presented the summary of weather patterns and application rates for the 1971 – 2003 time period. This data assessment shows that dry years result in decreased usage and wet years increase usage rates. The period of record used in this analysis was not used any further for the loading calculations as much of the data is from winters prior to the Salt Solutions Report (SRF Consulting Group, 1998) and thus may not be indicative of current winter road maintenance practices. It does however provide strong support for the adjustment of application rates due to weather variability from year-to-year based upon snowfall amounts.

The applications rates for each MnDOT District, and thus for each basin, is based upon the use of statewide averages based upon their relationship to snowfall amounts over a winter. Application rates for salt and sand were then adjusted to account for the wet, dry and average conditions based upon the ratios derived from the 1971 – 2003 time period and the relationship between the years of detailed information provided in the Salt Solutions Report and MnDOT's Work Management System Reports (SRF Consulting Group, 1998; MnDOT, 2003;). See Tables 9 – 11 for the results of these calculations for salt, sand and brine use for each scenario for the state highway types.

The use of brine for deicing has increased in recent years, but the period of record for its application is limited and thus 2002 rates were used in the calculations as insufficient data was available to attempt to adjust for year-to-year variability in its application rate. The NaCl brine solution used by MnDOT is a 26% solution having a delivered concentration of phosphorus of 0.49 ppm per gallon. MnDOT has also recently started use of $MgCl_2$, with 78,199 gallons applied in 2002 – 03 in Districts 1, 2 and 3 combined. MnDOT uses a number of different $MgCl_2$-based deicing agents in various quantities; Calibre M1000, Calibre M2000, 30% $MgCl_2$, and Freezgard Zero. The current data does not provide a breakdown of the amounts of each deicer, but if for discussion purposes the total volume applied was for each of the alternative compounds then the quantity of phosphorus would be as follows:

Deicing Compound	Phosphorus concentration	Kg of P for 78,199 gallons per year
Calibre M1000	76 ppm P	1.6 kg P
Calibre M2000	249 ppm P	5.1 kg P
30% $MgCl_2$	6.2 ppm P	0.13 kg P
Freezgard Zero	42 ppm P	0.87 kg P

The limited quantity of phosphorus involved in this current use (less than 0.001% of annual deicer load), the short-term experience for use of these compounds, and limited records of use did not warrant its inclusion in this analysis.

Table 9. MnDOT Dry Year Deicer Usage Rate Calculations Based Upon 2002 - 2003 (Dry Year) Recorded Usage

"Dry year"	Average Sand (Tons)/LM	Average Salt (Tons)/LM	Average Sand (Tons)/LM	Average Salt (Tons)/LM	Average Sand (Tons)/LM	Average Salt (Tons)/LM	Average Brine (Gals)/LM
District	Interstate Trunk Highways		US Trunk Highways		Minnesota Trunk Highways		All State Roads
1	0	14.76	4.43	10.33	7.38	7.38	70.9
1A	0	13.61	4.08	9.53	6.81	6.81	48.15
1B	0	16.34	4.90	11.44	8.17	8.17	99.06
2	0	6.00	1.80	4.20	3.00	3.00	9.62
3	0	9.27	2.78	6.49	4.64	4.64	62.12
3A	0	10.56	3.17	7.39	5.28	5.28	40.3
3B	0	7.73	2.32	5.41	3.87	3.87	80.75
4	0	6.87	2.06	4.81	3.44	3.44	40.81
METRO	0	11.83	3.55	8.28	5.92	5.92	8.63
6	0	12.47	3.74	8.73	6.24	6.24	62.42
6A	0	14.95	4.49	10.47	7.48	7.48	75.36
6B	0	9.78	2.93	6.85	4.89	4.89	48.44
7	0	5.49	1.65	3.84	2.75	2.75	36.31
7E	0	4.89	1.47	3.42	2.45	2.45	44.52
7W	0	5.91	1.77	4.14	2.96	2.96	26.95
8	0	6.23	1.87	4.36	3.12	3.12	42.57

Table 10. MnDOT Average Year Deicer Usage Rate Calculations Based Upon 2002 - 2003 (Dry Year) Recorded Usage

"Average year"	Average Sand (Tons)/LM	Average Salt (Tons)/LM	Average Sand (Tons)/LM	Average Salt (Tons)/LM	Average Sand (Tons)/LM	Average Salt (Tons)/LM	Average Brine (Gals)/LM
District	Interstate Trunk Highways		US Trunk Highways		Minnesota Trunk Highways		All State Roads
1	0	14.76	9.32	10.33	15.53	7.38	70.9
1A	0	13.61	11.18	9.53	18.63	6.81	48.15
1B	0	16.34	4.13	11.44	6.89	8.17	99.06
2	0	6.00	6.32	4.20	10.53	3.00	9.62
3	0	9.27	7.21	6.49	12.02	4.64	62.12
3A	0	10.56	5.27	7.39	8.78	5.28	40.3
3B	0	7.73	4.70	5.41	7.83	3.87	80.75
4	0	6.87	8.10	4.81	13.50	3.44	40.81
METRO	0	11.83	8.51	8.28	14.18	5.92	8.63
6	0	12.47	10.21	8.73	17.01	6.24	62.42
6A	0	14.95	6.72	10.47	11.21	7.48	75.36
6B	0	9.78	3.73	6.85	6.21	4.89	48.44
7	0	5.49	3.32	3.84	5.54	2.75	36.31
7E	0	4.89	4.05	3.42	6.75	2.45	44.52
7W	0	5.91	4.29	4.14	7.16	2.96	26.95
8	0	6.23	0.00	4.36	0.00	3.12	42.57

Table 11. MnDOT Wet Year Deicer Usage Rate Calculations Based Upon 2002 - 2003 (Dry Year) Recorded Usage

"Wet year"	Average Sand (Tons)/LM	Average Salt (Tons)/LM	Average Sand (Tons)/LM	Average Salt (Tons)/LM	Average Sand (Tons)/LM	Average Salt (Tons)/LM	Average Brine (Gals)/LM
District	Interstate Trunk Highways		US Trunk Highways		Minnesota Trunk Highways		All State Roads
1	0	14.76	16.88	10.33	28.13	7.38	70.9
1A	0	13.61	15.53	9.53	25.88	6.81	48.15
1B	0	16.34	18.63	11.44	31.05	8.17	99.06
2	0	6.00	6.89	4.20	11.48	3.00	9.62
3	0	9.27	10.53	6.49	17.55	4.64	62.12
3A	0	10.56	12.02	7.39	20.03	5.28	40.3
3B	0	7.73	8.78	5.41	14.63	3.87	80.75
4	0	6.87	7.83	4.81	13.05	3.44	40.81
METRO	0	11.83	13.50	8.28	22.50	5.92	8.63
6	0	12.47	14.18	8.73	23.63	6.24	62.42
6A	0	14.95	17.01	10.47	28.35	7.48	75.36
6B	0	9.78	11.21	6.85	18.68	4.89	48.44
7	0	5.49	6.21	3.84	10.35	2.75	36.31
7E	0	4.89	5.54	3.42	9.23	2.45	44.52
7W	0	5.91	6.75	4.14	11.25	2.96	26.95
8	0	6.23	7.16	4.36	11.93	3.12	42.57

Application rates for state highways for all Districts used for the “dry” year scenario used application rates based upon the recorded uses for the winter of 2002 – 03. The level of detail in Work Management System Reports allowed for the development of usage rates for each of the districts and some of the sub-districts. Salt usage rates remained constant at the 2002 – 2003 rates throughout the three loading scenarios and varied based upon the sand/salt ratios described for each service level below.

“Wet” year conditions were calculated using the Metro District data for the winters of 1995 – 97 and then adjusting for the other district usage rates based upon percentage differences using the 2002 – 03 data. While the years of 1995 – 97 were not within the 10th percentile of the years from 1971 – 2003 dataset, they were the wettest years for the time period since the implementation of the Salt Solutions Report recommendations and are the usage estimates that provided the closest agreement with actual use rates for sand (SRF Consulting Group, 1998).

“Average” year conditions and sand usage rates were calculated in a similar fashion using the winter of 1994 – 95 data and extrapolating to the other districts. Development of usage rates to the sub-district level allowed for a finer scale of estimation as to state highway loadings across the basins. See Figure 1 for MnDOT District, sub-district and watershed basin boundaries.

MnDOT’s road classes (service levels) were used to further define the application assumptions for the mix ratios of deicers used on the three road types maintained by MnDOT. Based upon and examination of the 2003 – 02 deicer usage report the total salt plus sand application, in tons per lane mile, was modified for the three types of roads maintained by MnDOT (MnDOT, 2003a).

- 01 - Interstate Trunk Highway – uses a 100% salt assumption (assuming "super commuter" service level)
- 02 - U.S. Trunk Highway – uses a 70% salt assumption (assuming "urban commuter" service level)
- 03 - Minnesota Trunk Highway – uses a 50% salt assumption (assuming "rural commuter" service level)

County and Local Government Maintained Roads:

County and local road agency specific data was less readily available for use in this analysis, except for the TCMA counties (SRF Consulting Group, 1998). An analysis was undertaken using the 1994 – 1997 data available for the TCMA to develop usage rates for the County State Aid Highway (CSAH) system. The TCMA deicer usage rates were summarized based upon average conditions (1994 – 95) for both salt and sand usage on a lane mile basis. The 1995 – 1997 period was used for calculation of the wet year conditions. The dry year conditions were used based upon the 90th percentile summary statistics presented in Table 8. These usage numbers were applied to all CSAH miles across the state as they were viewed as the more heavily traveled and thus more highly maintained roads in both the TCMA and out-state areas. These usage numbers are conservatively high based upon the sand to salt ratios reported in the Minnesota Legislative Auditor (1995) report, with a salt percentage of 33%. The sand and salt application rates used for this analysis are shown in Table 12.

Table 12. Sand and Salt Application Rates for County State Aid Highways for Loading Calculations.

Year	Sand (tons/LM)	Salt (tons/LM)
Dry	7.1	3.2
Average	10.0	5.0
Wet	15.5	7.5

Deicer usage rates for other county highways and local roads were developed based upon an even smaller database of actual usage rates. As such, the usage rates for the “rural” counties in the TCMA – Scott, Carver and Chisago counties – were used to develop usage rates for other roads included in this analysis. An analysis was undertaken using the 1994 – 1997 data available for these TCMA in manner consistent with the CSAH analysis described above. Again this estimate is conservatively high due to a lack of actual applications rate up0n which to further refine the estimates. Those rates are presented in Table 13.

Table 13. Sand and Salt Application Rates for County and Local Roads for Loading Calculations.

Year	Sand (tons/LM)	Salt (tons/LM)
Dry	3.8	1.4
Average	6.0	2.0
Wet	7.5	2.5

Results of Phosphorus Loading Computations and Assessments

The basin loading calculations were computed using the application rates and concentrations defined in the Approach and Methodology section for the lane miles in each basin. Each basin calculation was completed using the application rates for the respective MnDOT Districts that encompass the basin; whenever the basin includes TCMA counties, those state highway lane miles were calculated using the higher Metro District rates for each county. Table 14 provides a summary of the district and Metro counties included in each basin calculation.

Table 14. Summary of the district and Metro counties included in each basin calculation.

Basin	MnDOT District (state roads)	Metro District (Metro counties)
St. Croix River	1A	Chisago, Ramsey, Washington
Upper Mississippi River	3	Anoka, Carver, Dakota, Hennepin, Ramsey, Washington
Lower Mississippi River	6	Dakota, Scott
Red River	2 & 4 avg	
Rainy River	1B	
Lake Superior	1A	
Missouri River	7W	
Minnesota River	7 & 8 avg	Carver, Dakota, Hennepin, Scott
Cedar River	6B	
Des Moines River	7W	

Table 15 presents the phosphorus loading results for each of the basins under the three loading scenarios and a summary for the state-wide total phosphorus load from deicing agents under the same three scenarios.

Table 15. Phosphorus loading results for Minnesota basins and state-wide totals for three snowfall scenarios.

Basin	Snowfall Scenario	Tons of Salt	Tons of Sand	Gallons of Brine	Kg P from Salt	Kg P from Sand	Kg P from Brine	Total Kg P
St. Croix River	Dry Year	37,525	55,343	59,431	170	1893	0.03	2,063
	Avg Year	47,143	88,364	59,431	213	3022	0.03	3,236
	Wet Year	57,862	124,331	59,431	262	4252	0.03	4,514
Upper Mississippi River	Dry Year	214,976	376,477	521,969	973	12876	0.26	13,849
	Avg Year	279,640	600,253	521,969	1266	20529	0.26	21,795
	Wet Year	350,167	835,955	521,969	1585	28590	0.26	30,176
Lower Mississippi River	Dry Year	88,034	132,454	268,117	399	4530	0.13	4,929
	Avg Year	110,716	213,189	268,117	501	7291	0.13	7,793
	Wet Year	136,270	302,924	268,117	617	10360	0.13	10,977
Red River	Dry Year	112,554	240,506	135,874	510	8226	0.07	8,735
	Avg Year	156,495	374,579	135,874	708	12811	0.07	13,519
	Wet Year	204,893	546,846	135,874	928	18703	0.07	19,630
Rainy River	Dry Year	32,576	57,318	160,864	147	1960	0.08	2,108
	Avg Year	41,389	95,993	160,864	187	3283	0.08	3,470
	Wet Year	51,190	138,824	160,864	232	4748	0.08	4,980
Lake Superior	Dry Year	37,625	60,767	91,289	170	2078	0.04	2,249
	Avg Year	47,755	98,765	91,289	216	3378	0.04	3,594
	Wet Year	59,068	140,577	91,289	267	4808	0.04	5,075
Missouri River	Dry Year	16,903	32,231	25,586	77	1102	0.01	1,179
	Avg Year	23,002	49,589	25,586	104	1696	0.01	1,800
	Wet Year	29,845	68,392	25,586	135	2339	0.01	2,474
Minnesota River	Dry Year	141,111	285,517	251,770	639	9765	0.12	10,404
	Avg Year	193,267	446,062	251,770	875	15256	0.12	16,131
	Wet Year	251,497	589,445	251,770	1138	20160	0.12	21,298
Cedar River	Dry Year	15,504	21,514	43,379	70	736	0.02	806
	Avg Year	19,503	33,493	43,379	88	1145	0.02	1,234
	Wet Year	24,042	46,803	43,379	109	1601	0.02	1,710
Des Moines River	Dry Year	13,370	27,606	18,403	61	944	0.01	1,005
	Avg Year	18,573	42,620	18,403	84	1458	0.01	1,542
	Wet Year	24,447	59,097	18,403	111	2021	0.01	2,132

		Tons of Salt	Tons of Sand	Gallons of Brine	Kg P from Salt	Kg P from Sand	Kg P from Brine	Total Kg P
Statewide Totals	Dry Year	710,178	1,289,734	1,576,683	3,215	44,110	0.77	47,326
	Avg Year	937,483	2,042,906	1,576,683	4,244	69,869	0.77	74,114
	Wet Year	1,189,280	2,853,194	1,576,683	5,384	97,582	0.77	102,966

Phosphorus Loading Variability and Uncertainty

All of the loading estimates prepared for phosphorus from deicing agents were based upon information reported by road maintenance agencies whenever possible. MnDOT and other agencies readily acknowledge that better record keeping is needed and better measurements are needed to document the actual usage numbers (SRF Consulting Group, 1998; Weber, 2003;). While MnDOT data is of relatively high quality, the near absence of local road agency data for use in this analysis creates concern for the accuracy of the final numbers beyond those for state maintained roads, given the amount of variability that currently exists due to year-to-year weather patterns and the resulting deicer usage patterns. For this uncertainty analysis we have confined the actual MnDOT usage data to the 1996 – 2003 time period. This period is the period of time that includes MnDOT operations since the start of implementation for the Salt Solutions study recommendations and most accurately represents current deicer use trends for the state highway system (Vasek, 2003).

Based upon a state-wide sum of salt and sand usage for MnDOT maintained roads and the reported state-wide deicer use data from MnDOT has allowed for an analysis of the loading estimate uncertainty against actual application information. The estimation methods were assessed against actual MnDOT usage levels and those results are summarized in Table 16, for the wet, average and dry years based upon a comparison to actual application quantities for similar years. The usage estimation for sand and salt usage, and thus the phosphorus load estimates from MnDOT uses for the three scenarios are reasonable given the limitations of the data (+/- 22%). The MnDOT salt usage estimate for the “average” year, i.e., for those years of data upon which the other scenario estimates were constructed has a smaller error than for the sand and brine. The error for Brine is about 30% , but the phosphorus loading due to brine is less than 0.001% of the total phosphorus load and thus is insignificant. Without further data for other road agencies the accuracy of the other estimates can only be assumed to be similar. Table 17 presents a breakout for the estimated MnDOT deicer usage by scenario for each basin.

Much of the phosphorus content analysis for these deicing agents has been collected from widespread sources having differing and sometime poorly documented analysis methods. The limited number of studies and the ongoing citation of a few early studies by current investigators suggest that more analytical studies on deicing agents and phosphorus should be completed. The summary statistics for the data on salt and sand gleaned from the literature presented in Table 5, highlight the relative lack of data on the subject and the variability of concentrations. Many of these analyses results are from across the U.S.; a data set that is confined to deicing agents used in Minnesota would provide a more accurate estimate of the loads.

Table 16. Comparison of calculated and actual statewide deicer usage on Minnesota state

Snowfall Scenario Database Year(s)	Calculated Tons sand	Actual Tons sand	% Difference (calc/actual)
Calculated dry year 2002 - 03	118,358	106,478	111.16%
Calculated average year Mean 1996 - 2003	268,874	220,529	121.92%
Calculated wet year 1996 - 1997	448,522	369,289	121.46%
	Calculated Tons salt	Actual Tons salt	Difference %
Calculated Median 1996 - 2003	242,177	222,894	108.65%
	Calculated Gallons Brine	Actual Gallons Brine	Difference %
Calculated average year 2002 -2003	1,576,683	1,215,915	129.67%

Table 17. Estimated deicer usage totals by basin for Interstate, US Trunk and Minnesota Trunk highways.

Basin	Low Year Salt (tons)	Low Year Sand (tons)	Avg Year Salt (tons)	Avg Year Sand (tons)	High Year Salt (tons)	High Year Sand (tons)	Brine (gallons)
Upper Mississippi River	80,732	38,486	80,732	86,725	80,732	144,126	521,969
St. Croix River	17,789	6,065	17,789	13,830	17,789	23,048	59,431
Red River	21,801	12,857	21,801	29,393	21,801	80,026	135,874
Rainy River	14,469	12,066	14,469	27,515	14,469	45,858	160,864
Missouri River	4,434	1,180	4,434	2,692	4,434	4,487	25,586
Minnesota River	34,183	18,699	34,183	42,648	34,183	40,875	251,770
Lower Mississippi River	41,761	17,404	41,761	39,583	41,761	65,961	268,117
Lake Superior	16,858	8,954	16,858	20,431	16,858	34,046	91,289
Cedar River	7,381	1,378	7,381	3,159	7,381	5,265	43,379
Des Moines River	2,769	1,270	2,769	2,899	2,769	4,831	18,403
Estimated MnDOT Deicer Use	242,177	118,358	242,177	268,874	242,177	448,522	1,576,683
Estimated Total Deicer Use	710,178	1,289,734	1,246,445	2,042,906	1,868,976	2,853,194	1,576,683
MnDOT Percentage	34.1%	9.2%	19.4%	13.2%	13.0%	15.7%	100.0%

Recommendations for Future Refinements

See previous section for relevant discussion.

Recommendations for Lowering Phosphorus Export

Efforts currently underway as part of MnDOT's road weather information system (RWIS) use timely and accurate weather and road data in deicing application decisions; these efforts have optimized the use of deicing materials. The Minnesota Legislative Auditor (1995) reported that "(M)ost counties (93 percent), cities providing their own service (91 percent), and townships providing their own service (59 percent) rely on television or radio weather reports, including the National Weather Service reports via telephone, for weather information." More accurate weather information could lead to reduced usage of deicing agents. The use of brines can also improve the effectiveness of deicing agents and in all cases where the quantities of deicers are reduce there as cost savings to the road agency and safety benefits to the public.

The high phosphorus content of many of the agriculturally derived alternatives to road salt is noteworthy. In most cases the high phosphorus content for the alternatives is due to the corrosion inhibitor portion of the mixtures. As concerns for the environmental impacts has chlorides increased, additional emphasis may be placed on the use of these alternatives. While this analysis does not make any attempt to quantify what those impacts would be, a cursory evaluation of the concentrations shows that many of these products have phosphorus concentrations 100 to 10,000 times greater than road salt or sand.

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Technical Memorandum

To: Marvin Hora, Doug Hall and Mark Tomasek, Minnesota Pollution Control Agency

From: Greg Wilson

Subject: Final — Detailed Assessment of Phosphorus Sources to Minnesota Watersheds — Streambank Erosion

Date: December 21, 2003

Project: 23/62-853 EROS 009

c: Henry Runke

The purpose of this memorandum is to provide a discussion about streambank erosion as a source of phosphorus to Minnesota watersheds. This discussion is based on a review of the available literature, monitoring data and the results of phosphorus loading computations done for each of Minnesota's major watershed basins as part of this study. This memorandum is intended to:

- Provide an overview and introduction to streambank erosion as a source of phosphorus
- Describe the results of the literature search and review of available monitoring data
- Discuss the characteristics of each watershed basin as it pertains to streambank erosion as a source of phosphorus
- Describe the methodology used to complete the phosphorus loading computations and assessments for this study
- Discuss the results of the phosphorus loading computations and assessments
- Discuss the uncertainty of the phosphorus loading computations and assessment
- Provide recommendations for future refinements to phosphorus loading estimates and methods for reducing error terms
- Provide recommendations for lowering phosphorus export from streambank erosion

Overview and Introduction to Streambank Erosion as a Source of Phosphorus

The stability of stream channels is a complex issue that is highly influenced by the dynamics of natural and anthropogenic disturbances. Under natural conditions, the processes of erosion and deposition result in imperceptible morphologic changes to streams over long periods of time. The banks of unstable streams typically undergo erosion, both in the form of particle detachment from hydrodynamic drag and mass failure following erosion of the bank toe (FEMA, 1999). These adjustments to unstable stream channels can involve small time (days) and spatial scales (a reach) or a longer time (hundred or more years) and extent (entire systems), depending on the magnitude and scale of disturbance (Simon, 1994). Simon and Rinaldi (2000) determined that human disturbances to floodplains and upland areas in the loess area of the midwestern U.S., beginning around 1910, have resulted in accelerated channel erosion, degradation and property damages over the next 80 years. In Minnesota, this loess area covers all of the Lower Mississippi, Cedar and Missouri River Basins, along with a portion of the Minnesota River Basin (Simon and Rinaldi, 2000; Luttenegger, 1987). Adjustments occur in unstable streams until the distribution of particle sizes in each section of the stream reaches equilibrium (FISRWG, 2001).

Lane (1955) completed some of the early work of defining how alluvial channels become unstable and adjust to changes in order to re-establish equilibrium and offset the effects of the imposed changes. The general expression, presented by Lane (1995), shows that the product of the bed-material sediment load and median grain size should balance the product of the water discharge and channel slope. If any of these four variables are altered, it indicates that proportional changes in one or more of the other variables must take place to re-establish equilibrium in the stream.

Simon and Hupp (1986) developed a six-stage, semi-quantitative model of channel evolution in disturbed channels, for bed-level trends, that qualitatively recognizes bank slope development (as illustrated in Figure 1). Stages III and IV represent stream degradation, characterized by the lowering of the channel bed and basal erosion, with a subsequent increase in bank heights and slopes, leading to mass-wasting from slab, pop-out and deep-seated rotational failures (Simon and Hupp, 1986). The critical bank height (h_c) is the height of the bank, above which, the stream bank experiences mass wasting or slab failures. The degradation stage (Stage III) ends, and Stage IV begins, when the critical height of the bank material is reached (Simon and Hupp, 1986). This model of channel evolution is somewhat qualitative and requires a clear understanding of when the bank height has shifted to properly identify the stage class. Stage VI represents re-stabilization of the stream to the present watershed land use and altered hydrologic regimes (Simon and Rinaldi, 2000). Stage I represents a natural or “reference” condition for areas with minimal disturbance, while Stage VI represents a reference (or re-stabilized equilibrium) target for areas following significant disturbance (Simon et al., 2001).

The total suspended sediment load in streams includes the wash load (portion of the sediment load comprised of particle sizes finer than those present in the streambed, primarily derived from the

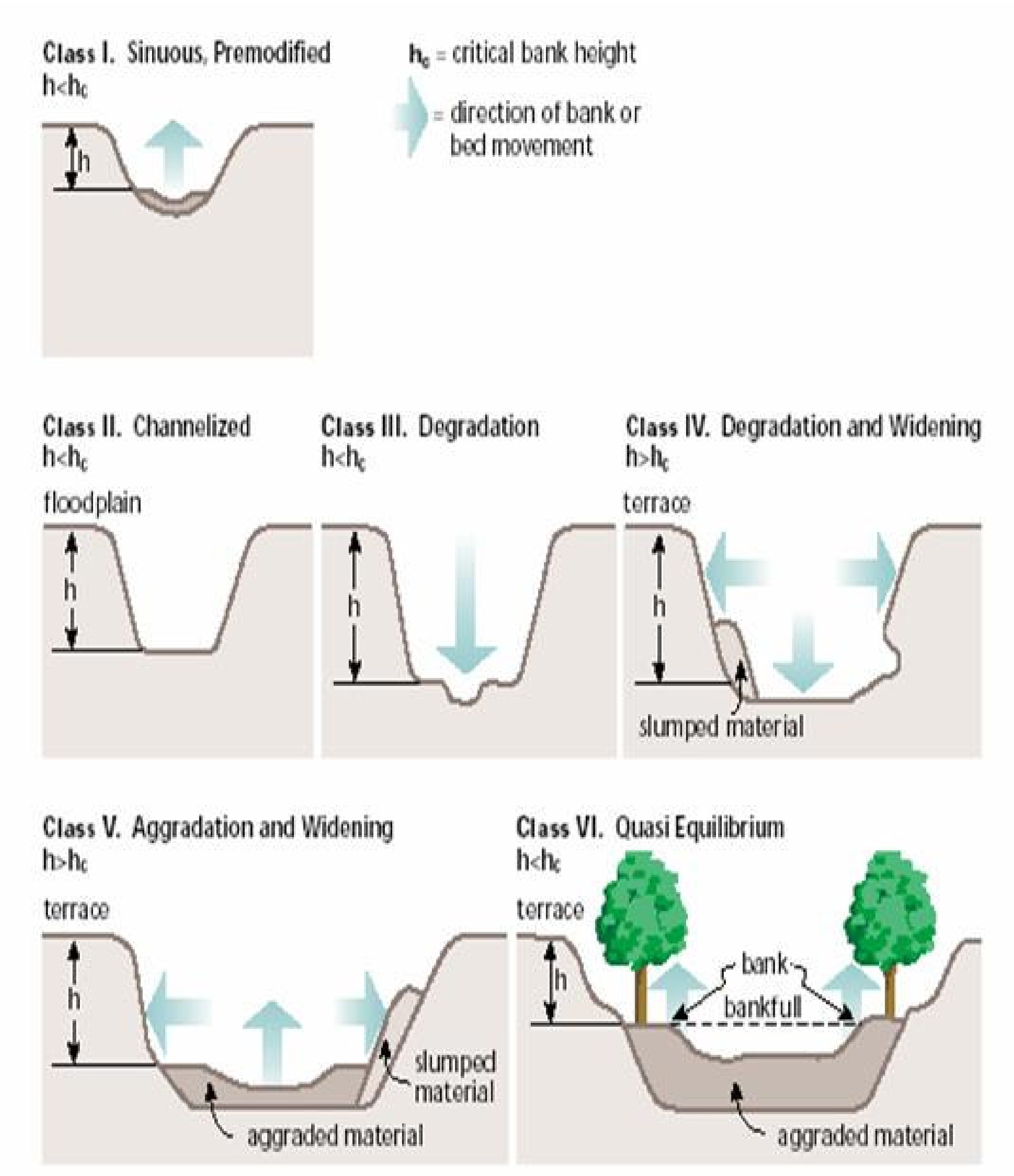


Figure 1
Six Stages of Channel Evolution (from Simon and Hupp, 1986)

watershed) and suspended bed material load or the portion of the total sediment load that is suspended by turbulent fluctuations of flowing water (FISRWG, 2001). The amount of sediment discharged at a given stream cross-section depends on the following (Colby, 1964):

- Depth, width, velocity, energy gradient, temperature, and turbulence of the flowing water
- Size, density, shape, and cohesiveness of particles in the banks and beds at the cross-section and in upstream channels
- Geology, meteorology, topography, soils, subsoils, and vegetal cover of the drainage area

Several researchers have determined that the stream sediment load is proportional to stream discharge (Lane, 1955; Glysson, 1987; Tornes, 1986; Kuhnle and Simon, 2000; Syvitski et al., 2000). Glysson (1987) provided methods for the development and interpretation of sediment-transport curves. Instantaneous flow and sediment transport data are used to develop sediment-transport rating curves based on the following regression relationship:

$$Q_S = a * Q^b \quad \text{or} \quad \log Q_S = \log a + b * \log Q$$

where: Q_S = sediment discharge, in tons per day

Q = stream discharge, in cubic-feet per second

a = constant, or intercept solved by regression

b = constant, slope of linear regression for log-log suspended-sediment rating relationship

Figure 2 provides an example of sediment-transport curves with two different slopes (based on Glysson, 1987). In some cases, two or three linear segments may be needed to adequately represent the sediment discharge at the various intervals of stream discharge (Glysson, 1987; Tornes, 1986; Simon, 1989; Simon et al., 2003). A steep regressed slope (as per Figure 2) to the rating relationship indicates both high sediment availability and high transport capacity. By multiplying the sediment concentration from the resulting rating relation by the discharge and percent occurrence for each discharge class, Simon et al. (2003) determined the discharge class contributing the highest sediment load, which is defined as the effective (or channel forming) discharge. This supported the work of Wolman and Miller (1960). The effective discharge is considered the discharge that shapes the channel, or performs the most geomorphic work, and may be analogous to the bankfull discharge in

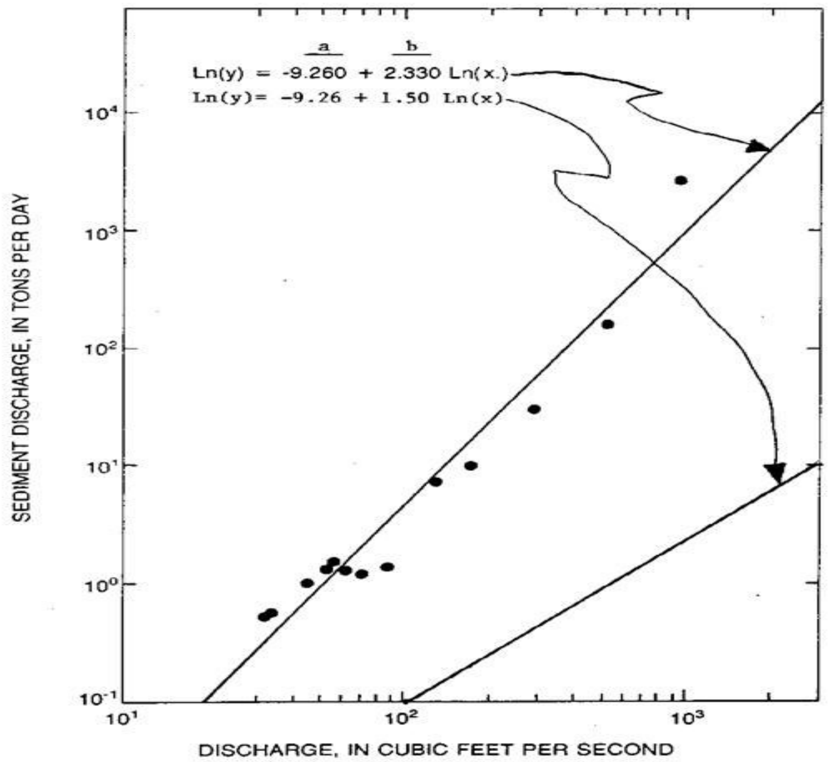


Figure 2 --Sediment-transport curve based on log-linear regression analysis. (Based on Glysson, 1987)

stable streams (Simon et al., 2001). The slope of the suspended-sediment rating relationship (b, from the above expression) varies (Simon, 1989a; Simon et al., 2003), depending upon the stage of channel evolution shown in Figure 1. Figure 3 shows that the highest slope of the suspended-sediment rating relationship corresponds to the stream stages (III and IV) that are undergoing the highest degree of degradation (Simon, 1989a), as previously described above. Migration of knickpoints (or vertical step-changes in bed surface elevation) up tributary streams during Stage III, and bank failures by mass wasting during Stage IV, both serve to significantly increase sediment yield (Simon, 1989a). For re-stabilized streams (Stage VI), Figure 3 shows the slope of the suspended-sediment rating relation is approximately 1.5, as opposed to 1.0 for "natural" streams (Stage I).

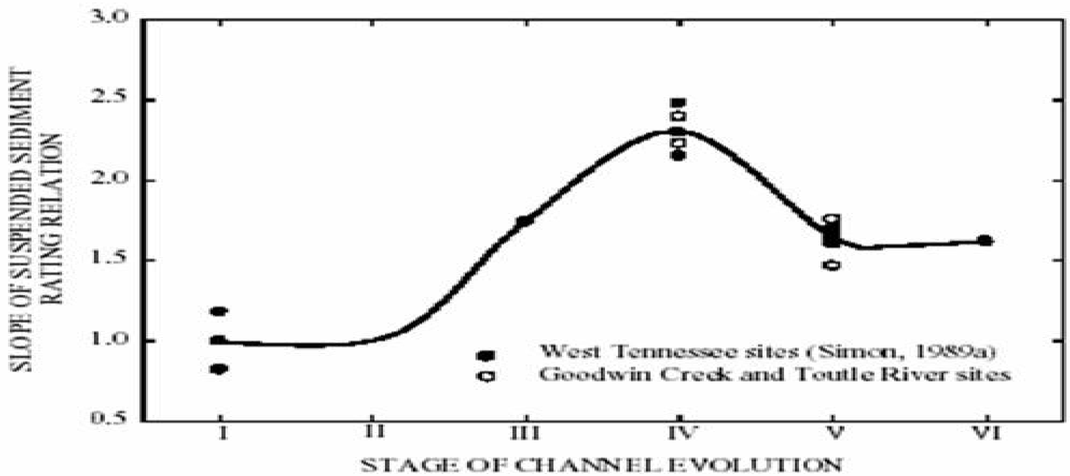


Figure 3
Relationship Between Stage of Channel Evolution and Suspended Sediment Transport (from Simon, 1989a)

The phosphorus attached to eroded streambank material is immediately delivered to the receiving water where it may ultimately become available for biologic uptake, re-deposited downstream, or transported with the flow out of the system. The approach for this assessment will utilize the data and techniques from the literature to estimate total phosphorus loadings to the surface waters within each of the ten major basins in Minnesota.

Results of Literature Search and Review of Available Monitoring Data

The literature search and review of available monitoring data involved a compilation of streambank erosion studies completed within Minnesota, along with an evaluation of the literature pertaining to sediment yield from Minnesota watersheds, to define the contribution of streambank erosion to the total phosphorus budget. Wherever possible, streambank erosion studies completed for Minnesota streams were used to determine the phosphorus load under low, average and high flow conditions for the respective basins. Sediment yield literature specific to the various regions of the state was consulted to develop an approach and assist with the assessment of the remaining unstudied watersheds.

In addition to the literature search, the following sources were consulted for streambank erosion studies or data compiled for Minnesota streams:

- The University of Minnesota Department of Soil, Water and Climate, Department of Forest Resources, Saint Anthony Falls Hydraulics Laboratory, Soil and Landscape Analysis Laboratory, and Water Resources Center
- Natural Resource Conservation Service (NRCS) and County Soil & Water Conservation Districts
- U. S. Geological Survey
- U.S. Forest Service
- U. S. Army Corps of Engineers
- Minnesota Pollution Control Agency
- Minnesota Department of Natural Resources
- Iowa State Water Resources Research Institute
- USDA-ARS National Sedimentation Laboratory

Literature and Monitoring Data Specific to Streambank Erosion in Minnesota Basins

Table 1 presents the results of the literature search and monitoring data specific to streambank erosion within Minnesota watersheds. Five published studies were found that specifically addressed streambank erosion for streams that originate in Minnesota. Wherever possible, average annual streambank sediment erosion, average annual erosion per stream mile, slope of suspended sediment rating relation, sediment erosion as a percentage of observed downstream suspended solids loading, and EPA Level III Ecoregion were expressed for each stream studied. Most of the estimates of streambank sediment erosion were the result of stream channel surveys (including aerial photos) to evaluate streambank retreat (or migration) and eroding bank area to determine the average annual volume of material eroded. The EPA Level III Ecoregion numbers refer to the areas shown in Figure 4. Each ecoregion is discussed in more detail in the following section "Watershed Basin Characteristics".

Table 1 shows that the average annual erosion rate per stream mile for the Iowa streams is significantly higher than the remaining studies. Also, the slope of the suspended sediment rating relations for the Iowa streams is indicative of degraded streams (Simon, 1989a). However, the erosion rates per stream mile for the Des Moines and Cedar Rivers are based on data collected down to the southern portion of Iowa (Odgaard, 1984). As a result, these erosion rates are probably not as indicative of erosion from the respective streams in Minnesota. The estimated erosion rates for the Rock and Upper Iowa Rivers should be more indicative of the respective streams in Minnesota, as the downstream portions of these watersheds are very close to the Minnesota border. The Cedar, Rock, and Upper Iowa River erosion estimates in Table 1 are a result of modeling (Odgaard, 1984). With the exception of the Upper Iowa River, 90 percent, or more, of the eroded stream channel material remains in suspension as it flows downstream.

Skunk, Deer, and Elim Creeks are smaller streams within the Nemadji River watershed which drains into Wisconsin before discharging to Lake Superior. Channel incision into deposits of lacustrine red clay, combined with forest harvesting and land use conversion, have made this basin susceptible to streambank erosion (Riedel et al., 2002; NRCS & USFS, 1998a). Table 1 shows that approximately 98 percent of the eroded stream channel material is delivered to Lake Superior as suspended sediment. Riedel et al. (2002) noted that channel incision and mass wasting account for more than 95% of the annual sediment load in the Nemadji River basin. The authors also found that stream evolution within this basin was consistent with the model identified by Simon and Hupp (1986).

The Blue Earth River also produces significant streambank erosion, accounting for 31 to 44 percent of the sediment in the flow that discharges to the Minnesota River (Sekely et al., 2002). Sekely et al. (2002) also estimated that streambank slumping accounts for 7 to 10 percent of the annual contributions to total phosphorus load in the Blue Earth River. Bauer (1998) estimated that streambank slumping accounted for 36 to 84 percent of the total suspended solids load in the Blue Earth River. Sekely et al. (2002) also produced a probability plot of annual streambank erosion rates which indicates that erosion rate for the 10% flow rate exceedance probability is 374% higher than the erosion rate for the 50% exceedance probability, while the erosion rate for the 90% exceedance probability is 20% of the erosion rate for the 50% exceedance probability (see Figure 5). Water quality modeling, calibrated for major watersheds within the Minnesota River basin, indicates that bank and bluff erosion should account for 40% of the modeled total sediment load in the Blue Earth River watershed, approximately 35% for the Cottonwood and LeSueur River watersheds, 20 to 25% for the Watonwan and Redwood River watersheds, and 2% of the Yellow Medicine River watershed for the 1986-1992 time period (TetraTech, 2002).

Table 1
Literature and Monitoring Data Specific to Studies of Minnesota Basins

Stream(s)	Average Streambank Sediment Erosion (tons/yr)	Average Erosion (tons/yr/stream mile)	Slope of Suspended Sediment Rating Relation	Sediment Erosion as a Percentage of Observed TSS Loading	EPA Level III Ecoregion	Reference
Des Moines River, Iowa		17,000	2	90	47	Odgaard, 1984
Cedar River, Iowa		5,100	2	100	47	Odgaard, 1984
Rock River, Iowa		8,400	2	93	46	Odgaard, 1984
Upper Iowa River, Iowa		1,180	3	17	52	Odgaard, 1984
Nemadji River	117,000	351	2	98	50	NRCS & USFS, 1998a
Skunk Creek	2,800	190		98	50	NRCS & USFS, 1998a
Deer Creek	4,800	516		98	50	NRCS & USFS, 1998a
Elim Creek	230	256		98	50	NRCS & USFS, 1998a
Blue Earth River	100,292			31 - 44	47	Sekely et al., 2002
Whitewater River, Beaver Creek	142,000	609		80	47/52	NRCS, USFS & MPCA, 1996
Bear Creek	2,200	440			52	NRCS & USFS, 1998b

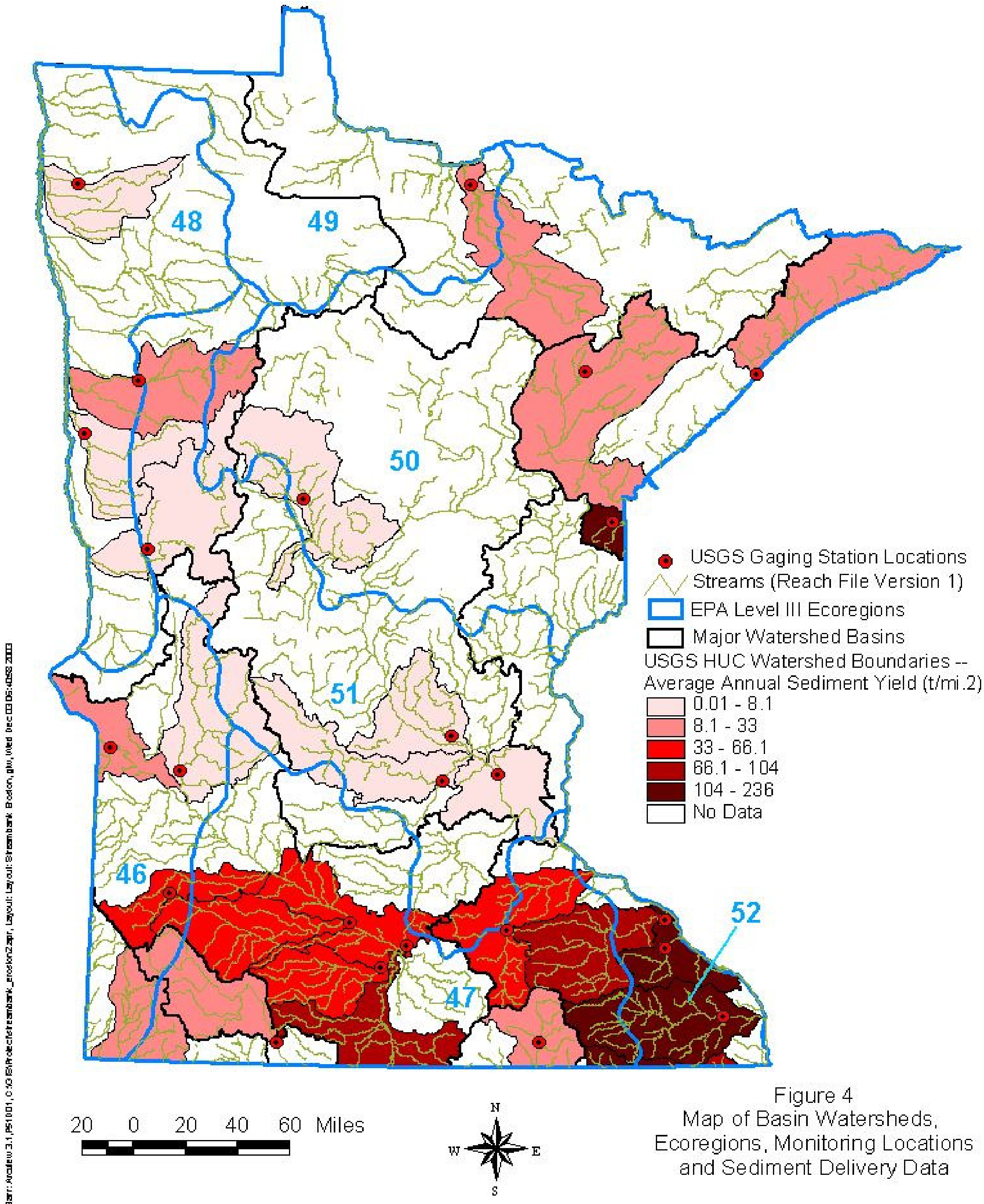


Figure 4
Map of Basin Watersheds, Ecoregions, Monitoring Locations and Sediment Delivery Data

Figure 5 (from Sekely et al., 2002)
Probability plot of streambank erosion rates.

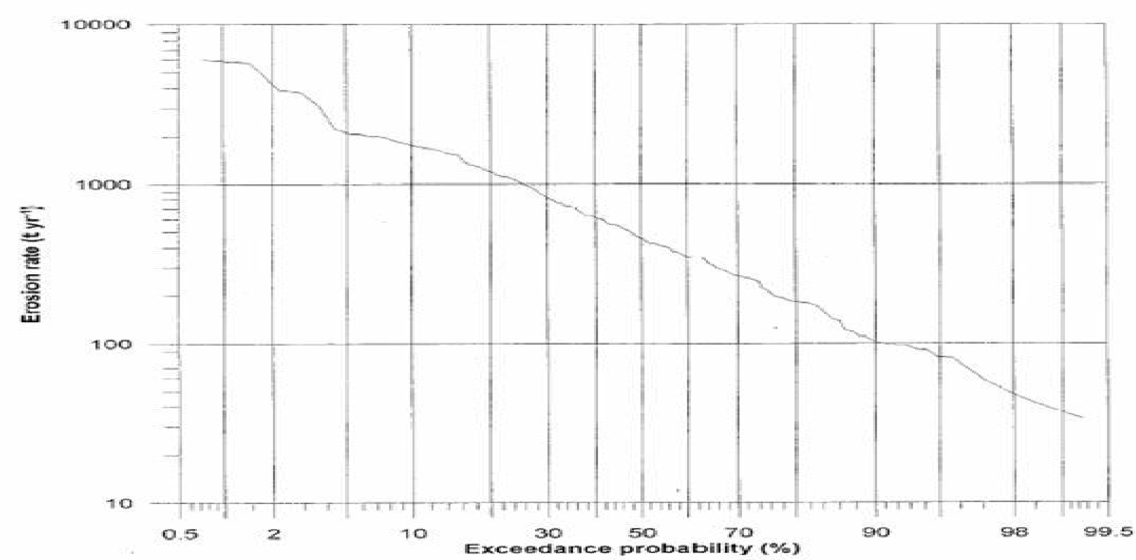


Table 1 shows that the Whitewater River, Beaver and Bear Creek watersheds produce some of the highest rates of streambank erosion in the state. A large part of the Bear Creek watershed is located in Iowa (NRCS & USFS, 1998b). Streambank erosion in the Whitewater River system also accounts for 80 percent of the suspended solids loading that moves downstream (NRCS & USFS, 1998b).

Regional Sediment Yield Literature

In addition to the streambank sediment erosion studies (described above), two regional studies have been completed involving sediment yield data for Minnesota watersheds (Tornes, 1986; Simon et al., 2003). Tornes (1986) analyzed the average annual sediment yield data for 33 USGS gaging stations, in or adjacent to Minnesota, while Simon et al. (2003) determined sediment yield, on the basis of the 1.5-year recurrence interval flow rate, for each of the EPA Level III Ecoregions. Figure 4 shows the locations of the 24 gaging stations utilized for this study, along with the corresponding watersheds, based on the associated USGS Hydrologic Unit Code (HUC). The difference between the 33 USGS gaging locations used by Tornes (1986) and the 24 gaging station sediment yield watersheds utilized for this study is due to the fact that some of the gaging stations were further upstream within monitored watersheds or were not located in Minnesota.

Tornes (1986) determined the average annual sediment yield for each of the gaging stations by developing sediment-transport curves for each of the stations and applying the relationships to flow-duration curves to calculate and sum the sediment loadings at each interval. Most of the sediment-transport curves were best represented by two linear segments. Tornes (1986) solved for and reported the slope and intercept for each segment of the sediment-transport curves for each station.

Tornes (1986) notes that, at extreme high flow, maximum daily sediment yields may nearly double the average annual sediment yield at several stations in southern Minnesota. During these extremely high flows, the normal sediment load for two years may be observed at the sampling station in slightly more than one day.

The recurrence interval of the effective discharge for sediment loading is typically 1.5 years (Wolman and Miller, 1960; Simon et al., 2003). Simon et al. (2003) determined sediment yield quartiles, minimum, and maximum yields, on the basis of the 1.5-year recurrence interval flow rate, for each of the EPA Level III Ecoregions shown in Figure 4. This analysis involved some of the same data and USGS gage locations used by Tornes (1986), but would have included data from other gages, outside of Minnesota, that were within the same ecoregions. This is primarily due to the fact that the USGS has developed a suspended-sediment database containing matching suspended-sediment sample results and instantaneous flow discharge measurements throughout the country (Turcios and Gray, 2001). Most of the Lake Agassiz Plain and all of the Northern Minnesota Wetlands Ecoregions are contained within Minnesota, while the remaining ecoregions generally possess half of their area outside of Minnesota. The difference between the 75th and 25th percent quartiles for sediment yields varied among the ecoregions. There was an order of magnitude difference for Ecoregions 46, 51 and 52; two orders of magnitude difference for Ecoregions 47 and 50; and less than an order of magnitude difference for Ecoregions 48 and 49. Finally, suspended sediment yields from stable streams in eight ecoregions were used by Simon et al. (2003) to determine "background" or "reference" conditions for sediment transport. Within a given ecoregion, the median value for stable sites is approximately one order of magnitude lower than for nonstable sites. None of the seven ecoregions used in this analysis were located in the upper Midwest.

Other literature sources reviewed for this analysis, but not cited, are listed at the end of this memorandum.

Watershed Basin Characteristics

As discussed previously, the large range in observed sediment yields throughout the state (shown in Figure 4) can be attributed to the variability of the geology, topography, land use and climatology of each region. As a result, the following sections discuss the variability associated with the seven EPA Level III ecoregions that cover the state (shown in Figure 4).

Northern Glaciated Plains Ecoregion (No. 46)

Located in the southwest portion of the state, this ecoregion consists of relatively flat agricultural land with loess, clay and sandy soils and low annual precipitation. Tornes (1986) notes that the clay and loess soils, combined with cultivation, result in average suspended solids concentrations above 50 mg/L.

Western Corn Belt Plains Ecoregion (No. 47)

Occupying most of the southern portion of the state, this ecoregion is predominantly agricultural lands with variable topography, clayey and loess soils, and higher precipitation from west to east. Tornes (1986) notes that average suspended solids concentrations in the Minnesota River basin were near 100 mg/L, but it was not uncommon for the maximum concentrations to exceed 2,000 mg/L. The wide fluctuations are presumably due to erosion of the fine-grained soils exposed by heavy cultivation (Tornes, 1986).

Lake Agassiz Plain and Northern Minnesota Wetlands Ecoregions (Nos. 48 and 49)

Located in the north and west portion of the state, these ecoregions consist of relatively flat land, with peat and clayey soils, and low annual precipitation. Tornes (1986) notes that most of the suspended solids concentrations measured in these ecoregions were below 50 mg/L, primarily due to the low precipitation and flat topography.

Northern Lakes and Forests Ecoregion (No. 50)

Located in the northeast portion of the state, this forested ecoregion consists of relatively hilly topography with rock, sand, and peat soils and higher annual precipitation. Most of the average suspended solids concentrations were below 50 mg/L, presumably due to the combination of rocky and sandy soils with forested land use (Tornes, 1986). The Nemadji River basin, with its highly erodible clay soils and high runoff volumes, is a notable exception within this ecoregion.

Northern Central Hardwood Forests Ecoregion (No. 51)

Located in the central portion of the state, this ecoregion with mixed landuse, consists of variable topography, with sand and clay soils, and higher annual precipitation. Tornes (1986) notes that the area drains predominantly sandy soils which is not as easily carried as suspended sediment. This land is not as heavily cultivated as the south portion of the state.

Driftless Area Ecoregion (No. 52)

Located in the southeast portion of the state, this ecoregion with mixed landuse, consists of hilly topography with highly erodible loess and rock or sandy soils, and high annual precipitation. Tornes (1986) notes that tillage of the loessial soils, combined with high runoff from the steep topography, result in average suspended solids concentrations above 50 mg/L, and maximum concentrations exceeding 5,000 mg/L at several monitoring stations.

Approach and Methodology for Phosphorus Loading Computations

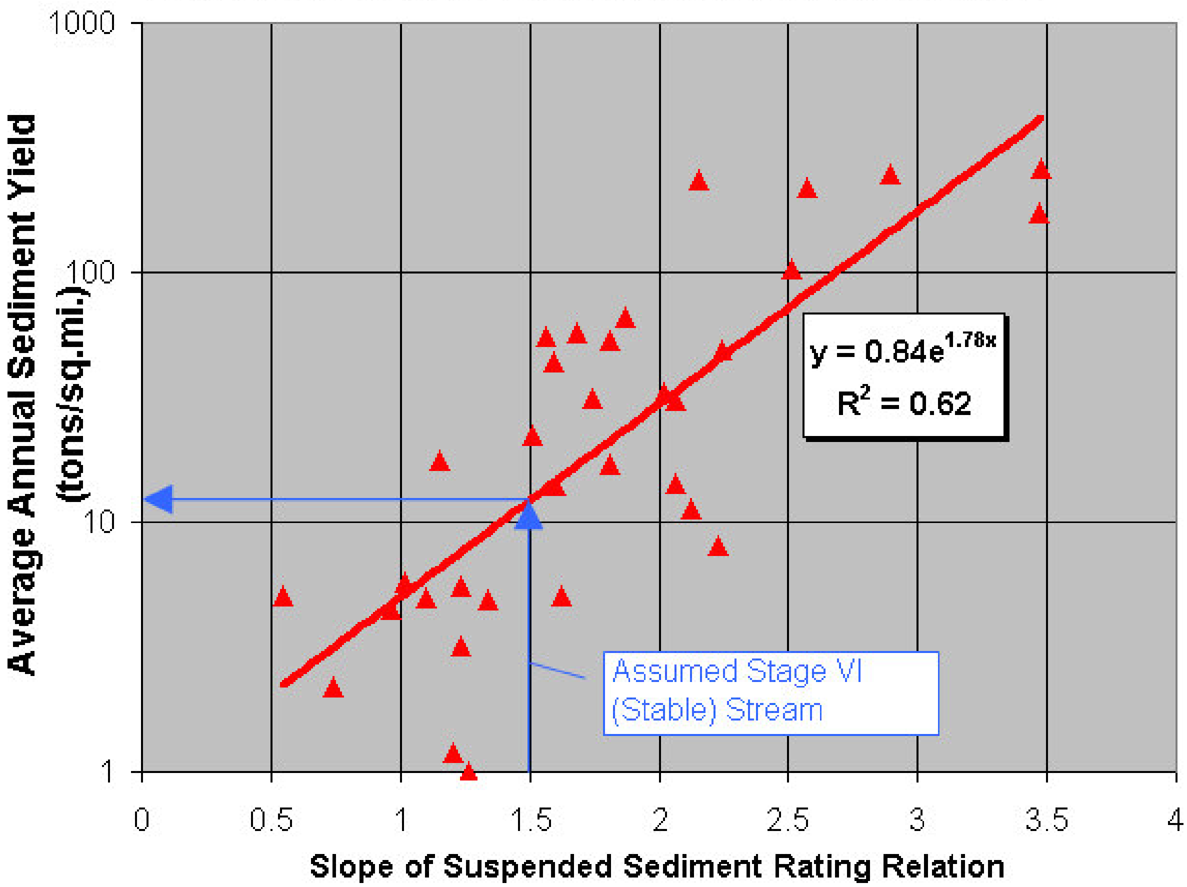
The approach for determining phosphorus loading from streambank erosion generally involves the following steps:

- Convert published streambank erosion estimates from Table 1 into average annual sediment yield
- Using the published sediment-transport curves from Tornes (1986), determine the relationship between average annual sediment yield and the slope of the sediment-transport curve segment containing the 1.5-year recurrence interval flow rate, as a surrogate for the effective discharge
- Apply average annual sediment yields from published streambank erosion estimates and Tornes (1986) to respective watershed units in GIS and determine average annual area-weighted monitored sediment yield for each of the EPA Level III Ecoregions in Minnesota
- Compare average annual monitored sediment yield for each of the EPA Level III Ecoregions in Minnesota to the effective discharge rate sediment yields published by Simon et al. (2003) for the same ecoregions and make adjustments, if necessary
- Assume that we can apply average annual sediment yield for each of the EPA Level III Ecoregions to the unmonitored portions of the state and estimate streambank sediment erosion component based on difference between average annual sediment yield for ecoregion and estimated annual sediment yield for stable (Stage VI) stream, with slope of suspended sediment rating relation equal to 1.5 (per Simon, 1989a)
- Estimate annual streambank sediment erosion for all watersheds under low and high flow conditions, based on the probability plot relationship (taken from Sekely et al., 2002) of annual streambank erosion rates, which indicates that the erosion rate for the 10% exceedance probability is 374% higher than the erosion rate for the 50% exceedance probability, and the erosion rate for the 90% exceedance probability is 20% of the erosion rate for the 50% exceedance probability
- Combine the streambank erosion sediment loadings associated with each watershed with the average soil test phosphorus concentration of 441 ppm (based on 16 surface samples collected from Blue Earth River escarpments, as described in Sekely et al., 2002) to calculate the total

phosphorus load associated with sediment loading estimated from streambank erosion in each basin for each flow condition

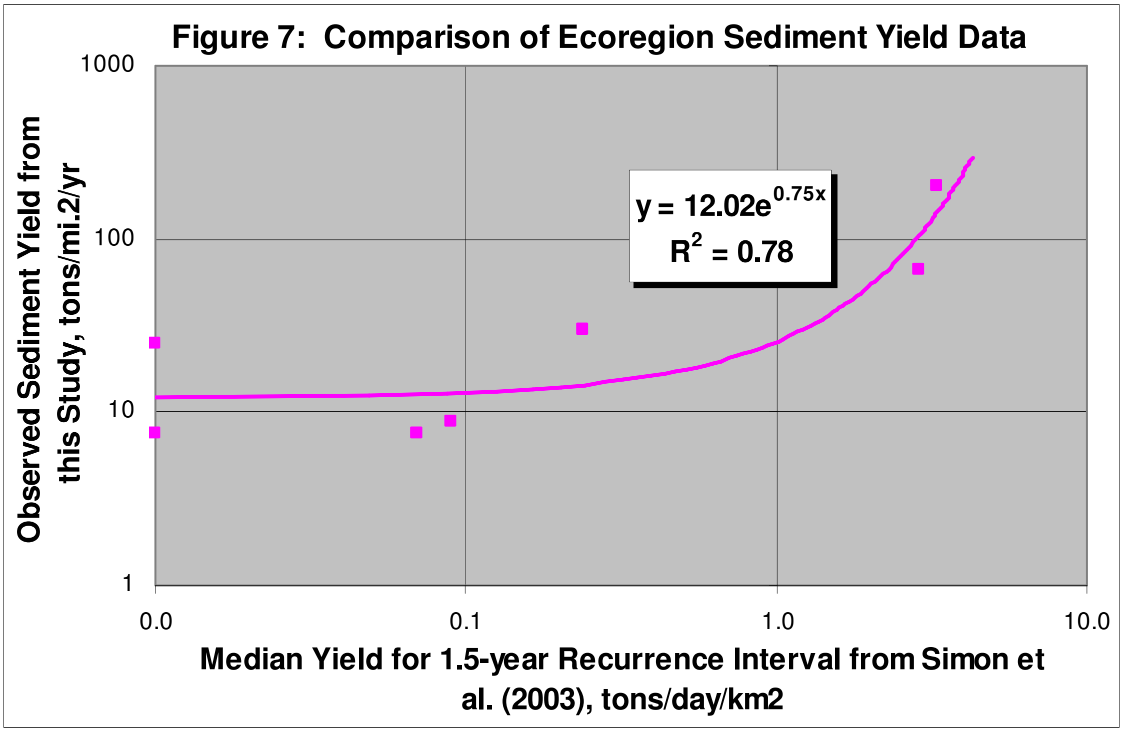
With the exception of the Iowa streams (Odgaard, 1987), the published streambank erosion estimates from Table 1 were converted into average annual sediment yield. Using the published sediment-transport curves from Tornes (1986), the slope of the sediment-transport curve segment containing the 1.5-year recurrence interval flow rate, which is comparable to the effective discharge (Simon et al., 2003), was estimated and tabulated in Excel, along with average annual sediment yield for each watershed. The relationship between average annual sediment yield and the slope of the sediment-transport curve is shown in Figure 6. This graph also shows that the linear regression done on the log-transformed data was significant, with an r^2 of 0.62.

Figure 6: Sediment Yield vs. Slope of Rating Curve



Average annual sediment yields from the published streambank erosion estimates and Tornes (1986) were applied to their respective USGS HUC watershed areas in ArcView (GIS). The coverage of watershed areas representing published average annual sediment yields was intercepted with the coverage representing the EPA Level III Ecoregion areas. By area-weighting the watershed areas with the published sediment yields within each ecoregion, the average annual sediment yield was determined for each of the EPA Level III Ecoregions in Minnesota.

The average annual sediment yield determined for each of the EPA Level III Ecoregions in Minnesota was tabulated in Excel, along with the effective discharge rate sediment yields published by Simon et al. (2003) for each ecoregion. Both datasets were graphed as a means of verifying that the relative differences between the estimated annual sediment yield determined for each ecoregion corresponded well with the larger dataset developed by Simon et al. (2003). The relative difference and ranking of ecoregion sediment yields estimated for each dataset agreed well, with the exception of the Northern Minnesota Wetlands (No. 49 in Figure 4) Ecoregion, which had an average annual sediment yield of 33 tons per square mile. The estimated yield for this ecoregion is more than four times higher than the estimated yield for the nearby Lake Agassiz Plain ecoregion, at 7.59 tons per square mile. Simon et al. (2003) determined that the median sediment yield for the Northern Minnesota Wetlands ecoregion should be comparable to that of the Northern Glaciated Plains (No. 46) or the Lake Agassiz Plain (No. 48) ecoregions. In addition, there was only one data point for this analysis (the Little Fork River sediment yield) and only three data points in the analysis done by Simon et al. (2003) for the Northern Minnesota Wetlands ecoregion. No other published streambank erosion or sediment loading data could be found for this ecoregion. Tornes (1986) noted that the Little Fork River at Littlefork had a higher sediment yield than other sites in the area. As a result, the sediment yield used in this analysis for the Northern Minnesota Wetlands ecoregion was assumed to be the same as the calculated yield for the nearby Lake Agassiz Plain ecoregion. Following this adjustment, the relationship between average annual sediment yield and the effective discharge rate sediment yield for each ecoregion was developed, as shown in Figure 7. This graph also shows that the linear regression done on the log-transformed data was significant, with an r^2 of 0.78.



The average annual sediment yield determined for each of the EPA Level III Ecoregions was applied to the unmonitored watersheds within each ecoregion, based on the area of the respective ecoregions within each watershed area using ArcView. The estimated average annual sediment yield for each of the watersheds was then used to estimate the streambank sediment erosion component based on difference between its average annual sediment yield and the estimated annual sediment yield for a stable (Stage VI) stream, with a slope of the suspended sediment rating relation equal to 1.5 (per Simon, 1989a). The regression equation from Figure 6 shows that the suspended-sediment rating relation slope of 1.5 translates to an average annual sediment yield of 12.13 tons per square mile. As a result, it was assumed for this analysis that if the estimated average annual sediment yield was greater than 12.13 tons per square mile, then the difference in sediment yield was a result of streambank erosion under average flow conditions. With the exception of the observed streambank erosion sediment loadings from Table 1, streambank erosion sediment loadings were estimated for the remaining watersheds in the State, based on the difference between the estimated sediment yield and the average annual sediment yield of 12.13 tons per square mile. It was assumed that there was no streambank erosion occurring in watersheds with average annual sediment yields below 12.13 tons per square mile.

The annual streambank sediment yield for all watersheds under low and high flow conditions was then estimated, based on the probability plot relationship (see Figure 5; from Sekely et al., 2002). The probability plot of annual streambank erosion rates indicated that erosion rate for the 10% exceedance probability is 374% higher than the erosion rate for the 50% exceedance probability, while the erosion rate for the 90% exceedance probability is 20% of the erosion rate for the 50% exceedance probability (Sekely et al., 2002). For this analysis, the proportion of 10% and 90% exceedance probabilities to the 50% exceedance probability was assumed to represent the proportional difference between streambank sediment yield during average flow conditions and the high and low flow conditions, respectively. These relationships were then utilized to estimate the streambank sediment erosion loadings under low and high flow conditions.

Sekely et al. (2002) estimated streambank slumping phosphorus loadings based on an average soil total phosphorus concentration of 441 ppm, resulting from 16 surface samples collected from Blue Earth River escarpments. No other data for total phosphorus content in other escarpments, throughout the state, could be located in the literature. As a result, the total phosphorus load associated with sediment loading estimated from streambank erosion in each basin, for each flow condition, was estimated for this analysis based on an assumed soil total phosphorus concentration of 441 ppm.

Results of Phosphorus Loading Computations and Assessments

Table 2 presents the results of the phosphorus loading computations and assessments for each flow condition, by watershed basin and the entire state. Table 3 compares the phosphorus yield associated with streambank erosion for each flow condition, by watershed basin and the entire state. Table 2 shows that the estimated streambank erosion total phosphorus loadings under low flow conditions are approximately an order of magnitude lower than average flow conditions, while the streambank erosion estimates under high flow conditions are about a half an order of magnitude higher than average flow conditions.

Table 2
Summary of Total Phosphorus Loading Estimates for Streambank Erosion (kg/year)

Basin	Low Flow Conditions	Average Flow Conditions	High Flow Conditions
Cedar River	140	12,200	59,600
Des Moines River	130	7,350	47,900
Lake Superior	4,730	35,100	207,000
Lower Mississippi	45,500	322,000	1,280,000
Minnesota River	9,910	200,000	900,000
Missouri River	1,440	16,100	71,600
Rainy River	0	52,700	318,000
Red River of the North	0	8,840	146,000
St. Croix River	20	15,500	98,000
Upper Mississippi	430	79,900	477,800
Statewide Totals	62,300	750,000	3,606,000

Table 3
Summary of Total Phosphorus Yield Estimates for Streambank Erosion (kg/km^2/year)

Basin	Average Flow Conditions
Cedar River	4.6
Des Moines River	1.9
Lake Superior	2.2
Lower Mississippi	19.7
Minnesota River	5.2
Missouri River	3.5
Rainy River	1.8
Red River of the North	0.2
St. Croix River	1.7
Upper Mississippi	1.5
Statewide Totals	3.4

Table 3 shows that the relative difference between the estimated phosphorus loadings for each basin corresponds well with the variation of observed sediment yields throughout the State (as shown in Figure 4), although sediment yield and streambank erosion loadings would not necessarily be expected to vary the same if other sources of phosphorus and sediment measured in the yield vary significantly. Based on the estimated yield from each basin, the Lower Mississippi River basin loadings are significantly higher than any other basin, followed by the Minnesota and Cedar River basins. This corresponds well with the portion of the State with significant loess deposits, and corresponds with the findings of other researchers (Tornes, 1986; Simon and Rinaldi, 2000; Simon et al., 2003). For each flow condition, the Lower Mississippi River basin streambank erosion estimates from Table 2 account for more than a third of the total loading estimated for the State. Under the low flow condition, the Lower Mississippi River basin streambank erosion estimates accounts for more than 70 percent of the total loading estimated for the State.

Phosphorus Loading Variability and Uncertainty

The variability and uncertainty of the phosphorus loading computations done for this analysis is the result of each of the following sources of error:

- The natural variability associated with the published streambank erosion and sediment yield data
- the uncertainty that is introduced in this analysis as a result of extrapolating the monitored sediment yield data to the unmonitored areas for each ecoregion
- the variation in sediment yield within each ecoregion
- the assumptions that the Simon and Hupp (1986) model of channel evolution applied to Minnesota streams and the slope of the suspended-sediment rating relationship could be used to characterize stable versus unstable streams, based on data published in Simon (1989a)
- the standard error in the regression between the slope of the suspended-sediment rating relationship and the sediment yield
- the assumption that the probability plot of Blue Earth River streambank erosion rates from Sekely et al. (2002) could be utilized to estimate the variation of streambank erosion during low and high flow conditions for the remaining streams in the state
- the variation in the total phosphorus concentration of the sediment eroding from streambank escarpments throughout the state

Tornes (1986) reported coefficients of variation for the sediment-transport curves, used to estimate sediment discharge for each USGS gage site, in tons per day. Based on the sediment-transport curve segments used for this analysis, the median coefficient of variation was 13 percent, with most of the coefficients of variation below 33 percent (Tornes, 1986).

As previously mentioned, the difference between the 75th and 25th percent quartiles for sediment yields varied among the ecoregions (Simon et al., 2003). There was an order of magnitude difference for Ecoregions 46, 51 and 52; two orders of magnitude difference for Ecoregions 47 and 50; and less than an order of magnitude difference for Ecoregions 48 and 49. This variation in sediment yield for each of the ecoregions indicates that the sediment yield can vary significantly, within each ecoregion. As a result, it may not be unexpected for the error of the streambank erosion estimates to approach an order of magnitude when comparing the observed loadings against the estimates for an average annual condition. A semi-quantitative study, completed by the NRCS (1996), estimated streambank sediment erosion in the Thief and Red Lake River basins based on assessments of 30 to 40 percent of the streambanks along each river. This study provided an opportunity to compare the sediment erosion estimates from this study with the estimates obtained by the NRCS (1996). The NRCS (1996) estimated that the long-term average annual streambank sediment erosion should be 31,200 tons per year for both river basins. Using the approach from this study, applied to the Thief and Red Lake River basins, the estimated streambank sediment erosion was 24,700 tons per year, under high flow conditions. This estimate is 20 percent less than the NRCS estimate for both basins, combined.

The Simon and Hupp (1986) model of channel evolution assume that channelization occurs during certain stages of the process. This should be a good assumption for many of the southern and western streams in Minnesota, with the exception of southeastern Minnesota. As discussed previously, the slope of the suspended-sediment rating relationship has been used to characterize stable versus unstable streams, based on data published in Simon (1989a) and shown in Figure 3. This is probably the most significant assumption made for this analysis since this relationship has not been broadly tested across a variety of climate and watershed conditions and may not apply to all of the streams in Minnesota. The slope of the suspended-sediment transport curves will be influenced by: cohesive versus noncohesive parent material, morphology of the new stream alignment, and extent of vegetative restoration during the last stage of evolution.

The relationship developed between the average annual sediment yield and the slope of the sediment-transport curve introduces some uncertainty into this analysis (as shown in Figure 6). The linear regression done on the log-transformed data explained approximately 62 percent of the observed variance. The primary impact of this regression on the overall analysis is that it both impacts the sediment yield (12.13 tons per square mile) assumed for a stable stream (Figure 3, taken from Simon, 1989a), as well as the magnitude of the estimated sediment yield used to estimate the streambank erosion loadings for the unmonitored portions of the State. Based on the 90 percent confidence intervals for the regression, the lower sediment yield estimate used for a stable stream would be 2.88 tons per square mile, while the higher sediment yield estimate is 51.3 tons per square mile. The linear regression done on the log-transformed data was also done separately on the data from the western and eastern portions of the state, but each of the new relationships did not explain significantly more than 62 percent of the observed variance (as it did with all of the data), nor did it change the average annual sediment yield based on the assumed slope of the sediment-transport curve for a stable stream in each of the new regressions.

As discussed previously, the probability plot of Blue Earth River streambank erosion rates from Sekely et al. (2002) was utilized to estimate the variation of streambank erosion during low and high flow conditions for the remaining streams in the state. As a result, the annual streambank erosion rate under high flow conditions was assumed to be 374 percent higher than the rate under average flow conditions. This assumption should be good for streams located within glacial till plains (such as the Blue Earth River), but the proportion may not be high enough for use in estimating erosion from streambanks located within outwash plains.

The total phosphorus load associated with sediment loading estimated from streambank erosion in each basin, for each flow condition, was estimated for this analysis based on an assumed soil total phosphorus concentration of 441 ppm. Sekely et al. (2002) estimated streambank slumping phosphorus loadings based on an average soil total phosphorus concentration of 441 ppm, resulting from 16 surface samples collected from Blue Earth River escarpments. No other data for total phosphorus content in other escarpments or native soils, throughout the state, could be located in the literature. Most of the total phosphorus concentrations of the sixteen samples collected for the Blue Earth River study varied within 50 to 75 ppm of the median concentration (Thoma, 2003). As a result, variation in the estimated phosphorus load associated with streambank erosion from the Blue Earth River could vary by 10 to 20%, and would be expected to result in significantly more variation in the estimates made for the rest of the state.

Recommendations for Future Refinements

Figure 4 shows that many areas of the State have not been adequately sampled for definition of sediment-transport characteristics. Only a few or no sediment samples (with corresponding discharges) have been collected from most of the streams in northern and central Minnesota, with almost no samples present for the Northern Minnesota Wetlands Ecoregion (Tornes, 1986; Simon et al., 2003). Some rivers in west-central Minnesota, parts of the Red River of the North, the Rock

River, and the Pomme de Terre River drain areas underlain by clayey or loess soils may have sediment yields that are similar to those in the southeast part of the State (Tornes, 1986). In addition, no sediment-transport curves or erosion assessments have been published for streams in the St. Croix River basin. The current lack of sediment-transport data and erosion assessments throughout the state make it difficult to adequately ascertain the impacts of streambank erosion, especially as it pertains to impaired biota. Collecting more data for streambank erosion assessments can be used to further refine this analysis, reduce the current level of uncertainty, and improve the understanding of the linkage between sediment and phosphorus loadings with biological impairments.

The MPCA should install continuous flow monitoring equipment, and begin developing stage-discharge-sediment transport curves, as a means of assessing erosion within some of the existing State milestone monitoring watersheds, that are not currently being monitored by the USGS. Additional streambank erosion assessments, similar to those discussed in Table 1, should be done in conjunction with stream water quality and biological monitoring, and channel evolution stage determinations, to develop and refine empirical models and provide a better understanding of the impacts of streambank erosion throughout the State. One such assessment, recently completed by the MPCA, was done to evaluate the relationship between suspended sediment transport, stream classification and fish index of biological integrity (IBI) scores (Magner et al., 2003).

All of these assessments should also be done to evaluate streambank erosion during low and high flow conditions and address the variability and uncertainty associated with the estimates presented here. Also, more total phosphorus data should be collected from eroding streambanks across the state to further evaluate how much of the phosphorus loading is entering the streams from upland sources versus fluvial processes.

Recommendations for Lowering Phosphorus Export

There is the potential for substantial water quality benefits associated with lowering phosphorus export from streambank erosion, including reduced eutrophication and sedimentation and improved biological habitat within reservoirs, lakes and wetlands, along with the river systems themselves. Land use planning should consider the potential adverse impacts associated with the increased runoff volumes and sediment erosion. Stream road crossings should be designed with consideration to the potential hydrodynamic changes to the system. Exclusion of pastured animals and preservation of riparian vegetation will also assist with maintaining streambank stability.

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Technical Memorandum

To: Marvin Hora, Doug Hall and Mark Tomasek, Minnesota Pollution Control Agency

From: Greg Wilson and Tim Anderson

Subject: Final — Detailed Assessment of Phosphorus Sources to Minnesota Watersheds — Individual Sewage Treatment Systems/Unsewered Communities

Date: January 16, 2004

Project: 23/62-853 ISTS 009

c: Henry Runke

The purpose of this memorandum is to provide a discussion about unsewered communities and Individual Sewage Treatment Systems (ISTS) as sources of phosphorus to Minnesota watersheds. This discussion is based on a review of the available literature, monitoring data and the results of phosphorus loading computations done for each of Minnesota's major watershed basins as part of this study. This memorandum is intended to:

- Provide an overview and introduction to these sources of phosphorus
- Describe the results of the literature search and review of available monitoring data
- Discuss the characteristics of each watershed basin as it pertains to these sources of phosphorus
- Describe the methodology used to complete the phosphorus loading computations and assessments for this study
- Discuss the results of the phosphorus loading computations and assessments
- Discuss the uncertainty of the phosphorus loading computations and assessment
- Provide recommendations for future refinements to phosphorus loading estimates and methods for reducing error terms
- Provide recommendations for lowering phosphorus export from unsewered communities and individual sewage treatment systems

Overview and Introduction to Unsewered Communities and ISTS Sources of Phosphorus

"Unsewered" or "undersewered" areas are communities or residential areas which have inadequate or no centralized wastewater treatment (sewer) systems. In many cases they may have a sanitary sewer system. Individual sewage treatment system (ISTS) refers to a sewage treatment and disposal system located on a property, using subsurface soil treatment and disposal for an individual home or establishment. MPCA

(2002a) states that most unsewered communities and many failing septic systems have relatively direct connections to surface waters through tiles lines, resulting in a very high delivery potential. Failing systems are systems that are adversely impacting groundwater, while those systems which discharge partially treated sewage to the ground surface, road ditches, tile lines, and directly into streams, rivers and lakes are considered an imminent threat to public health and safety (ITPHS).

Unsewered areas include but are not limited to incorporated cities (some), unincorporated communities, clusters of homes, trailer parks or other rural residential areas where wastewater collection is not done through a large sewer system. Undersewered areas may include unincorporated communities, incorporated cities (some), clusters of homes, trailer parks, or rural residential areas where existing wastewater treatment methods are not adequate to protect public health or the environment. The situations range from failing individual systems to cities with inadequate collection and treatment infrastructure.

Minnesota Rules Chapter 7080 contains minimum standards and criteria for the location, design, installation, use, maintenance and abandonment of ISTS, a licensing program for ISTS professionals and administrative requirements for local units of government. The conventional ISTS consists primarily of a septic tank and a soil absorption field. Septic tanks remove most settleable and floatable material and function as an anaerobic bioreactor that promotes partial digestion of retained organic matter (EPA, 2002). Septic tank effluent, which contains significant concentrations of pathogens and nutrients, has traditionally been discharged to soil, sand, or other media absorption fields for further treatment through biological processes, adsorption, filtration, and infiltration into underlying soils. Conventional systems work well if they are installed in areas with appropriate soils and hydraulic capacities; designed to treat the incoming waste load to meet public health, ground water, and surface water performance standards; installed properly; and maintained to ensure long-term performance (EPA, 2002).

Phosphorus is present in significant concentrations in most wastewaters treated by ISTS. After treatment and percolation of the wastewater through the infiltrative surface biomat and passage through the first few inches of soil, the wastewater plume begins to migrate downward until nearly saturated conditions exist (EPA, 2002). Reduced treatment occurs when the plume is mixing with an elevated water table (see Figure 1). At that point, the wastewater plume will move in response to the prevailing hydraulic gradient. The movement of subsurface aqueous contaminant plumes is highly dependent on soil type, soil layering, underlying geology, topography, and rainfall (EPA, 2002). In regions with moderate to heavy rainfall, descending effluent plumes remain relatively intact as the water table is recharged from above. Monitoring below ISTS systems has shown that the amount of phosphorus leached to ground water depends on several factors: the characteristics of the soil, the thickness of the unsaturated zone through which the wastewater percolates, the applied loading rate, and the age of the system (EPA, 2002). The amount of phosphorus in ground water varies from background concentrations to concentrations comparable to that of septic tank effluent. The capacity of the soil to retain phosphorus is finite. With continued loading, phosphorus movement deeper into the soil profile and downgradient water resources can be expected.

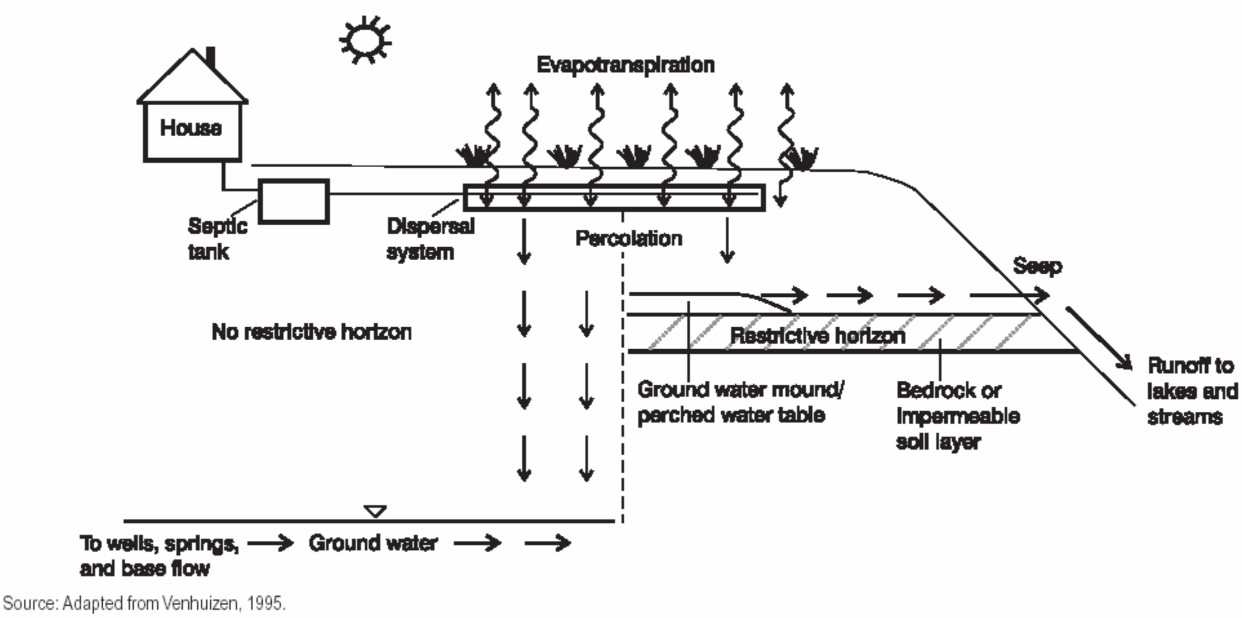

Figure 1: Schematic of ISTS wastewater discharge.

As previously discussed, conventional treatment systems work well if they are installed in areas with appropriate soils and hydraulic capacities; designed to treat the incoming waste load to meet public health, ground water, and surface water performance standards; installed properly; and maintained to ensure long-term performance (EPA, 2002). As a result, phosphorus export to surface waters from ISTS and unsewered communities is dependent on the following factors:

- Phosphorus content of waste load
- Population served by ISTS or unsewered communities
- Compliance of treatment systems with performance standards
- Characteristics of soil absorption field, groundwater conditions and proximity to surface waters

Review of Available Data and Estimation of Population Served by ISTS/ Unsewered Communities

Data pertaining to the phosphorus content of the untreated waste load from unsewered communities was addressed in the Point Sources Technical Memorandum (Barr, 2003), prepared for this project. For the purposes of this analysis, the phosphorus contained in untreated sewage discharge from ISTS or unsewered communities consists of the following sources, with the corresponding per capita loadings of phosphorus (taken from the Point Sources Technical Memorandum):

Source	Phosphorus Load (kg/cap/yr)
Automatic dishwasher detergent	0.1250
Dentifrices	0.0115
Food soils and garbage disposal wastes	0.1895
Ingested Human wastes	0.5585
Total	0.8845

Dentifrices include toothpaste and other dental care products. Food soils include waste food and beverages poured down the sink, and food washed down the drain as a result of dish rinsing and washing (Barr, 2003). The total per capita phosphorus load of 0.8845 kg/yr, which corresponds to 1.946 lbs/cap/yr, was assumed to apply to the population served by ISTS or unsewered communities throughout the state.

The number of people served by ISTS was estimated from a variety of data sources.
Table 1 provides a summary of population served by ISTS by basin using four data sources. A description of each of these data is discussed below. Two of the data sources were spreadsheets provided by the Minnesota Pollution Control Agency, another was the 1990 Census (United States Census Bureau, 1990), and the last was estimated based on the results from the Point Sources Technical Memorandum. Table 1 contains a summary of the population served by ISTS by major drainage basin for each of the four methods examined.

The method using the difference between the 2000 Census (United States Census Bureau, 2000) population and the POTW population served totals were used in the study to estimate phosphorus loadings from ISTS. This data showed good consistency with the other data available for ISTS in

Table 1
Estimates of Population Served

Major Basin	1990 Census Population	2000 Census Population	POTW Data				1990 Census Data		LUG Spreadsheet		Unsewered Areas	
			2000 POTW Population Served	Loss or gain of Population due to Basin Transfer	2000 ISTS by Difference	ISTS Percentage of 2000 Population	1990 Population Served by ISTS	ISTS Percentage of 1990 Population	Population Served by ISTS	ISTS Percent of 2000 Population	2002 Unsewered Population	Percentage of 2000 Population
Cedar River	66,144	66,934	49,280	0	17,654	26%	16,687	25%	11,207	17%	299	0%
Des Moines River	34,517	34,955	28,137	0	6,818	20%	12,231	35%	13,198	38%	1,028	3%
Lake Superior	212,223	221,000	181,581	0	39,419	18%	62,885	30%	20,306	9%	342	0%
Lower Mississippi	471,122	558,351	378,098	-36787	143,466	26%	136,049	29%	81,967	15%	11,272	2%
Minnesota River	763,066	861,292	743,145	40110	158,257	18%	169,309	22%	162,244	19%	25,872	3%
Missouri	35,377	33,777	17,080	0	16,697	49%	13,992	40%	12,858	38%	509	2%
Rainy River	48,476	46,946	13,413	0	33,533	71%	26,855	55%	40,380	86%	6,216	13%
Red River	237,920	244,216	131,742	0	112,474	46%	105,823	44%	100,025	41%	8,966	4%
St. Croix River	157,613	206,190	52,242	-43,428	110,520	54%	85,184	54%	110,427	54%	32,612	16%
Upper Mississippi	2,350,483	2,645,132	2,231,380	40105	453,857	17%	458,195	19%	520,096	20%	154,696	6%
TOTAL	4,376,940	4,918,793	3,826,098	0	1,092,695	22%	1,087,208	25%	1,072,708	22%	241,812	5%

LUG: Local Unit of Government

Minnesota. By using the by difference method, a total accounting of domestic waste disposal is provided in this study.

Below is a description of the data used to develop the summary in Table 1.

MPCA Unsewered Communities Spreadsheet

The MPCA developed a spreadsheet, updated in September, 2003, providing a list of unsewered communities within Minnesota (MPCA, 2003a). Included in the spreadsheet are 841 communities. The major basin for each of these communities was estimated by assigning an approximate geographic location based on a city, township, lake/county, or township-range-section location (whichever provided the most detailed location). The locations were determined for 785 of the 841 communities. The remaining 57 communities were not located. Many of the communities that were not located were subdivisions or unmapped communities using local names.

The sum of the population served by ISTS in these communities was approximately 253,000. The total for unsewered communities under-represents the amount of ISTS systems in the state since it includes only systems within a community. Although summarized in Table 1, these data were not directly used in the comparison of methods.

MPCA ISTS Local Units of Government (LUG) Spreadsheet

This spreadsheet consists of a summary of ISTS by local units of governments with ISTS ordinances in 2002 (MPCA, 2002b). Included in the spreadsheet was the LUG name and type (e.g. city, township or county). An estimate of the number of full time and seasonal residences served by ISTS was included in the spreadsheet. There was also an estimate of the number of failing systems and an estimate for the number of systems which are considered an ITPHS. The population served was estimated by multiplying the number of full time residences by the population per household values (for the 2000 census) for the LUG's respective county.

The LUGs in this spreadsheet were located geographically as polygons using MnDOT's base map GIS layers for municipalities, townships, and counties. To prevent overlap between counties and the smaller governmental units, ArcInfo GIS was used to clean the boundaries between the overlapping jurisdictional boundaries. For example, if a municipality had its own ISTS ordinance, the city boundary was excluded from the area of the County (which would also have an ordinance) in which it is located.

The resulting polygons were overlaid with the ten major basins to estimate the ISTS totals for each major basin. In cases where a jurisdiction was in two or more major basins, the ISTS population served for each basin was weighted by area. The sum of all the population served for the State of Minnesota was approximately 1,073,000 based on the LUG spreadsheet.

1990 Census of the United States

The 1990 Census (United States Census Bureau, 1990) included questions regarding sewage disposal for both vacant and occupied housing units. Below is a description of the data provided by the Census Bureau:

> *SEWAGE DISPOSAL*
> *The data on sewage disposal were obtained from questionnaire item H16, which was asked at both occupied and vacant housing units. This item was asked on a sample basis. Housing units are either connected to a public sewer, to a septic tank or cesspool, or they dispose of sewage by other means. A public sewer may be operated by a government body or by a private organization. A housing unit is considered to be connected to a septic tank or cesspool when the unit is provided with an underground pit or tank for sewage disposal. The category, "Other means" includes housing units which dispose of sewage in some other way.*
>
> *Comparability--Data on sewage disposal have been collected since 1940. In 1970 and 1980, data were shown only for year-round housing units. In 1990, data are shown for all housing units.*

Note that sewage disposal data were not collected in the 2000 census (United States Census Bureau, 2000). The “septic tank or cesspool” and “other units” were combined as an estimate for ISTS in this study.

In the 1990 census, the sewage disposal data were not split between year-round and vacant/seasonal housing. For this study, it was assumed that the percentage of all housing units with ISTS were equal to the percentage of year-round housing units with ISTS. Therefore, the total ISTS in each census-blockgroup was estimated by multiplying the ratio of year-round housing to all housing units by the total number of households with ISTS in that census-blockgroup. The population served was calculated by multiplying the number of households with ISTS by the population per household for the census blockgroup.

The estimated population served by ISTS in Minnesota using the 1990 census data is 1,087,000.

Estimation of Population Served by ISTS by Difference Between 2000 Census and WWTP Population Served (Difference Method)

The sum of the population served by public/private wastewater treatment systems and ISTS can be assumed to be the population of the State of Minnesota during the 2000 census. The estimate of population served using ISTS by basin can be estimated by calculating the difference between the total population of each basin and the number of persons served by wastewater treatment plants in the basin.

The population served for each of the POTWs and privately owned wastewater treatment facilities were estimated. The population served for each facility was not readily available for all of the permitted facilities. Therefore, the following approach was taken and the following assumptions made (as per the Point Sources Technical Memorandum):

1. MPCA Delta Database. When available, the population served by a treatment facility as listed in the Delta database was used.
2. MNPRO Database. If population data was not available from the Delta database, the population of the community corresponding to the permit was assumed to equal the population served by the WWTP. This information was obtained from the MNPRO data base.
3. ISTS unsewered communities and LUG spreadsheets. These communities and the population served by ISTS systems were compared to the communities having an NPDES permit as listed in the Delta database. If a community had both a NPDES permit to discharge to

surface water and was listed as being served by an ISTS, the difference of the City's population and the ISTS population was used as the population served by the treatment facility. If no information could be located, the permit holder was called to determine the population served by each system.

4. MNPRO Database. The complete listing of communities within the state of Minnesota as contained in the MNPRO database was compared to both the NPDES list and the unsewered communities list to verify that all communities within the state were accounted for. Any communities with a population greater than 1,000, that were unaccounted for, were contacted and the final disposition of their wastewater was determined. In many cases these communities transferred their wastewater to another community's treatment facilities.
5. Communities with a population of less than 1,000 that did not have either an NPDES permit, or were listed as an ISTS or unsewered community, were assumed to be served by an ISTS system.
6. Finally, the population served by unsewered and ISTS systems was tallied on a major basin basis. These results are presented in Table 1.

The state-wide estimate for population served by ISTS based on the difference between the 2000 census and the POTW totals is approximately 1,094,000. The basin total ISTS values in Table 1 were corrected for the number of people whose domestic wastewater is treated in a wastewater treatment plant outside of the basin where they live. This correction was done for the four basins that include Twin City Metro Area. To determine the areas where there are basin transfers, 1997 Metropolitan Council sewersheds, showing the areas draining to specific wastewater treatment plants in the Metropolitan Area, were overlaid with the major basins. The result of this analysis was the area in each of the basins which discharge to a WWTP in a different basin. These data were then overlaid on the 2000 Census blockgroup data to determine the populations of the areas. The net results of this analysis are shown in Table 1.

The breakdown of population served by major basin presented in Table 1 was relatively consistent between the three methods summarized. The LUG spreadsheet and the POTW by difference methods showed the same overall percentage (22 percent) of the total population of the state is served by ISTS. The 1990 Census total had approximately the same state-wide population served value, but its percentage usage was higher since the population of the state was lower in 1990 compared to 2000.

In general, the three methods indicate that the total number of people served by ISTS in Minnesota is approximately 1,080,000, 22 percent of the total population in 2000.

The comparison shows a good match between the three methods for the Upper Mississippi River, Cedar River, St. Croix River, Red River of the North and Minnesota River basins. The Lake Superior and Rainy River basins have the largest discrepancy between the three methods, but the difference method value is near the average of the other two methods for both basins.

The smaller basins in southwest Minnesota (Missouri and Des Moines rivers) had the largest percentage differences, although their numerical differences were small since the populations of these basins are low. The reason the differences are so great in these two basins, on a percentage basis, is not clear.

The results in Table 1 show that using the difference method provides a good estimate for the number and distribution of ISTS users across the state. By using the difference method, the entire population of the state is accounted for in the phosphorus calculations for domestic wastewater generation.

Basin Characteristics

Population served by ISTS or unsewered communities, compliance of treatment systems with performance standards, groundwater conditions, and characteristics of soil absorption field and proximity to surface waters are important factors in determining phosphorus export. As previously discussed, the major basin for each of the communities in MPCA unsewered communities spreadsheet was determined by assigning an approximate geographic location based on the available city, township, lake/county, or township-range-section location data. The MPCA ISTS LUG spreadsheet provided estimates of the number of full time and seasonal residences served by ISTS, along with the number of failing systems and an estimate for the number of systems which are an ITPHS. The population data used for both ISTS and unsewered communities are included in Tables 1 and 2. Table 2 also shows the number of residential systems in each basin. The Upper Mississippi River basin accounts for almost one-quarter of the population served by ISTS and more than 60 percent of the unsewered areas population. The Minnesota, Lower Mississippi, Red and St. Croix River basins serve ISTS populations of between 110,000 and 160,000, while the Minnesota and St. Croix River basins have unsewered area populations between 25,000 and 33,000. The remaining basins represent small fractions of the statewide populations served by ISTS and unsewered communities.

Table 2 shows the percentages of failing systems and systems which discharge partially treated sewage (or are considered an ITPHS), estimated for each of the basins and the state. These estimates show that the Des Moines River basin has the highest percentage (41%) of ISTS systems considered an ITPHS, followed by the Minnesota and Missouri River basins with 29 and 22 percent, respectively. The St. Croix, Lake Superior, Rainy and Upper Mississippi River basin estimates for percentages of ISTSs considered an ITPHS were all less than 8 percent. Table 2 shows that the Rainy River basin had the highest (43%), while the St. Croix basin had the lowest (11%), percentages of failing ISTS systems. All of the other basins had estimated percentages of failing ISTS systems between 24 and 35 percent. The high percentage for the Rainy River basin may be partially due to the presence of high water tables relative to the other basins.

Retardation of phosphorus contamination of surface waters from ISTSs is enhanced in fine-textured soils without continuous macropores that would allow rapid percolation. Increased distance of the system from surface waters is also an important factor in limiting phosphorus discharges because of greater and more prolonged contact with soil particle surfaces. The risk of phosphorus contamination, therefore, is greatest in karst regions and coarse-textured soils without significant iron, calcium, or aluminum concentrations located near surface waters (EPA, 2002). The presence of karst regions in portions of the Lower Mississippi River basin means that the 27 percent of failing ISTSs (from Table 2) might be lower than the actual percentage of systems adversely impacting groundwater. For this analysis, no attempt has been made to vary the estimates of phosphorus discharged to surface waters from conforming and non-conforming systems, based on the presence of karst regions, elevated water tables or various types of soils in each basin.

Table 2
Estimated Annual Phosphorus Loadings for ISTS/Unsewered Communities

											Estimated P Load Produced (kg)				Estimated P Load Discharged to Surface Waters (kg)				
Major Basin	ISTS Population by Difference	Total Residential Systems	Percent Partially Treated	Percent Failing	Unsewered Areas Population	Avg. Pop. per Household	Direct-to-Tile Systems	Direct-to-Tile Pop.	Remaining ISTS Pop.	Seasonal Pop.	Unsewered Areas	Direct-to-Tile Systems	Seasonal ISTS	Remaining ISTS	Unsewered Areas	Direct-to-Tile Systems	Seasonal ISTS	Remaining ISTS	Total
Cedar River	17,654	4,500	15.7%	34.6%	299	3.92	514	2,016	15,339	0	264	1,784	0	13,568	114	767	0	2,999	3,880
Des Moines River	6,818	5,420	41.1%	23.8%	1,028	1.28	419	536	5,254	191	909	474	56	4,647	391	204	20	1,316	1,930
Lake Superior	39,419	16,000	5.5%	35.0%	342	4.80	0	0	39,077	16,363	303	0	4,825	34,565	130	0	1,415	6,507	8,051
Lower Mississippi	143,466	31,002	10.6%	26.8%	11,272	4.75	450	2,137	130,057	1,676	9,971	1,891	494	115,041	4,287	813	141	21,707	26,949
Minnesota River	158,257	67,100	29.4%	32.8%	25,872	2.55	7,399	18,847	113,538	10,437	22,885	16,671	3,077	100,430	9,841	7,168	1,056	26,377	44,442
Missouri	16,697	5,233	22.1%	33.4%	509	3.27	227	743	15,445	281	450	658	83	13,662	194	283	27	3,275	3,778
Rainy River	33,533	23,928	7.0%	43.1%	6,216	2.02	0	0	27,317	15,395	5,498	0	4,539	24,163	2,364	0	1,431	5,056	8,851
Red River	112,474	46,447	13.1%	27.0%	8,966	2.92	0	0	103,508	16,655	7,931	0	4,911	91,558	3,410	0	1,434	18,038	22,882
St. Croix River	110,520	45,249	2.3%	11.4%	32,612	2.76	0	0	77,908	10,857	28,847	0	3,201	68,913	12,404	0	741	8,987	22,132
Upper Mississippi	453,857	227,515	7.8%	24.7%	154,696	2.32	436	1,014	298,147	67,809	136,836	897	19,993	263,725	58,839	386	5,497	46,250	110,972
TOTAL	1,092,695	472,394	11.6%	26.4%	241,812	2.69	9,445	25,294	825,589	139,665	213,894	22,373	41,180	730,271	91,974	9,621	11,762	140,510	253,867

The Minnesota River basin had a significant number of households served by sewage treatment systems that involved direct discharge to a tile drain line (Tetra Tech, 2002). The majority of these systems, referred to as direct-to-tile ISTS, include a septic tank with no other treatment. Assuming that most of the direct-to-tile ISTS are located in rural areas with tile lines, Tetra Tech (2002) extracted data from the Minnesota River Assessment Project, or MRAP (MPCA, 1994), to develop a relationship between the number of direct-to-tile ISTS and cropland. The ISTS densities and cropland were then mapped by minor watersheds across the Minnesota River basin. The higher densities of direct-to-tile ISTS occurred in the southeastern watersheds, while the lower densities occurred in the northwestern watersheds (Tetra Tech, 2002). The geographic trend in density was assumed to be consistent with the MRAP designations for three nutrient source regions, and the average density of direct-to-tile ISTS per 10,000 acres of cropland was determined for each source region. The average densities determined for Source Regions 1, 2, and 3 were 0.78, 4.88, and 18.17 direct-to-tile ISTS per 10,000 acres of cropland, respectively (Tetra Tech, 2002). Source Regions 1, 2, and 3 progress from the northwest to the southeast in the Minnesota River basin.

For this analysis, the assumptions about direct-to-tile ISTS density per 10,000 acres of cropland for each source region were retained for the Minnesota River basin. Since no assessments of direct-to-tile ISTS had been published for any other basins in Minnesota, several of the minor watersheds in surrounding basins were assumed to have direct-to-tile ISTS densities comparable to Source Regions 1, 2, and 3, based on knowledge of the presence of drain tiles, cropland and their proximity to the MRAP study areas. Figure 2 shows how these minor watersheds, with their assumed Source Region designations, provide a transition in the direct-to-tile ISTS densities assumed to exist outside of the areas studied in MRAP (MPCA, 1994). The amount of cropland and area of each Source Region was determined and multiplied to determine the total number of direct-to-tile systems for each basin (shown in Table 2). The population served by direct-to-tile ISTS was estimated by multiplying the number of systems by the average household size for each basin (shown in Table 2).

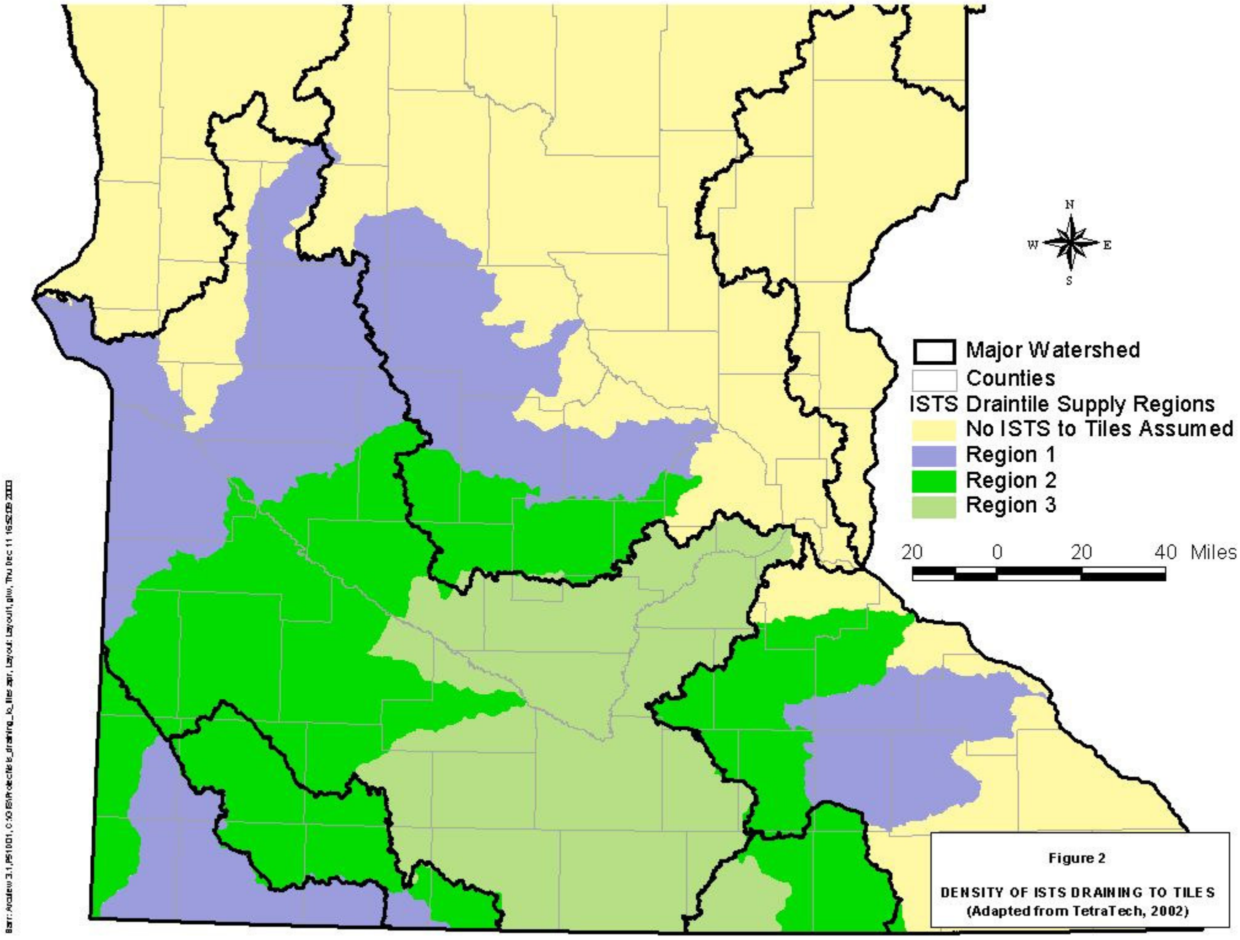

Figure 2

DENSITY OF ISTS DRAINING TO TILES
(Adapted from TetraTech, 2002)

Approach and Methodology for Phosphorus Loading Computations

Based on the availability of data and the potential for variation in phosphorus export from unsewered communities and the various types of conforming and nonconforming ISTS, phosphorus loadings were estimated for each of the following source categories:

- Unsewered communities
- Direct-to-tile ISTS
- Conforming and nonconforming seasonal ISTS
- Remaining conforming and nonconforming ISTS

As previously discussed, Table 2 presents the populations associated with unsewered communities and direct-to-tile ISTS in each basin. The per capita total phosphorus wastewater load of 0.8971 kg/yr was applied to the population served by direct-to-tile ISTS and unsewered communities for each basin. Both of these source categories were assumed to receive treatment from septic tanks before discharging to surface waters. Forty-three percent of the incoming wastewater load from each source category was assumed to pass through the septic tank, which is consistent with the assumptions made for the Minnesota River Basin Model (Tetra Tech, 2002).

As previously discussed, the number of seasonal residences had been estimated in the MPCA ISTS LUG spreadsheet (MPCA, 2002). Since no data was available for the population served by seasonal ISTS, a household size of 2.1 was assumed and applied to the number of seasonal residences in each basin. This assumption is consistent with the household size used for the Minnesota River Basin Model (Tetra Tech, 2002). No literature was found, so it was assumed that each of the seasonal residences were occupied for four months each year. It was further assumed that, since seasonal residences are typically located in close proximity to surface waters, nonconforming ISTS (both failing and ITPHS) would contribute all of the 43 percent of phosphorus passing through a septic tank to surface waters. Conforming seasonal ISTS were assumed to remove 80 percent of the total phosphorus loading, due to treatment from the septic tank and soil absorption field, before discharging to surface waters in each basin.

As previously discussed, the total number of residential residences had been estimated in the MPCA ISTS LUG spreadsheet (MPCA, 2002) and the population served by ISTS had been estimated by difference (shown in Table 1). Since most of the permanent residences are not typically located as close in proximity to surface waters as seasonal residences, it was assumed that both fully conforming and failing ISTS would provide higher phosphorus attenuation for permanent residences than what was assumed for seasonal residences. Conforming ISTS were assumed to remove 90 percent of the overall total phosphorus loading, while failing ISTS were assumed to remove 70 percent of the overall total phosphorus loading, before discharging to surface waters in each basin. The nonconforming ISTS, considered an ITPHS, were assumed to be contributing all of the 43 percent of phosphorus passing through a septic tank to surface waters. The phosphorus removal and soil phosphorus attenuation percentages assumed for conforming and nonconforming ISTS in this analysis are within the range of literature values (Viraraghavan and Warnock, 1975; Reckhow and Simpson, 1980; Kellog et al., 1995; EPA, 2002; ENSR, 2003).

Results of Phosphorus Loading Computations and Assessments

Table 2 presents the results of the phosphorus loading computations done for the assessment of ISTS and unsewered communities. The last five columns of Table 2 show the estimated total phosphorus loadings to surface waters from unsewered communities, direct-to-tile ISTS, all seasonal ISTS, the remaining ISTS, and the total load in each basin (and the state) from all four source categories. On a statewide basis, Table 2 shows that more than half of the phosphorus load from unsewered communities/ISTS is coming from permanent ISTS, while approximately 35 percent of the total load originates from unsewered communities. Unsewered communities represent a large percentage of the total load to the St. Croix and Upper Mississippi River basins (56 and 53 percent, respectively). Unsewered communities represent less than 27 percent of the total phosphorus load for the remaining basins. Direct-to-tile ISTS represents 20, 16 and 11 percent of the total phosphorus load in the Cedar Minnesota, and Des Moines River basins, respectively; but less than 8 percent for the remaining basins. The estimated seasonal ISTS contributions are 16 and 18 percent of the total phosphorus loads in the Rainy River and Lake Superior basins, respectively, and less than 7 percent for the remaining basins. The remaining ISTS contributions (from both conforming and nonconforming systems) accounts for more than 40 percent of the total phosphorus load from ISTS/unsewered communities in all of the basins. The highest total phosphorus contribution from the remaining ISTS category is 87 percent in the Missouri River basin.

Phosphorus Loading Variability and Uncertainty

The primary sources (and estimated magnitudes) of variability and uncertainty in the total phosphorus loading computations done for this assessment, in descending order, include:

- Percentage of phosphorus attenuation in soil absorption field for permanent and seasonal residences—(these percentages are likely to vary by 50 percent or more, depending on the proximity to surface water, soils and water table characteristics, etc.; if the all of the conforming systems from the remaining ISTS category removed 100% of the P load produced, the 140,510 kg total P load discharged to surface waters [in Table 2] would be reduced by approximately 30%)

- Portion of unsewered communities receiving various levels of treatment, more or less than septic tank removals (as assumed)—(these percentages are likely to vary by 50 percent or more, as some of the unsewered communities may be receiving good treatment with soil absorption, while others may not even receive treatment from septic tanks)
- Population of unsewered communities—(population figures may vary significantly within each basin depending on each counties ability to determine, report or verify and update the presence and population of unsewered communities)
- Population served and portion of direct-to-tile ISTS receiving various levels of treatment, more or less than septic tank removals (as assumed)—(these values are likely to vary by 100 percent or more, as the number of systems and population served are extrapolated from a small subset of areas studied in the MRAP which may or may not have already been counted with the ITPHS percentages, and some of the direct-to-tile ISTS may not even receive treatment from septic tanks)
- Population served and per capita P loadings for permanent versus seasonal residences—(the current P loading estimates assume that all of the population served by seasonal residences [2.1 people per seasonal residence for 4 months each year] is in addition to all of the P loadings generated by the current permanent residents of Minnesota, which may overestimate the P load from permanent Minnesota residents that maintain seasonal residences, but helps to offset both the fact that seasonal residences may be under-represented in the databases and the fact that people from other states maintain seasonal residences; in addition, the per capita loadings for dishwashing detergents and dentifrices are based on actual nationwide consumption, while the per capita loadings for human waste and food soils are based on monitoring of permanent residences)

Table 2 shows that the average ISTS household size determined for each basin can vary significantly from the statewide average of 2.7. The average ISTS household size was determined by dividing the total population served by ISTS by the total number of residential systems. The low household size value of 1.3 for the Des Moines River basin, may be the result of an underestimate of the population served by ISTS and unsewered communities or an overestimate of the number of residential systems. The high household sizes of approximately 4.8 for the Lower Mississippi and Lake Superior basins indicate that there may be an overestimate of the population served by ISTS and unsewered communities or an underestimate of the number of residential systems. There was much smaller variability from the statewide average for household size in the remaining basins. Over- or underestimates of population are much more important in the calculations of the total phosphorus loadings for each basin than the estimates of the number of residential systems because the population figures determine the amount of wastewater (and phosphorus) that is generated and available for export in each basin.

Recommendations for Future Refinements

The following refinements are recommended to reduce the error terms or uncertainty of the phosphorus loading estimates:

- The counties should work with the MPCA to develop, populate and maintain a geographic database, similar to MPCA's feedlot database that shows where each of the failing systems, straight pipe discharges and other types of ITPHS are located
- County personnel should be trained to assess the proper functioning of each type of system and be provided with an incentive to track all inspected and nonconforming systems, such that uniform assessments can be made throughout the state
- The estimates for population served by conforming and nonconforming systems, as well as unsewered communities and direct-to-tile ISTS, should be refined, updated and linked to a geographic database
- Additional analyses should be done to study the treatment effectiveness of conforming and nonconforming treatment systems, throughout the state, to evaluate the variability of the estimated phosphorus loadings to surface waters under various settings

Recommendations for Lowering Phosphorus Export

Many of the counties are delegated to implement the Minnesota Rules (Chapter 7080) for ISTS, which require conformance with state standards for new construction and disclosure of the state of the ISTS when a property transfers ownership. Several counties require ISTS upgrades at property transfer.

Lack of knowledge is thought to be a major impediment to making more rapid progress toward goals and objectives for ISTS and unsewered communities (MPCA, 2003b). This includes a lack of awareness of the management and operational requirements of ISTS, and the environmental consequences of widespread system failure. The complexity of addressing unsewered community issues tends to discourage county activity in this area. The availability of financial assistance, particularly low-interest loans, is thought to be an essential catalyst to accelerating fixes of failing ISTS. This and other forms of financial assistance are needed to accelerate progress with unsewered communities (MPCA, 2003b).

Owners of ISTS that are failing and pose an "Imminent Public Health Threat," through direct discharge to tile lines or surface ditches or system failure caused by lack of proper management should be targeted through mail surveys (and one-to-one visits in targeted watersheds) to help residents determine whether their ISTS are adequately functioning, inadequately installed, or are failing to function properly because of poor management (MPCA, 2003b). Programs proposed to follow up on specific problems include ISTS management workshops for failing systems and technical and financial assistance to owners needing new systems.

Residents of unsewered communities would be targeted to help them understand the need for wastewater treatment and assist them through each phase of the community decision-making process, while building the capacity of local and regional government staff to provide such assistance to other communities in the future (MPCA, 2003b).

County ISTS inspectors, Planning and Zoning Administrators, and County Water Planners should be targeted with MPCA audits of county ISTS programs to determine adequacy of performance in a number of key areas, including spot checks on recent ISTS installations, level of effort on ISTS inspections and follow-through on noncompliant systems, and dealing with contractors (MPCA, 2003b).

Since septic system failure is a widespread problem, a basinwide approach to reducing fecal coliform from this source should be pursued (MPCA, 2003b). Failing systems with potential for high delivery of pollutants to public waters, such as straight pipe discharges and other types of ITPHS should be given priority attention. Careful targeting is needed to ensure that resources devoted to providing wastewater treatment yield environmental results in the form of reduced concentrations of total phosphorus. The counties should work with the MPCA to develop, populate and maintain a database, similar to MPCA's feedlot database that shows where each of the failing systems, straight pipe discharges and other types of ITPHS are located. County personnel should be trained about the assessment of each type of system and provided with an incentive to track all inspected and nonconforming systems, such that uniform assessments can be made throughout the state.

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Technical Memorandum

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Subject: Detailed Assessment of Phosphorus Sources to Minnesota Watersheds – Non-Agricultural Rural Runoff

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The purpose of this memorandum is to provide a discussion of non-agricultural rural land use runoff as sources of phosphorus to Minnesota watersheds. This discussion is based on a review of the available literature, monitoring data and the results of phosphorus loading computations done for each of Minnesota's major watershed basins as part of this study. This memorandum is intended to:

- Provide an overview and introduction to this source of phosphorus
- Describe the results of the literature search and review of available monitoring data
- Discuss the characteristics of each watershed basin as it pertains to this source of phosphorus
- Describe the methodology used to complete the phosphorus loading computations and assessments for this study
- Discuss the results of the phosphorus loading computations and assessments
- Discuss the uncertainty of the phosphorus loading computations and assessment
- Provide recommendations for future refinements to phosphorus loading estimates and methods for reducing error terms
- Provide recommendations for lowering phosphorus export from this source

Overview and Introduction to Non-Agricultural Rural Runoff Sources of Phosphorus

The non-agricultural rural land use components of watershed ecosystems investigated in this technical memorandum includes native vegetation that still function at an ecosystem level in ways that are very similar to their undisturbed natural condition. The major natural land cover types included in this land use group are forests (coniferous, deciduous and mixed), grasslands and shrublands. Rural residential areas, transportation infrastructure, and other typically urban land uses such as residential and commercial developed areas outside the boundaries of incorporated urban areas are also included in this assessment.

Many of these natural plant communities in Minnesota have undergone change over the last two hundred years; in some cases these changes have led to the complete loss of a community type, i.e., conversion of native prairie to agricultural production, and in other cases the conversion of one community to another, i.e., regrowth of white pineries to mixed forests following extensive logging in the late 1800s and early 1900s. Many areas of native plant coverage have been lost to the growth of urban areas; in many instances the invasion of exotic species has altered the hydrologic cycles of these urban natural areas.

Within some of the major basins of Minnesota, forests and grasslands still cover up to 60% of the watershed area. The hydrologic cycling of annual precipitation in natural vegetation moves most of the water to infiltration and thus promotes stable stream base flows and reduces surface runoff. Native plant communities have relatively high rates of evapotranspiration (ET) and the loss of vegetation can lead to higher annual water yields due to decreased ET (Brooks et al, 2003).

In natural plant communities, much of the phosphorus pool is retained within the plant community and the soil profile, with plant biomass creation, senescence and subsequent decomposition processes cycling nutrients back into the soil profile. As a result most of the phosphorus pool is relatively immobile (Tester, 1995). The high soil infiltration rates in these plant communities lead to low surface runoff rates and little soil loss via erosion, and thus low rates of nutrient export to surface waters. In most cases the surface runoff rates are less than 10% of the annual precipitation for these plant communities and phosphorus export rates are below 0.169 kilograms of phosphorus per hectare per year (0.151 pounds per acre per year).

Results of Literature Search and Review of Available Monitoring Data

The scientific literature was reviewed to determine the hydrologic regimes, nutrient cycling mechanisms and phosphorus loading factors for each of the land use categories included in the Non-Agricultural Rural Runoff category. The hydrologic and nutrient export relationships examined for the rural land use categories are discussed in the Forest (Deciduous Forest, Evergreen (Coniferous) Forest, and Mixed Forest), Shrubland and Grasslands/Herbaceous vegetation below. The hydrologic and nutrient export relationships for rural residential areas within the land use categories are discussed in the Low Intensity Residential and High intensity residential land use sections of the urban runoff technical memorandum (Barr Engineering, 2003). The phosphorus loadings for Commercial/Industrial/Transportation land are also discussed in the urban runoff technical memorandum. That discussion will not be repeated here, other than a recap of loading calculations included in the methodology section.

Forests

Singer and Rust (1975) is the most frequently cited research for runoff from deciduous forests. Based upon runoff and nutrient studies on maple-basswood forest at the Minnesota Landscape Arboretum they found that the litter layer was responsible for high infiltration rates and thus little water loss to surface runoff occurred. Spring runoff over frozen soils accounted for most of the surface water runoff, and phosphorus loads in surface runoff occurred during the snowmelt period and immediately following leaf drop in the fall. They calculated the rate of phosphorus loss to be 0.09 kg P per hectare per year. They also found that the phosphorus export rate exceeded the atmospheric inputs of phosphorus on an annual basis. The authors cautioned that extrapolation of these loading rates to large forests areas may misrepresent actual loadings. Vaithiyanathan and Correll (1992) found that 77% of the phosphorus exported from forested watersheds was particulate phosphorus and primarily organic forms (61%). The authors suggest that this indicates that sediment movement was responsible for a large portion of the phosphorus exported by forests. St. Onge, *et al* (in press) reported increased total phosphorus concentrations in runoff from forested catchments that had been harvested or burnt, but also found that larger basins exported less phosphorus than smaller basins on a unit area basis.

Leete (1986) examined the runoff of phosphorus from mixed hardwood forests in the Superior Highlands of northeastern Minnesota. Leete found that phosphorus export from two plots before and after harvest to be 0.107 kg P/ha/yr and 0.207 kg P/ha/yr before harvest, and 0.159 kg P/ha/yr and .244 kg P/ha/yr post-harvest. Increased erosion was cited as the cause for the post-harvest phosphorus load increase. Leete also reviewed literature values at the time of her work and found phosphorus loadings rates for forests in Minnesota to range from 0.090 kg P/ha/yr (Sanger and Rust, 1975) to 0.71 kg P/ha/yr (Knighton and Steigler, 1980).

Sartz (1971) completed an assessment of runoff from dual-use watersheds (i.e., watersheds with agricultural and forested land covers) in the driftless area of southwestern Wisconsin near La Crosse. In a very elegantly designed study Sartz was able to document runoff from the upland pasture and hillside deciduous forest components of four watersheds to downhill lowland areas. The study results showed that as much as 33% of the upland flow was retained in the hillside forests and the deciduous forest hillsides generated no runoff. Sartz (1969) also reported that peak flows from undisturbed deciduous forests were 0.010 inches per hour compared to 2.42 inches per hour for alfalfa for the same 3-hour 4-inch rainfall event. Sartz, et al (1977) reported that driftless area catchments smaller than 250 hectares had no perennial streams, and cropland was the major source of surface runoff. These findings have been further confirmed by recent runoff studies in the Whitewater River watersheds (Wotzka, 2003). Peterjohn and Correll (1984) found that phosphorus export (loss) from riparian forest systems was divided between surface runoff (59%) and groundwater flow (41%). The external phosphorus inputs to riparian forests were calculated to be 3.8% from bulk precipitation, 94% via surface runoff from and 2.5% via groundwater; the riparian forest had a calculated phosphorus retention of 80%.

Hewlett and Hilvey (1970) measured no storm event surface water flow volumes from a 108-acre intact mixed hardwood forest over 18 years of monitoring. Scott, et al, (2001) found that elevated phosphorus levels in runoff from early successional forests on abandoned agricultural lands were due to previous agricultural inputs of fertilizer. The authors concluded that this increase in soil phosphorus will be detectable in runoff for up to 40 years. Metcalfe and Buttle (1999) found that disturbances to boreal forests could lead to reduced runoff and lower stream flows due to increased evapotranspiration rates.

Binkley (2001) reviewed the literature related to harvesting and phosphorus concentrations in stream flow. He found little increase in phosphorus concentration – concentrations increased from 12 ug P/L to 13 ug P/L, following logging. Hewlett and Hilvey (1970) found that in mixed hardwood forests, following clear cutting, the storm flow volumes increased by 11% but this increase was confined to subsurface flow, so the site still provided very little overland flow. Devito, *et al*, (2000) report that in boreal forested lakes, the largest increases in post-harvest total phosphorus concentrations were found in areas with groundwater recharge or shallow local discharge to lakes and wetlands.

Interception of rainfall occurs at multiple levels within the forest – tree canopy, tree and shrub layer stems, shrub canopy, herbaceous layer and ground litter – to reduce overland flows (Brooks, et al, 2003; Verry 1976). Other authors have reported little or no overland flow from intact deciduous or coniferous forests due to interception (Binkley, 2001; Knighton and Steigler, 1980; Metcalfe and Butle, 1999; Verry, 1969). Martin, *et al,* (2000) reported that in northern hardwood forests, clear-cutting and strip-cutting lead to increased water yield due to decreased transpiration and interception. They also noted that the increased water yield disappeared within 4-6 years due to regrowth of natural vegetation. Boelter and Verry (1977) reported the phosphorus export rate from peatland forests to be 0.08 kg P/ha/yr.

Shrublands and Grasslands

While there exists a fair amount of literature on forest hydrology and nutrients, comparable literature for shrublands and grasslands is much less extensive. Many authors suggest that runoff rates and nutrient exports form these communities are low, however the supporting evidence is limited. In the case of both plant communities, the limited number of studies related to phosphorus export rates required that export rates be developed for both plant communities based upon the limited data set.

Brye, et al (2000) and Brye, et al (2002) evaluated the water and phosphorus budgets of a restored prairie near Madison WI. The authors reported that rainfall interception by plant residue was a significant component of the annual water budget (nearly 70%). Higher soil storage and ET rates led to lower soil drainage and runoff volumes. Runoff volumes were 11% to 18% of the water budget, with a mean of 14.5% for the test plots. Snowmelt was responsible for nearly all of the runoff volumes.

Shjeflo (1968) reported on water budgets for prairie pothole wetlands in eastern North Dakota, including surface runoff from adjoining upland prairies. He reported that over the 1960 to 1964 time period, snowmelt contributed 1.0" of annual runoff and rainfall contributed 0.2" of runoff (ave. annual ppt. = 15.84") for a runoff rate of 7.5%.

Winter and Carr (1980), Winter, et al, (2001) and Winter and Rosenberry (1995 and 1998) examined the water budgets for wetlands in eastern North Dakota over a 17 year period. Their results indicate surface runoff rates of 10% or less were common and most of the overland flow occurred as snowmelt or during prolonged wet seasons. In all cases, the majority of overland flow occurs in the prairie vegetation during snowmelt, which also coincides with the greatest availability of soluble phosphorus from dead and dormant above ground plant tissues.

Timmons and Holt (1977) reported that phosphorus losses from grasslands to be in a range of 0.100 kg P/ha/yr to 0.250 kg P/ha/yr, with a phosphorus concentration in runoff of 0.200 mg P/L. Using the water budget data from Brye, et al (2000) and Brye, et al (2002) and phosphorus concentration data from Timmons and Holt (1977), an export loading rate of 0.169 kg P/ha/yr for ecoregion VIII was calculated. Using the water budget information from Winter and Carr (1980), Winter, et al, (2001), Winter, Rosenberry (1995 and 1998) and Shjeflo (1968) and concentration data from USACE (2001), a phosphorus export of 0.060 kg P/ha/yr was calculated for ecoregion VI. Data from Olness, et al (1988) and Menzel, et al (1978) provided an export rate 0.175 kg P/ha/yr for grassland pasture.

A search of the literature provided no reported shrubland phosphorus export rates (Holechek, et al, 1977; Dodds, et al, 1996: Burke, et al, 1990). Most shrublands are composed of a herbaceous layer of grasses and forbs with a sparse over story of trees and/or low shrubs. MN DNR (1993) and Leach and Givnish (1999) suggest that many of the hydrologic and ecologic attributes of forest and prairie communities are present in shrublands. Low runoff rates, high annual evapotranspiration and limited nutrient losses of the two shrubland community components of the provide a basis to conclude that shrublands are intermediate with regard to phosphorus export. Based upon these assumptions, the nutrient export rate for shrubland was determined from the average of the grassland and deciduous forest communities. The calculated value used for this assessment is 0.129 kg P/ha/yr.

Watershed Basin Characteristics

This investigation of phosphorus loadings from non-agricultural rural land uses draws upon ecoregion-based loading and export rates for phosphorus in Minnesota. The basis for this assessment of nutrient export from native vegetation and other rural land uses within Minnesota requires an understanding of the underlying ecologic and hydrologic conditions of each of these plant communities. The use of ecoregions allows the similarities in underlying ecological conditions to be aggregated across basin boundaries and state boundaries to develop accurate estimates of loadings. This discussion will overview the concept of ecoregions, and integrate the land use categories and Minnesota's native vegetation to help define the underlying loading mechanisms and basin characteristics Within the major basins of Minnesota, forests and grasslands still cover between 10% and 60% of the watershed area (see table 1),

Ecoregions are defined as regions of relative homogeneity in ecological systems, such that geographic characteristics such as soils, vegetation, climate, geology, and land cover are relatively similar within the bounds of each ecoregion (Omernik, 2000). Omernik (1987) recognized that areas of the U.S. have naturally different soil and parent material nutrient content, and different precipitation regimes. Based upon these distinct patterns the application of sorting criteria allowed for the development of a scheme of ecological regions that reflect this regional variation. The ecoregional approach was initially completed for the continental United States and has been used for regional water quality assessment and plant community management strategies in the US, Canada and by a number of international conservation organizations (Omernik, 1995). The continental U.S. was divided into 14 separate Level III aquatic ecoregions for the purpose of aquatic resource investigation and management (Omernik, 1977a: Omernik, 1977).

The US EPA has developed generalized "nutrient Ecoregions" that are aggregations of the Level III Ecoregions (EPA 2000d, EPA 2000e). Within Minnesota there are seven Level III ecoregions and the use of the EPA Level III Aggregate Ecoregions reduces the number to three (see Figure 1 and 2). As the number of phosphorus export studies completed in Minnesota is relatively small, the use of export rates from the larger Level III aggregate regions provides a wider data set that can be extrapolated across the basins (MPCA, 2003).

The US EPA acknowledges that the Aggregate Level III ecoregions have a higher degree of variability because of the lumping, but the Level III ecoregions are useful for setting nutrient criteria. Recent EPA guidance for development of ambient water quality criteria for lakes, stream and reservoirs has proposed the use of the Level III ecoregional framework by states and tribes. See Figure 2, 3, 4 and 5 for the boundaries of the Aggregate Level III and Level III Ecoregions.

Basin	Area (Sq Miles)	Average Precipitation (1979-2002)	Average Runoff (1979-2002)	Land Cover Percentages*					
				Urban	Forested	Tilled Agricultural	Pasture/ Grassland	Wetland/Open Water	Other
Cedar River	1,028	32.06	9.80	3.4%	3.3%	83.4%	6.2%	3.7%	0.0%
Des Moines River	1,535	27.98	5.68	1.8%	1.8%	79.9%	11.0%	5.5%	0.0%
Lake Superior	6,149	29.11	12.44	1.4%	57.1%	2.6%	3.5%	33.3%	2.1%
Lower Mississippi	6,317	33.29	10.28	2.4%	15.4%	52.2%	24.8%	5.1%	0.1%
Minnesota River	14,943	28.14	5.61	2.2%	4.6%	72.7%	12.6%	7.8%	0.1%
Missouri	1,782	27.16	5.25	1.5%	1.0%	78.9%	16.0%	2.6%	0.0%
Rainy River	11,236	26.20	8.01	0.4%	41.4%	2.0%	2.3%	52.5%	1.3%
Red River	17,741	23.29	3.42	0.7%	12.0%	54.6%	8.8%	23.8%	0.2%
St. Croix River	3,528	30.61	9.71	1.3%	36.8%	10.8%	20.6%	30.1%	0.2%
Upper Mississippi	14,943	28.07	6.87	3.5%	29.1%	20.2%	16.7%	29.7%	0.7%
State Wide	**79,202**	**27.39**	**6.83**	**1.9%**	**22.7%**	**38.1%**	**12.0%**	**24.7%**	**0.6%**

*Based on USGS National Land Cover Database (1992)

Table 1. Basin land use characteristics.

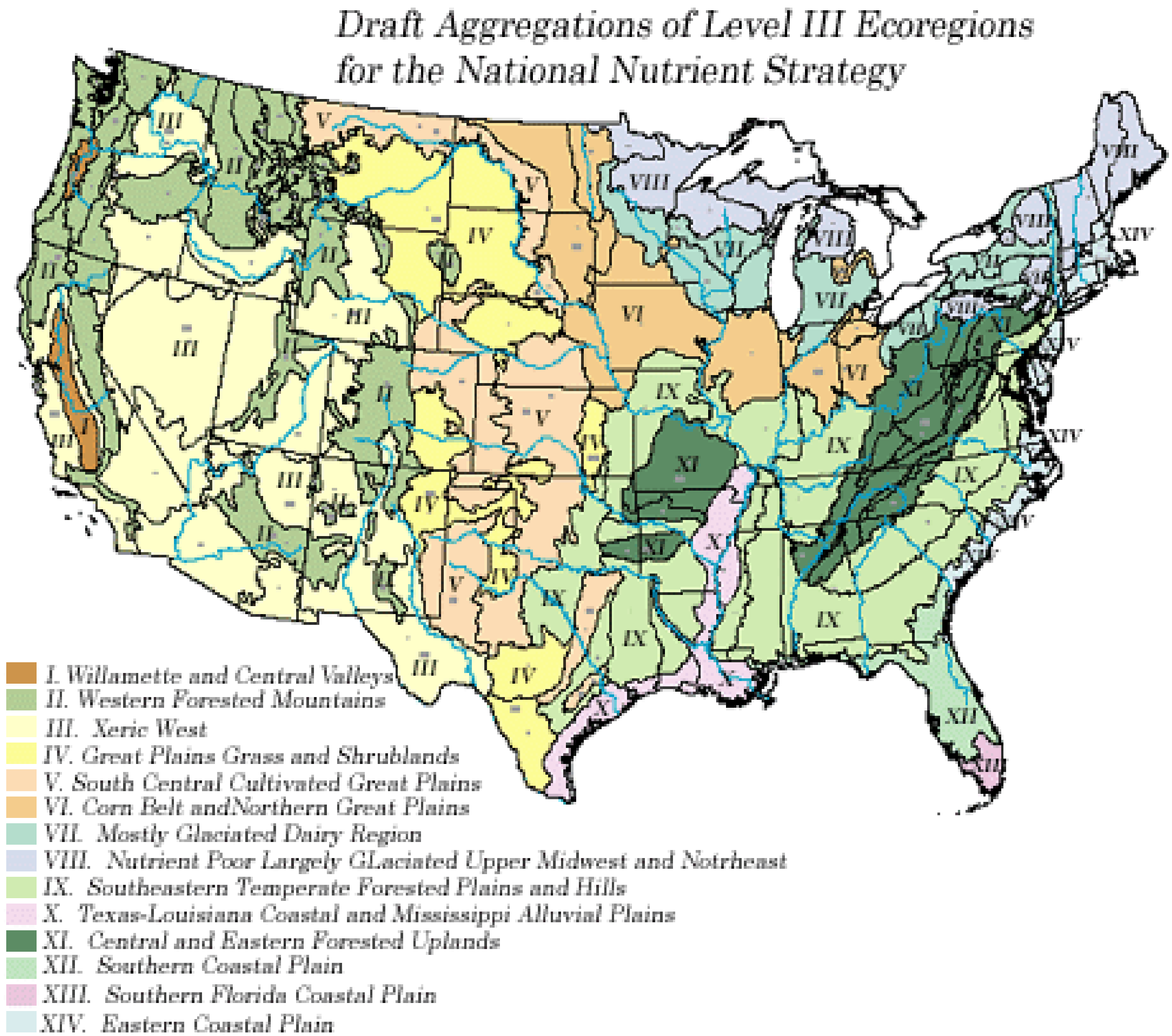

Figure 2 .Level III national aggregate nutrient ecoregions as delineated by Omernik (2000).

The Minnesota Pollution Control Agency has been at the forefront of the use of ecoregions for water quality assessment and management work (Heiskary, et al., 1987; Wilson and Walker 1989; McCollor, 1993). The MPCA has developed ecoregion-based assessments of lake and stream quality, evaluating water quality differences due to distinct ecoregion characteristics. The stream assessment information in Table 2 provides a summary of the differences in total phosphorus concentrations in Minnesota streams (MPCA, 2003). The ecoregion differences in stream phosphorus concentrations presented in Table 2 further validates the use of ecoregion-based loading rates for this assessment.

	Red River Valley	Northern Minnesota Wetlands	Northern Lakes and Forests	North Central Hardwood Forests	Northern Glaciated Plains	Western Corn Belt Plains	Driftless Area
pH	8.0 – 8.4	7.6 – 7.9	7.4 – 7.9	7.9 – 8.3	8.0 – 8.3	8.0 – 8.2	7.9 – 8.3
TSS (in mg/L)	11 – 59	4.8 – 16	1.8 – 6	4.8 – 16	11 – 63	10 – 61	4.8 – 16
NO_x (in mg/L)	0.01 – 0.21	0.01 – 0.08	0.01 – 0.09	0.04 – 0.26	0.01 – 0.51	1.4 – 7.4	0.04 – 0.26
TP (in mg/L)	0.11 – 0.3	0.04 – 0.09	0.02 – 0.05	0.06 – 0.15	0.09 – 0.25	0.16 – 0.33	0.06 – 0.15
Turb (in NTU)	6 – 23	4.1 – 10	1.7 – 4.3	3 – 8.5	5.6 – 23.5	5.2 – 22	3 – 8.5
FC (# organisms per 100 ml)	20 – 220	20 – 40	11 – 20	40 – 360	20 – 410	70 – 790	40 – 360
Temp (degrees C)	0 – 21	0 – 20	0.5 – 17	2 – 21	2.5 – 22	3.5 – 20	2 – 21
BOD_5 (in mg/L)	1.8 – 4.1	1.1 – 2.1	0.8 – 1.7	1.5 – 3.2	2.3 – 4.5	2.0 – 5.5	1.5 – 3.2

Table 2. Typical annual stream water quality conditions in Minnesota's ecoregions (from: MPCA, 2003).

A further description of the three Level III Aggregate Ecoregions is warranted so as to allow for a more complete understanding of the ecological conditions of each ecoregion and to provide a basis for the a discussion of the native vegetation that are found within the Minnesota boundaries of these regions (Omernik, 2000). The three Aggregate Level III ecoregions included in this assessment are (see Figure 2):

- VI - Corn Belt and Northern Great Plains
- VII - Mostly Glaciated Dairy Region
- VIII - Nutrient Poor Largely Glaciated Upper Midwest and Northeast

The Corn Belt and Northern Great Plains – Aggregate Ecoregion VI – is comprised of rolling plains and flat lake beds, dominated by extensive, highly productive cropland (EPA, 2000a). Nutrient-rich soils significantly influence surface and subsurface water quality and high concentrations of nitrate and phosphorus cause water quality problems in many basins. Many of ecoregion VI's water quality problems are the result of nutrient-rich agricultural runoff and wastewater treatment plant effluent. High concentrations of suspended sediment are found in many streams especially those in flat, agricultural areas with clayey soils and artificial drainage. Many urban, suburban, and industrial areas are also found in Region VI. Figure 3 presents the boundaries of Ecoregion VI and the Level III ecoregions included in this aggregate ecoregion. The Minnesota Level III ecoregions within the Aggregate Ecoregion VI (or 6 as in Figure 3) are described by EPA as:

> 46. Northern Glaciated Plains
> The Northern Glaciated Plains ecoregion is characterized by a flat to gently rolling landscape composed of glacial till. The subhumid conditions foster transitional grassland containing tallgrass and shortgrass prairie. High concentrations of temporary and seasonal wetlands create favorable conditions for waterfowl nesting and migration. Though the till soils are very fertile, agricultural success is subject to annual climatic fluctuations (EPA, 2000a).
>
> 47. Western Corn Belt Plains
> Once covered with tallgrass prairie, over 75 percent of the Western Corn Belt Plains is now used for cropland agriculture and much of the remainder is in forage for livestock. A combination of nearly level to gently rolling glaciated till plains and hilly loess plains, most of the annual precipitation occurs in the growing season, and fertile, warm, moist soils make this on of the most productive areas of corn and soybeans in the world. The region is also one of major environmental concerns regarding surface and groundwater contamination from fertilizer and pesticide applications as well as livestock concentrations (EPA, 2000a).
>
> 48. Lake Agassiz Plain (MPCA – Red River Valley)
> Glacial Lake Agassiz was the last in a series of proglacial lakes to fill the Red River Valley in the three million years since the beginning of the Pleistocene. Thick beds of lake sediments on top of glacial till create the extremely flat floor of the Lake Agassiz Plain. The historic tallgrass prairie has been replaced by intensive row crop agriculture. The preferred crops in the northern half of the region are potatoes, beans, sugar beets and wheat; soybeans, sugar beets, and corn predominate in the south (EPA, 2000a).

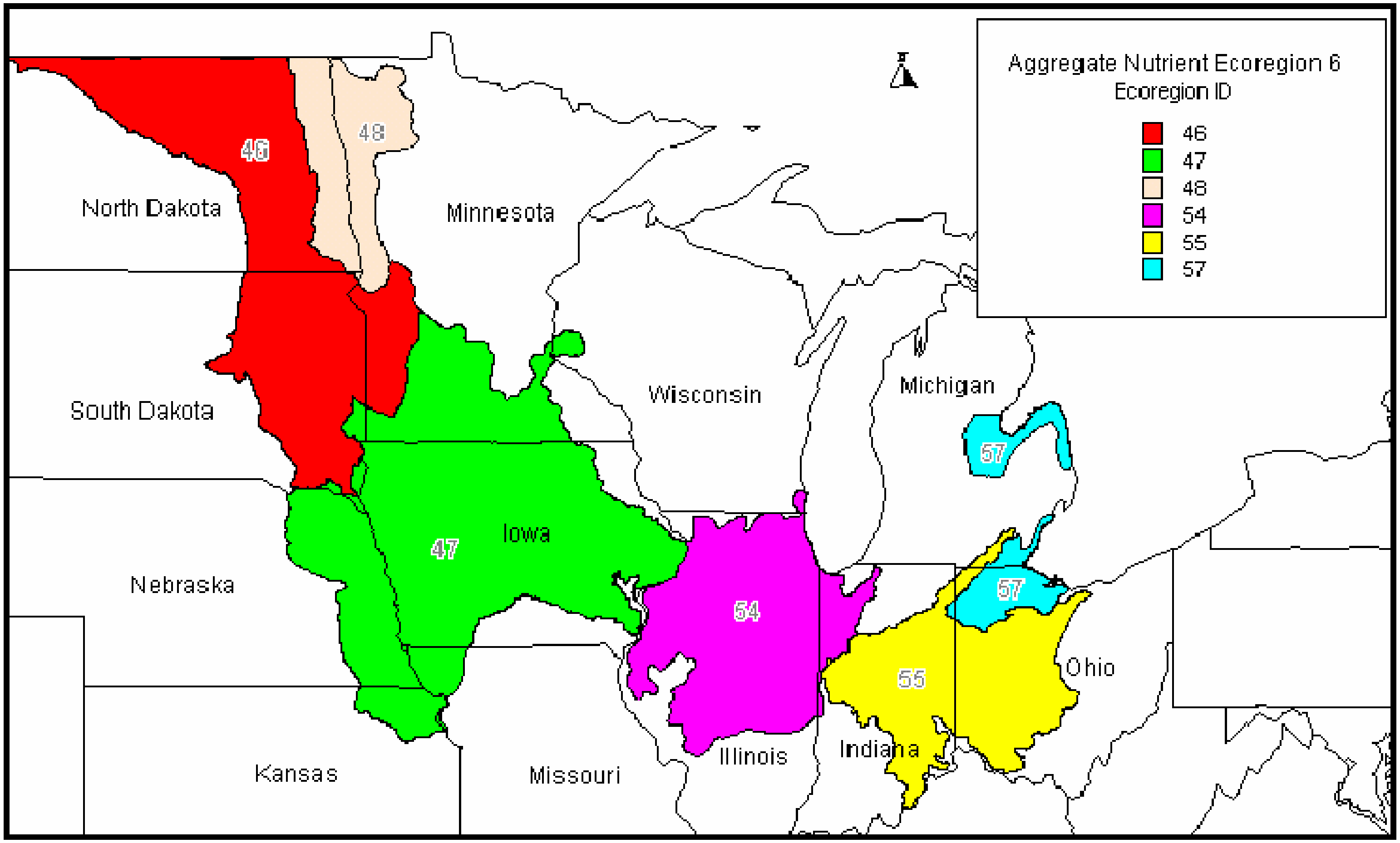

Figure 3. Level III ecoregions for Aggregate Ecoregion VI - Corn Belt and Northern Great Plains for Minnesota basins (from: US EPA 2000a;).

The Mostly Glaciated Dairy Region – Aggregate Ecoregion VII (or 7 as in Figure 4) – is dominated by forests, dairy operations, and livestock farming (EPA, 2000b). This ecoregion was mostly glaciated and includes flat lake plains, rolling till plains, hummocky stagnation moraines, hills, and low mountains. Figure 4 shows the boundaries and Level III ecoregions of Aggregate Ecoregion VII. Overall, it is not as flat nor as dominated by cropland as the Corn Belt and Northern Great Plains and has fewer lakes and less forests than Region VIII. Ecoregion VII has a mix of nutrient-rich and nutrient-poor soils that contrast with the mostly fertile soils of Region VI and the relatively thin, nutrient-poor soils of Region VIII. The Level III ecoregions within Minnesota Aggregate Ecoregion VII are described by EPA as:

51. Northern Central Hardwood Forests
The North Central Hardwood Forests is transitional between the predominantly forested Northern Lakes and Forests to the north and the agricultural ecoregions to the south. Land use/land cover in this ecoregion consists of a mosaic of forests, wetlands and lakes, cropland agriculture, pasture, and dairy operations (EPA, 2000b).

52. Driftless Area
The hilly uplands of the Driftless Area easily distinguish it from the surrounding ecoregions. Much of the area consists of a loess-capped plateau, deeply dissected by streams. Also called the Paleozoic Plateau, because there is evidence of glacial drift in this region, the glacial deposits have done little to affect the landscape compared to the subduing influences in adjacent ecoregions. Livestock and dairy farming are major land uses and have had a major impact on stream quality (EPA, 2000b).

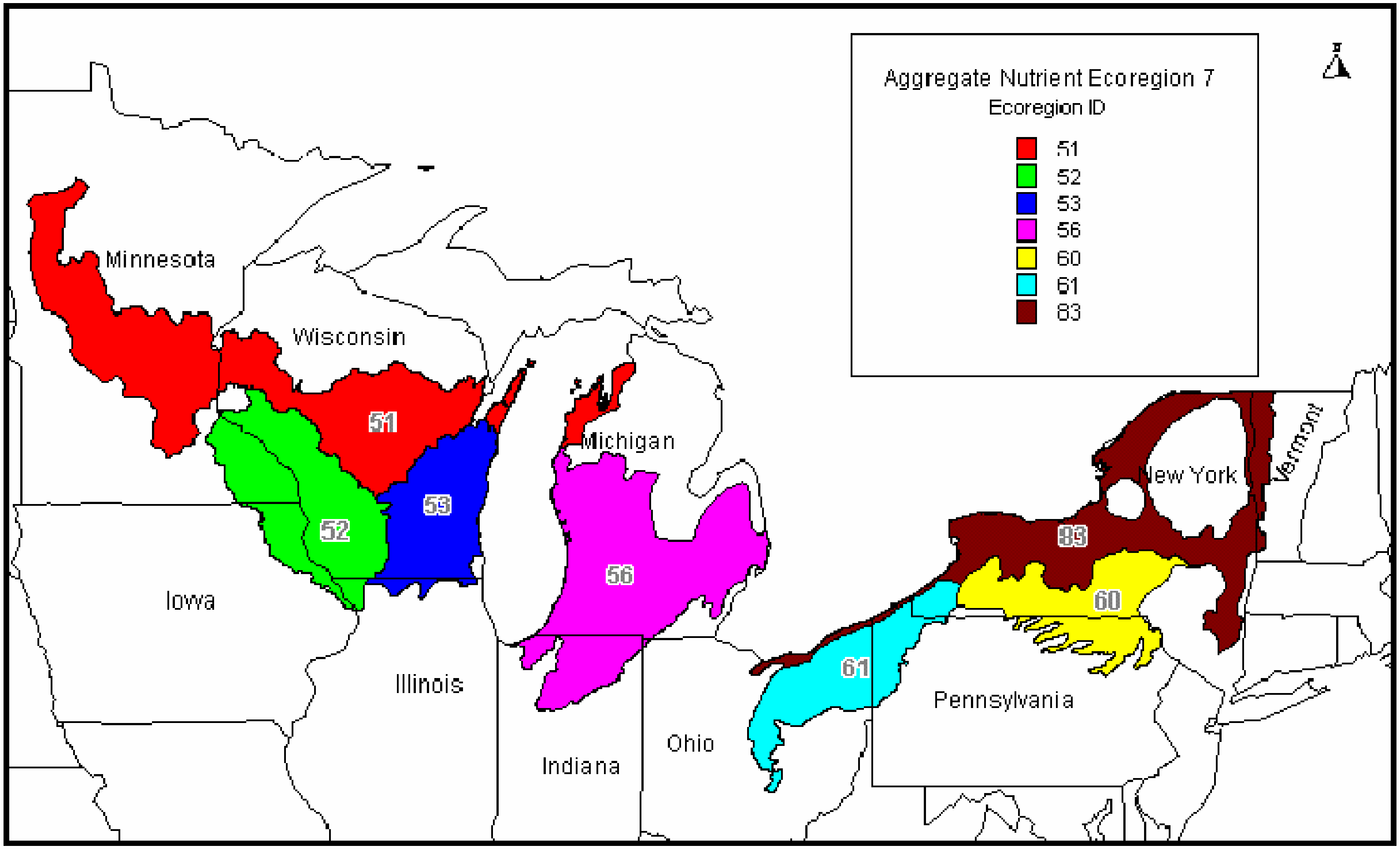

Figure 4. Level III ecoregions for Aggregate Ecoregion VII - Mostly Glaciated Dairy Region for Minnesota basins (from: US EPA 2000b).

The Nutrient Poor Largely Glaciated Upper Midwest and Northeast – Aggregate Ecoregion VIII (or 8 as in Figure 5) – is characterized by extensive forests, nutrient-poor soils, a short growing season, limited cropland, and many marshes, swamps, lakes, and streams (see Figure 5). Ecoregion VIII has less cropland and fewer people than in neighboring nutrient regions. Water quality issues center around the effects of acid precipitation, logging, lake recreation, and near lake septic systems (EPA, 2000c). Levels of total phosphorus and suspended sediment are also usually low and stream concentrations are typically much less than the more developed nutrient regions. The Minnesota Level III ecoregions within Aggregate Ecoregion VII are described by EPA as:

49. Northern Minnesota Wetlands
Much of the Northern Minnesota Wetlands is a vast and nearly level marsh that is sparsely inhabited by humans and covered by swamp and boreal forest vegetation formerly occupied by broad glacial lakes, most of the flat terrain in this ecoregion is still covered by standing water (EPA, 2000c).

50. Northern Lakes and Forests
The Northern Lakes and Forests is a region of nutrient poor glacial soils, coniferous and northern hardwood forests, undulating till plains, moraine hills, broad lacustrine basins, and extensive sandy outwash plains. Soils in this ecoregion are thicker than in those to the north and generally lack the arability of soils in adjacent ecoregions to the south. The numerous lakes that dot the landscape are clearer and less productive than those in ecoregions to the south (EPA, 2000c).

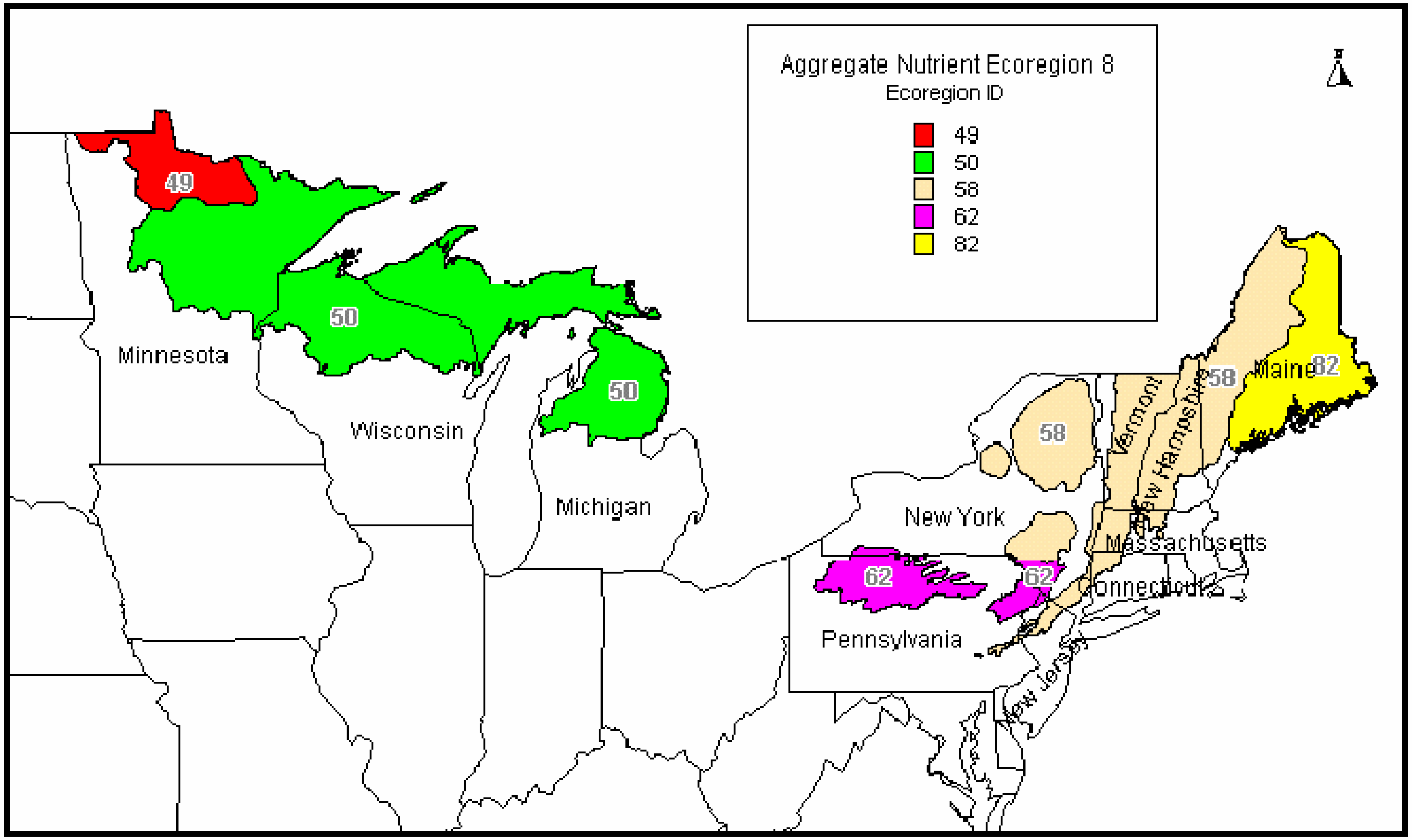

Figure 5. Level III ecoregions for Aggregate Ecoregion VIII - Nutrient Poor Largely Glaciated Upper Midwest and Northeast for Minnesota basins (from: US EPA 2000c).

For the purposes of defining and quantifying the phosphorus loads to Minnesota basins, the non-agricultural rural land uses within these three Aggregate Ecoregions were classified and enumerated using the USGS National Land Cover Data (NLCD). The National Land Cover Data Set for the Conterminous United States is derived from the Landsat thematic mapper data system (Vogelmann, 2001). While most of the non-agricultural rural land cover is composed of native vegetation, rural residential areas, transportation infrastructure, and other typically urban land uses such as residential and commercial developed areas outside the boundaries of incorporated urban areas are also included in this assessment. The NLDC cover classes included in the non-agricultural rural land uses assessed are:

- Unincorporated Urban Areas
    - Low intensity residential (outside incorporated urban areas)
    - High intensity residential (outside incorporated urban areas)
    - Commercial/Industrial/Transportation (outside incorporated urban areas)
- Deciduous Forest
- Evergreen Forest
- Mixed Forest
- Shrubland
- Grasslands/Herbaceous
- Urban / Recreational Grasses
- Other
    - Quarries/Strip Mines/Gravel Pits
    - Transitional

Figures 6a and 6b presents an overview of the land cover distribution of the non-agricultural rural land uses across the Minnesota basins.

The NLCD system of land cover classification defines each of these land use categories as follows:

Developed areas characterized by a high percentage (30 percent or greater) of constructed materials (e.g. asphalt, concrete, buildings, etc).

21. Low Intensity Residential - Includes areas with a mixture of constructed materials and vegetation. Constructed materials account for 30-80 percent of the cover. Vegetation may account for 20 to 70 percent of the cover. These areas most commonly include single-family housing units. Population densities will be lower than in high intensity residential areas.
22. High intensity residential outside incorporated urban areas - Includes highly developed areas where people reside in high numbers. Examples include apartment complexes and row houses. Vegetation accounts for less than 20 percent of the cover. Constructed materials account for 80 to 100 percent of the cover. Population densities will be higher than in low intensity residential areas.

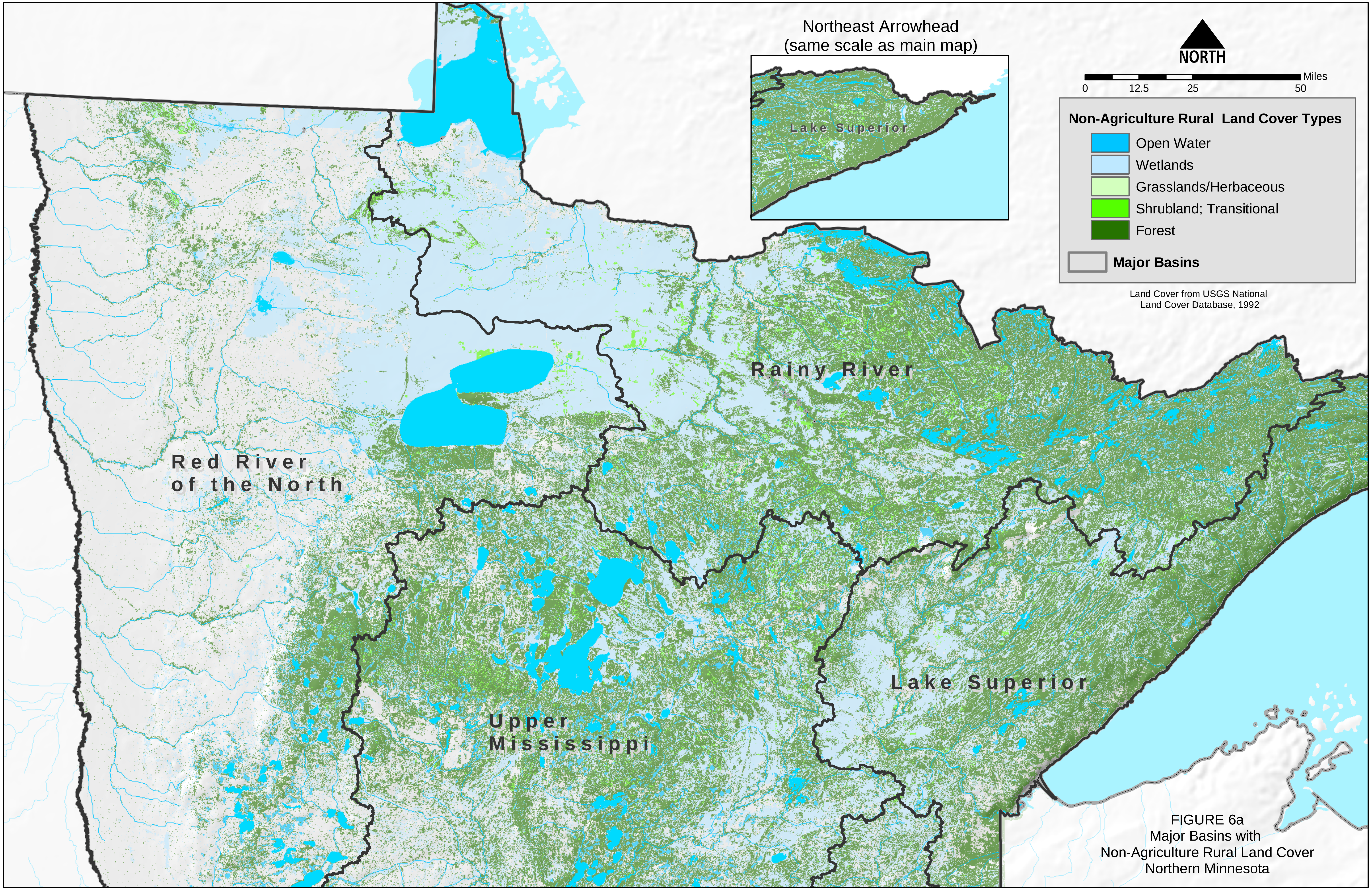

FIGURE 6a
Major Basins with
Non-Agriculture Rural Land Cover
Northern Minnesota

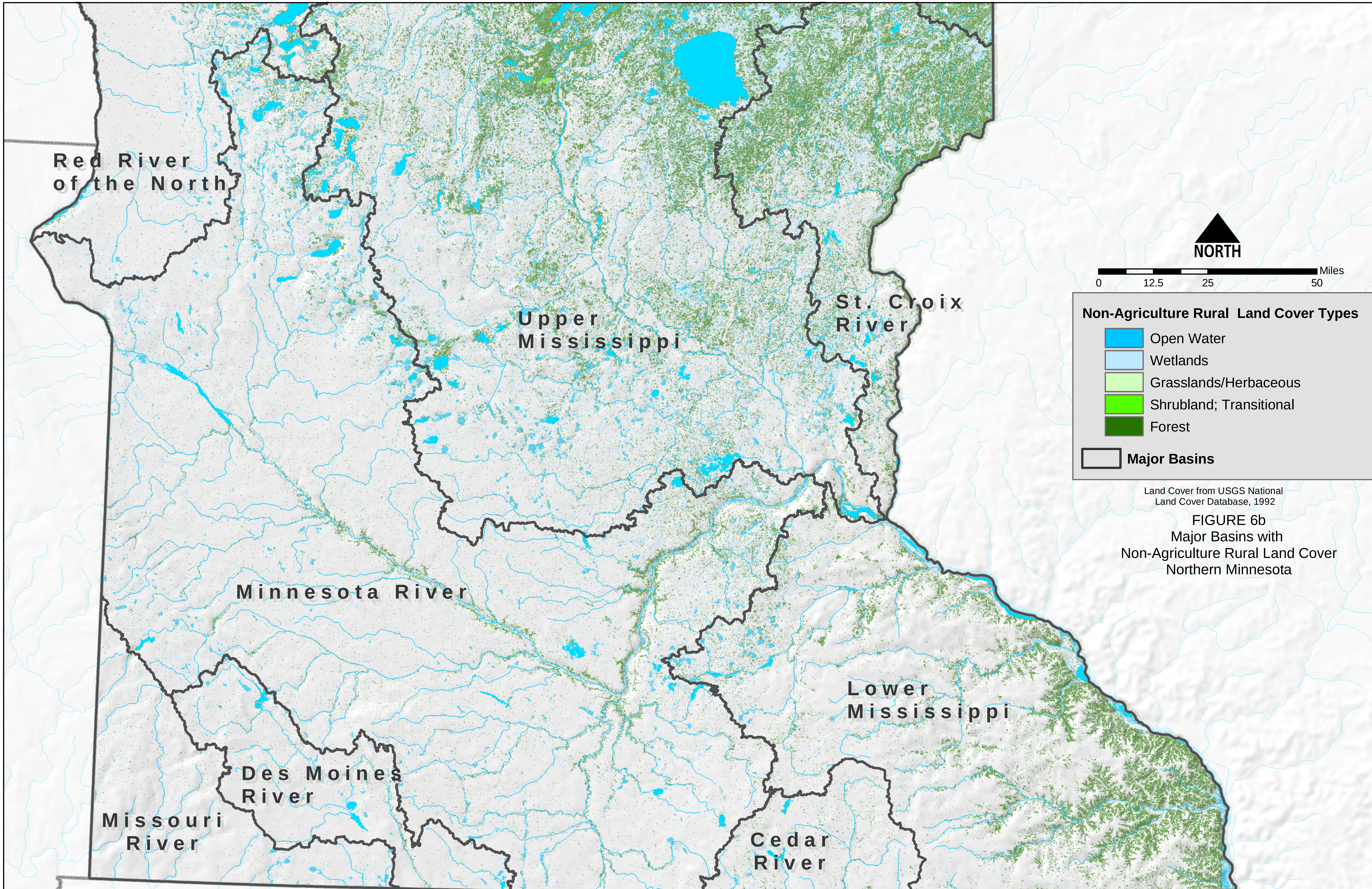

FIGURE 6b
Major Basins with
Non-Agriculture Rural Land Cover
Northern Minnesota

23. Commercial/Industrial/Transportation - Includes infrastructure (e.g. roads, railroads, etc.) and all highly developed areas not classified as High Intensity Residential.

Barren - Areas characterized by bare rock, gravel, sand, silt, clay, or other earthen material, with little or no "green" vegetation present regardless of its inherent ability to support life. Vegetation, if present, is more widely spaced and scrubby than that in the "green" vegetated categories; lichen cover may be extensive.

32. Quarries/Strip Mines/Gravel Pits - Areas of extractive mining activities with significant surface expression.
33. Transitional - Areas of sparse vegetative cover (less than 25 percent of cover) that are dynamically changing from one land cover to another, often because of land use activities. Examples include forest clear cuts, a transition phase between forest and agricultural land, the temporary clearing of vegetation, and changes due to natural causes (e.g. fire, flood, etc.). For transitional areas that are forest clear cuts, the runoff volumes and flow regime will be higher, up to twice as high, as for forest land cover for a period of 6 to 15 years (Devito, et al, 2000; Martin et al, 2000).

Undeveloped areas with forested upland - Areas characterized by tree cover (natural or semi-natural woody vegetation, generally greater than 6 meters (20 feet) tall; tree canopy accounts for 25-100 percent of the cover.

41. Deciduous Forest - Areas dominated by trees where 75 percent or more of the tree species shed foliage simultaneously in response to seasonal change.
42. Evergreen Forest - Areas dominated by trees where 75 percent or more of the tree species are coniferous, i.e., they maintain their leaves all year. Canopy is never without green foliage in most locations.
43. Mixed Forest - Areas dominated by trees where neither deciduous nor evergreen species represent more than 75 percent of the cover present. Clear-cut and burned areas are classed as "Transitional Bare" areas,

Shrubland - Areas characterized by natural or semi-natural woody vegetation with aerial stems, generally less than 6 meters (20 feet) tall, with individuals or clumps not touching to interlocking. Both evergreen and deciduous species of true shrubs, young trees, and trees or shrubs that are small or stunted because of environmental conditions are included.

51. Shrubland - Areas dominated by shrubs; shrub canopy accounts for 25-100 percent of the cover. Shrub cover is generally greater than 25 percent when tree cover is less than 25 percent. Shrub cover may be less than 25 percent in cases when the cover of other life forms (e.g. herbaceous or tree) is less than 25 percent and shrubs cover exceeds the cover of the other life forms.

Herbaceous upland areas characterized by natural or semi-natural herbaceous vegetation; herbaceous vegetation accounts for 75-100 percent of the cover.

71. Grasslands/Herbaceous - Areas dominated by upland grasses and forbs. In rare cases, herbaceous cover is less than 25 percent, but exceeds the combined cover of the woody species present. These areas are not subject to intensive management, but they are often utilized for grazing.
85. Urban / Recreational Grasses – Vegetation (primarily grasses) planted in developed settings for recreation, erosion control, or aesthetic purposes. Examples include parks, lawn areas that include large residential lawns, golf courses, airport grasses and industrial grass sites.

Ecologic and Hydrologic Functions

Intact ecologic and hydrologic functions in natural vegetation control the nutrient export of these natural vegetation systems. Understanding the hydrologic mechanisms involved in the nutrient export from these natural vegetation systems requires a brief description of the plants communities. Detailed plant community descriptions from Minnesota's Native Vegetation: A Key to Natural Communities (MN DNR, 1993) provides a starting point for the development of the runoff-loading relationships and factors that were considered in the selection of export coefficients and the loading calculations. This vegetation classification system is based upon the native plant communities found in Minnesota and is used to classify and define land cover based upon plant assemblages. Many of these native plant communities have been highly altered by human activities, such as logging, drainage and urban development, but still retain many of their original ecologic and hydrologic functions discussed in the literature review section of this report (Brooks, 2003; Tester, 1995).

Within Minnesota there are three natural plant community zones: the prairie zone, deciduous forest-woodland and the conifer-hardwood forest zone. These three zones generally align with the Aggregate Level III ecoregions; with the prairie zone corresponding to the Corn Belt and Northern Great Plains (VI) ecoregion, the deciduous forest-woodland zone aligning with the Mostly Glaciated Dairy Region (VII) ecoregion and the conifer-hardwood forest zone with the Nutrient Poor Largely Glaciated Upper Midwest and Northeast (VIII) ecoregion (see Figure 7).

Deciduous forests occur primarily in the deciduous forest-woodland zone (Mostly Glaciated Dairy Region VII); the deciduous forests are less common in the other two zones, but are present over some large areas due to changes in the fire disturbance regime. On dry sites, the most common tree species present in the canopy are oak, aspen, and birch. Sugar maple, basswood, elm, and ash are common on moist sites, with pines, especially white pine, sometimes forming a minor portion of the forest. In oak forests where the canopy may be more broken, there is usually a dense layer of tall shrubs, including hazelnuts, dogwoods, prickly ashes, and cherries. In the denser sugar maple forests, the shrub layer is sparse or absent. The dominant tree species occur in assemblages that are established primarily based upon environmental features that include soil texture, bedrock, firebreaks, and depth to the water table.

Many of the dry deciduous forests in the Corn Belt and Northern Great Plains (VI) ecoregion and Corn Belt and Northern Great Plains (VI) ecoregion have succeeded from deciduous brushland and savanna to forest communities over the past 100 to 125 years. This successional change has been attributed to forest fragmentation and fire suppression (MN DNR, 1993). In the Nutrient Poor Largely Glaciated Upper Midwest and Northeast (VIII) ecoregion, deciduous forests can be found on sites with poor drainage, in areas of locally high precipitation, or areas of high humidity, such as along the shore of Lake Superior. The dry deciduous forests of this zone are dominated by aspen, aspen-birch, and paper birch forests, occur on fire-prone sites and are considered early successional communities.

Coniferous forests are upland forest communities that occur primarily in Nutrient Poor Largely Glaciated Upper Midwest and Northeast (VIII) ecoregion, with small stands also found in southeastern Minnesota and in some parts of the Mostly Glaciated Dairy Region (VII) ecoregion. Generally, red pine forest and jack pine forest occur in dry fire-prone areas, while northern conifers such as white spruce, balsam fir, white cedar, and black spruce occur on wetter, fire-protected sites. In fire-protected areas, northern hardwoods, such as sugar maple, basswood and yellow birch, are commonly associated with these coniferous forests. The canopy trees sometimes occur in mixtures, but regularly form relatively pure stands that require fire for stand regeneration.

The mixed forests are upland forest communities composed of significant numbers of both coniferous and deciduous trees. The mixed forests are most common in the Nutrient Poor Largely Glaciated Upper Midwest and Northeast (VIII) ecoregion but can also occur in the Mostly Glaciated Dairy Region (VII) ecoregion. The logging and burning of coniferous forests that followed European settlement caused the loss of pine seed sources over large areas and has led to the conversion of large areas of coniferous forests to mixed forest and deciduous forests (MN DNR, 1993).

Shrublands are classified as upland brush-prairies in the MN DNR classification system and were originally found in all three ecoregions. Shrublands are open communities composed of various amounts of low brush with a ground layer of prairie species. Shrublands frequently have large numbers of small aspens and lesser number of balsam poplars, while on drier sites, bur oak grubs and stunted trees are often present. Frequent fire is important in maintaining shrublands, although in the past, bison and elk grazing may have maintained shrubland communities. Where they have not been converted to agricultural cropland, most remnants of shrubland have succeeded to woodland as the suppression of wild fires became widespread.

Grasslands (upland prairies) occur primarily in the Corn Belt and Northern Great Plains (VI) ecoregion, with scattered occurrences in the Mostly Glaciated Dairy Region (VII) ecoregion. The grasslands are dominated by grasses, with a forb component and a few widely scattered trees and shrubs. The variation in species composition in grasslands is due primarily to variation in soil moisture. The soil moisture regime is determined by slope, aspect, proximity to the water table, and soil texture. On a larger regional scale climatic variation due to the westward decline in precipitation and northward decline in temperature in Minnesota also become important. Prior to European settlement, the distribution of prairie across the landscape was controlled by local fire frequency and the growth rates of woody species. Fragmentation of grasslands since European settlement has reduced fire frequency throughout both Corn Belt and Northern Great Plains (VI) and Mostly Glaciated Dairy Region (VII) ecoregions. Most the current prairie remnants have more brush and trees than would have been present in the past (MN DNR, 1993).

Table 3 provides a summary overview of the coverage extent of natural vegetation across the Minnesota landscape and the basins.

Table 3. Land use categories, total coverage (acres) and percent of land area for all rural land use areas.

BASIN	Open Water	Low Intensity Residential	High Intensity Residential	Commercial/ Industrial/ Transportation	Bare Rock/Sand/ Clay	Quarries/ Strip Mines/Gravel Pits	Transitional	Deciduous Forest	Evergreen Forest	Mixed Forest	Shrubland	Grasslands/ Herbaceous	Pasture/Hay	Row Crops	Small Grains	Urban/ Recreational Grasses	Woody Wetlands	Emergent Herbaceous Wetlands	Total
Cedar River	6,970	641	81	10,081	4	177	0	20,270	0	117	0	0	39,097	541,569	0	254	3,454	11,903	634,619
Des Moines River	23,781	337	8	8,206	0	180	6	17,009	248	378	16	0	106,152	778,146	760	977	2,767	25,947	964,918
Lake Superior	145,398	1,352	437	15,940	666	14,491	35,069	1,158,968	389,361	527,649	12,924	8,128	115,041	87,915	2,294	1,475	1,035,939	51,318	3,604,363
Lower Mississippi	64,627	1,867	344	26,624	30	762	124	553,528	4,497	22,002	8	3,495	947,042	2,039,213	279	2,439	44,446	69,123	3,780,451
Minnesota River	239,691	4,503	302	39,053	15	4,482	352	378,576	7,211	16,684	5,182	0	1,166,038	6,810,010	64,615	13,948	70,538	386,064	9,207,264
Missouri	7,444	414	9	9,353	2	181	6	11,015	33	172	13	24	179,044	888,132	2,051	609	999	20,049	1,119,552
Rainy River	823,490	1,207	178	18,907	317	4,455	80,345	1,181,229	764,487	872,322	128,826	1,059	163,495	115,785	29,071	1,268	2,689,976	238,071	7,114,491
Red River	611,325	2,779	332	28,149	190	6,646	16,910	1,251,965	36,897	29,227	35,718	6	981,060	5,300,452	859,966	8,466	1,204,292	870,281	11,244,661
St. Croix River	54,059	1,439	248	5,469	0	927	4,027	734,076	24,889	32,788	2,989	1,310	401,415	193,902	4,833	3,299	401,033	193,373	2,060,076
Upper Mississippi	994,904	17,353	2,309	35,693	100	16,512	52,218	2,781,790	344,959	289,012	86,785	108	1,929,973	2,184,390	251,745	23,027	1,450,853	1,101,065	11,562,798
Statewide Total for Land Use Category for All Basins	2,971,689	31,894	4,250	197,475	1,325	48,814	189,057	8,088,427	1,572,583	1,790,350	272,461	14,131	6,028,357	18,939,513	1,215,613	55,762	6,904,296	2,967,194	51,293,192
Percent of All Non-Urban Land Uses (Land use category total / Statewide rural land uses)	5.79%	0.06%	0.01%	0.38%	0.00%	0.10%	0.37%	15.77%	3.07%	3.49%	0.53%	0.03%	11.75%	36.92%	2.37%	0.11%	13.46%	5.78%	100.00%

Basin land use breakdown

Tables 4 and 5 provide a breakdown of the land uses included in the non-agricultural rural loading phosphorus calculations. The acreage totals, percentage of total state land cover and percentage of total non-agricultural rural lands are presented for the basins and the contributory areas of each basin. The original scope of work envisioned four land use classes in the non-agricultural rural assessment. The current loading estimates uses eleven land use classifications based upon the 1997 NLDC coverage.

- Unincorporated Urban Areas
    - Low intensity residential (outside incorporated urban areas)
    - High intensity residential (outside incorporated urban areas)
    - Commercial/Industrial/Transportation (outside incorporated urban areas)
- Deciduous Forest
- Evergreen Forest
- Mixed Forest
- Shrubland
- Grasslands/Herbaceous
- Urban / Recreational Grasses
- Other
    - Quarries/Strip Mines/Gravel Pits
    - Transitional

Table 4. Land use categories, total land area coverage in acres and percent of land area for all rural land use areas included in Non-Agricultural Rural Runoff Sources for Minnesota Basins.

BASIN	Low Intensity Residential	High Intensity Residential	Commercial/ Industrial/ Transportation	Bare Rock/Sand/ Clay	Quarries/ Strip Mines/ Gravel Pits	Transitional	Deciduous Forest	Evergreen Forest	Mixed Forest	Shrubland	Grasslands/ Herbaceous	Urban / Recreational Grasses	Non-Agricultural Rural Basin Total
Non-Agricultural Rural - Acres													
Cedar River	641	81	10,081	4	177	0	20,270	0	117	0	0	254	31,625
Des Moines River	337	8	8,206	0	180	6	17,009	248	378	16	0	977	27,366
Lake Superior	1,352	437	15,940	666	14,491	35,069	1,158,968	389,361	527,649	12,924	8,128	1,475	2,166,459
Lower Mississippi River	1,867	344	26,624	30	762	124	553,528	4,497	22,002	8	3,495	2,439	615,721
Minnesota River	4,503	302	39,053	15	4,482	352	378,576	7,211	16,684	5,182	0	13,948	470,309
Missouri River	414	9	9,353	2	181	6	11,015	33	172	13	24	609	21,832
Rainy River	1,207	178	18,907	317	4,455	80,345	1,181,229	764,487	872,322	128,826	1,059	1,268	3,054,602
Red River	2,779	332	28,149	190	6,646	16,910	1,251,965	36,897	29,227	35,718	6	8,466	1,417,286
St. Croix River	1,439	248	5,469	0	927	4,027	734,076	24,889	32,788	2,989	1,310	3,299	811,462
Upper Mississippi River	17,353	2,309	35,693	100	16,512	52,218	2,781,790	344,959	289,012	86,785	108	23,027	3,649,867
Non-Agricultural Rural Land Use Category Total in Acres for All Basins (1)	31,894	4,250	197,475	1,325	48,814	189,057	8,088,427	1,572,583	1,790,350	272,461	14,131	55,762	12,266,529
Non-Agricultural Rural Land Use expressed as Percent of State Total for Each Land Use Area Total (2)	8.89%	3.00%	60.29%	66.24%	45.06%	97.63%	95.10%	97.14%	96.68%	98.21%	80.03%	32.46%	23.00%
Non-Agricultural Rural Land Use expressed as Percent of All Non-Urban Land Uses Statewide (3)	0.26%	0.03%	1.61%	0.01%	0.40%	1.54%	65.94%	12.82%	14.60%	2.22%	0.12%	0.45%	100.00%

Notes: (1) Sum of each Non-Agricultural Rural land use acres by land cover category across all basins in the state of Minnesota.
(2) Individual land use category area expressed as percent total statewide coverage for that land use category, i.e., a percentage of all low intensity residential land use, both urban and rural.
(3) Non-Agricultural Rural area total in (1) expressed as a precent of the state total area for all non-urban lands uses, including natural vegetation, agricultural, surface waters and rural developed areas.

Table 5. Land cover for 100 meter contributory areas for major basins for non-agricultural rural land uses in Minnesota.

BASIN	Low Intensity Residential	High Intensity Residential	Commercial/ Industrial/ Transportation	Bare Rock/Sand/ Clay	Quarries/ Strip Mines/ Gravel Pits	Transitional	Deciduous Forest	Evergreen Forest	Mixed Forest	Shrubland	Grasslands/ Herbaceous	Urban/ Recreational Grasses	100 Meter Contributory Area Total	Basin Total Acres - All Non-Agricultural Rural Lands	Contributory Area as Percentage of Total Basin Area
Non-Agricultural Rural Runoff Sources - 100 meter Contributory Areas (Acres)															
Cedar River	273	25	2,777	4	89	0	10,605	0	63	0	0	111	13,945	31,625	44.1%
Des Moines River	128	3	2,058	0	110	3	9,757	231	229	7	0	353	12,879	27,366	47.1%
Lake Superior	656	262	9,393	122	5,360	16,998	587,549	251,377	325,811	8,034	4,755	666	1,210,983	2,166,459	55.9%
Lower Mississippi River	673	128	7,901	18	352	34	232,739	1,974	9,462	8	834	983	255,106	615,721	41.4%
Minnesota River	1,852	161	11,494	0	1,711	128	230,420	5,959	11,011	3,616	0	5,508	271,860	470,309	57.8%
Missouri River	143	2	2,861	0	113	1	5,616	20	97	1	9	185	9,048	21,832	41.4%
Rainy River	865	123	14,542	258	2,827	44,531	723,562	510,958	558,598	78,079	708	765	1,935,817	3,054,602	63.4%
Red River of the North	1,307	133	13,784	183	3,116	10,356	829,664	22,268	21,916	24,479	6	3,574	930,785	1,417,286	65.7%
St. Croix River	821	178	4,121	0	632	2,770	555,376	17,842	26,575	2,025	864	2,389	613,593	811,462	75.6%
Upper Mississippi River	9,510	1,494	22,201	37	7,761	25,618	1,734,728	201,739	210,629	48,252	35	11,584	2,273,590	3,649,867	62.3%
Total Contributory Area Acres by Category for All Basins (4)	16,229	2,507	91,132	622	22,071	100,439	4,920,017	1,012,368	1,164,392	164,501	7,211	26,117	7,527,607	12,266,529	61.4%
Contributory Area Expressed as a Percent of Total Non-Agricultural Rural Land Use (4)	50.88%	59.00%	46.15%	46.96%	45.21%	53.13%	60.83%	64.38%	65.04%	60.38%	51.03%	46.84%	61.37%		

Notes: (4) Sum of contributory area by land coverage category for all basins.
(5) Contributory area for all basins, by land cover class, expressed as a percentage of the total acres for each of the Non-Agricultural Rural Land Use Category.

Approach and Methodology for Phosphorus Loading Computations

The development of nutrient loading estimates in the absence of direct monitoring has generally been completed by applying areal based nutrient export rates to the watershed area to calculate the annual nutrient mass (Beaulac and Reckhow, 1982: Reckhow, et al, 1980; Panuska and Lillie, 1995; Clesceri, et al, 1986a; Clesceri, et al, 1986b; McFarland and Hauck, 2001). Phosphorus export coefficients assume 100% of phosphorus transported from land will reach surface water. The phosphorous export coefficient is part of the total phosphorous loading equation:

$$L = \sum_{i=1}^{m} c_i \bullet A_i$$

> L is total phosphorus loading from land (in kilograms per year), m is number of land use types, c_i is the phosphorus export coefficient for land use i (in kilograms per hectare per year), and A_i is area of land use i (in hectares).

Over large watershed areas, the phosphorus export is not proportional to watershed area and some attenuation of phosphorus occurs, especially in natural vegetation that have low runoff rates. Recently, authors who have examined the nutrient export issue on landscape level scales (large watersheds and higher order streams) have raised concerns over the applicability of export coefficients across large watershed areas (Birr and Mulla, 2001; Cammermeyer, et al, 1999; Johnson and gage, 1997; Jones, et al, 2001; Mattson and Isaac, 1999; McFarland and Hauck, 1998; Richards, et al, 2001; Sharpley, et al, 1993; Soranno, et al, 1996; Worrall and Burt, 1999). The underlying issue related to this concern is that not all areas in a large watershed contribute nutrients and sediment equally. Novotny and Chester (1989) showed that the sediment delivery rate decreases with increasing watershed size. They report that in humid regions only a portion of a watershed contributes to surface runoff; they called these contributory areas of a watershed the "hydrologically active areas". (St. Onge, *et al*, in press). Frink (1991) reported that a review of the literature revealed a high degree of variability in phosphorus export rates reported. Johnes (1996) found that the application of export coefficients to the Slapton catchment in south Devon, U.K., resulted in a 9.12 % error in loads. The application of a distance decay function to the export rates for areas outside the 50 meter riparian corridor reduced the model error to 2.5% of the observed phosphorus load. Johnes (1996) stated that an understanding of hydrologic pathways and variability in transport mechanism is important for determining nutrient delivery to surface waters through the use of export coefficient models.

Soranno, et al. (1996) and Cammermeyer, et al, (1999) suggest two adjustments to account for the attenuation by including a transmission coefficient (T) that represents the proportion of phosphorus transported down slope along the path of overland flow and a phosphorus flux coefficient (f_i), that represents the phosphorus production and transport that reaches a surface water body. While this equation applies more strictly to watershed modeling with GIS software, the underlying premises apply directly to the loading assessment methodology used here. The authors suggest that the phosphorus loading equation can be modified:

$$L = \sum_{i=1}^{m} \sum_{p=1}^{n} f_i \bullet A_{p,i} \bullet T_i^p$$

T is the transmission coefficient (O<*T*<1) representing the proportion of phosphorus transported, f_i is the phosphorus flux coefficient, *n* is the number of pixels, and *p* is the pixel distance of overland flow.

Soranno, et al (1996) reported that the greatest contribution of loadings was derived from land uses within the riparian corridor, a corridor that varies in width depending upon topography and runoff conditions. Based upon modeling of monitored watersheds they found that the total annual rainfall affected the phosphorus loading from the riparian areas by creating variability as to the effective contributory area. In most cases, the transmission coefficient is determined through GIS modeling of the watershed area. Such modeling examines the down slope movement of water and thus nutrients from pixel to pixel across the watershed. The GIS-based development of transmission coefficients for use in this assessment was beyond the scope of the project. In the absence of a calculated *T*, an estimate of the contributory area of a watershed based upon land use and the application of a basin runoff factors were chosen for the load calculations. The basin runoff factor accounts for the differences in effective flow length and thus runoff volumes between the three precipitation scenarios (Soranno et al, 1996; Cammermeyer, et al, 1999; Barr Engineering, 2003b). The phosphorus loading estimation methodology used in this assessment assumes that c_i will be equal to f_i through the use of calculated loadings from the 100 meter contributory areas only.

The phenomenon of contributory area and variability in nutrient mass over a range of flow scenarios is a central question to the estimation of large basin loads. The literature was reviewed for a consensus on the size of this contributory area and the impact of hydrologic conditions upon the size and export estimation. Novotny and Chester (1989) calibrated and verified hydrologic models for a number of Milwaukee area basins and found that sediment delivery ratios ranged from 0.01 for pervious areas and 1.0 for completely storm-sewered urban areas. Naiman and Decamps (1997) emphasize that riparian zones strongly influence biogeochemical cycles and rates in streams and reduce external impacts to streams. Johnson, et al (1997) found that landscape factors within the 100 meter ecotone adjacent to streams were sufficient predictors of stream water chemistry. Richards, et al (1996) found that in central Michigan streams, the 100 meter area adjacent to streams was the strongest predictor of sediment related habitat variables. Tufford, *et al*, (1998) reported that the land within 150 meters of streams was a better predictor of nutrient concentrations. Predictor models for stream phosphorus concentrations best for land uses adjacent to streams, r2 = 0.183 for all land in the watershed versus $r^2 = 0.387$ and $r^2 = 0.334$ for land use within 31 – 150 meters and <150 meters of streams, respectively. Soranno, et al (1996) reported the variability in effective contributory area due to differences in runoff years was lowest for pre-settlement conditions, i.e., native plant communities.

The schedule and budget for this assessment did not allow for GIS modeling of the effective contributory area based upon hydrologic conditions. Many authors have suggested that riparian land cover within 100 meters can mediate upslope impacts on water quality (Schmitt, et al, 1999; Cole et al, 1997; Castelle, et al, 1994; Roth, et al, 1996; Osborne and Kovacic, 1993). Based upon this literature assessment, an evaluation was undertaken of two monitored watersheds. Phosphorus loadings were calculated based upon literature export rates applied to the entire watershed. This evaluation was completed for the Brule River using MPCA monitoring results for 2002 and the South

Branch of Valley Creek using results from the St. Croix Watershed Research Station (MPCA, 2003; Almendinger, et al, 1999; Zapp and Almendinger, 2001; Valley Branch Watershed District. 2002).

The application to literature derived phosphorus export loading rates to the Brule River watershed calculated a load that was 347% over the normalized annual phosphorus mass based upon 2002 monitoring data. Much of the phosphorus export predicted by the use of export coefficients is not measured at the river's mouth as annual load. A comparable assessment on the South Branch of Valley Creek provided similar results, but with an even greater margin of error – the annual load estimate is 732% of monitored loads for 1997-98. These results provide additional insight into the need to apply export coefficients only to the effective contributory areas of a large watershed.

Comparison of monitored and estimated phosphorus loads for the Brule River Watershed using watershed-wide application of export rates

Land Cover	Watershed Area (hectares)	TP Export Rate (kg/ha/yr)	Calculated TP Load (kg P/yr)
Deciduous Forest	19,045	0.155	2,952
Evergreen Forest	13,436	0.123	1,653
Mixed Forest	18,360	0.130	2,387
Grasslands/Herbaceous	357	0.146	52
Quarries/Strip Mines/Gravel Pits	8	0.000	0
Transitional	1,347	0.129	174
Pasture/Hay	176	0.250	44
Row Crops	393	1.000	393
Commercial/Industrial/Transportation	2	1.250	3
Water	7,278	0.000	0
Wetland	8,191	0.000	0
Total	**68,593**		**7,657**
2002 Monitored TP Load (kg)			**1,735**
Percent Difference (calculated/monitored)			**441.31%**
Normalized TP Load - Average Year (kg)*			**2202**
Percent Difference (calculated/normalized)			**347.72%**

* Nomalized load = 3 pounds of TP /square mile / inch runoff (3 # P x 265 sq.mi. x 6.1") as per MPCA (2003)

Comparison of monitored and estimated phosphorus loads for South Fork Valley Creek Watershed using watershed-wide application of export rates

Land Cover	Area (hectares)	TP Export Rate (kg/ha/yr)	Calculated TP Load (kg P/yr)
Forest	648	0.130	84
Urban	165	1.250	206
Grassland	165	0.169	28
Pasture	254	0.250	63
Agric, land	739	1.000	739
Roads	246	1.250	307
Water	41	0.000	0
Wetland	21	0.000	0
Total	**2,064**		**1,428**
Monitored TP Load (kg)			**195**
Percent Difference (calculated/monitored)			**732.13%**

Notes:	1997-98 data for calculations of load	
	Mean discharge	0.31 m^3/sec
	Annual discharge	9,776,160 m^3
	TP concentration	0.020 mg P/L
	South Fork Valley Creek watershed area from VBWD	

Based upon the literature review conclusion that the 100 meter riparian zone has the greatest influence on water chemistry, we have chosen to estimate phosphorus loads from the 100 meter zone of land use immediately adjacent to perennial streams, lakes and wetlands in all of the basins. The NLDC land use coverage for the non-agricultural rural was buffered using ArcView to create a land cover quantity for all lands within 100 meters of surface water – lakes, wetlands and perennial streams. This 100 meter wide area was used for the calculation of the effective contributory area for each land cover types for each basin (see Table 5).

An assessment was completed on the literature values for phosphorus export rates to examine any differences between the three aggregate level ecoregions. Tables 6 and 7 present the results of that analysis including summary statistics where available and the ecoregion mean value used for each plant community. These values were used for the phosphorus load calculations and provided the basis for discussion of load variability.

The phosphorus load for each land use was calculated by multiplying the phosphorus export coefficient by the 100 m contributory area and basin runoff factor for each land use category (see Table 8). The basin runoff factor is based upon the percent differences between runoff in the wet and dry precipitation scenarios compared to the average conditions for each basin. The basin runoff factor was developed to account for the changes in runoff volumes due to increased runoff and higher loadings due to longer overland flow lengths and thus larger contributory areas in wet years and inversely so for dry years. This information was generated from the basin hydrology technical memorandum (Barr Engineering, 2003b). The basin hydrology technical memorandum reported significant variability of runoff and precipitation across the state. That technical memo examined the precipitation patterns and developed the basin-wide runoff conditions used for each of the loading scenarios assessed. The basin runoff factor used for each of the three scenarios for non-agricultural rural land uses is present in Table 9. Use of the basin runoff factor and contributory watershed area for loading calculations, allowed for adjustment of the loadings based upon the annual runoff.

*Basin natural area load (kg) = Export rate (kg/ha/yr) * Contributory area (ha) * Basin runoff factor*

The load from unincorporated urban areas within the otherwise rural areas was calculated in the same manner as the for in the urban areas as presented in the Draft – Detailed Assessment of Phosphorus Sources to Minnesota Watersheds – Urban Runoff (Barr Engineering, 2003a). The unincorporated urban areas usually have developed drainage systems that bypass natural vegetation and provide for direct delivery of storm water runoff to surface waters.

*Basin load (kg) = Concentration (mg/L) * Contributory area (ha) * Percent impervious area*

> where, concentration is based upon the concentration regression equations developed for urban runoff in each of the basins, contributory area is equal to the total area for each land use class, runoff coefficient = 0.05 + 0.009 * impervious percentage, and annual rainfall depth is the annual precipitation for the loading flow condition scenario by basin.

Table 6. Phosphorus export coefficient data set used for calculation of the non-agricultural rural land uses.

Land Use Type / Location	Location / Aggregate Ecoregion	kg P/ ha / yr	pounds P/ ac / yr	Basis for determination	Reference
41 Deciduous Forest					
	So Wisconsin - VII	0.100	0.089	literature estimation	Soranno et al, 1966
	east coast	0.120	0.107	median	Frink 1991
	NE MN - VIII	0.107	0.095	preharvest measured	Leete, 1986
	NE MN - VIII	0.159	0.142	post-harvest measured	Leete, 1986
	TCMA - VII	0.090	0.080	measure .01 ha sites	Singer and Rust, 1975
	Manitoba	0.120	0.107	literature review	Bourne, et al, 2002
	Minnesota - VIII	0.260	0.232	literature value cited Leete 1986	Timmons, et al, 1977
	So Ontario - VIII	0.107	0.095		that much of the upland derived flows were retained by the hillside forest communities
	New Hampshire - VIII	0.019	0.017		reported in:Reckhow, et al,1980
	Ohio - VII	0.035	0.031		reported in:Reckhow, et al,1980
	Tennessee - XI	0.025	0.022	oak-hickory	reported in:Reckhow, et al,1980
	Minnesota - VIII	0.280	0.250		reported in:Reckhow, et al,1980
	Mean	**0.119**	**0.106**		
	Standard deviation	**0.082**	**0.074**		
	Number	**12**	**12**		
42 Evergreen Forest					
	WI - VIII	0.280	0.250	estimated - 84% forest/16% ag	Corsi, et al, 1997
	MN - VIII	0.080	0.071	peatland annual yields	Bolter and Verry, 1977
	No WI - VIII	0.112	0.100	mean - 3 sites 90% forest and wetlands	Clesceri, 1986a
	Eastern US	0.080	0.071	eastern US inc. MN	Omernik 1976
	Mean	**0.138**	**0.123**		
	Standard deviation	**0.096**	**0.086**		
	Number	**4**	**4**		
43 Mixed Forest					
	Popple River WI - VIII	0.044	0.039	wet year	Panuska and Lillie, 1995 based upon USGS data
	Popple River WI - VIII	0.094	0.084	average year	Panuska and Lillie, 1995 based upon USGS data
	Popple River WI - VIII	0.175	0.156	dry year	Panuska and Lillie, 1995 based upon USGS data
	statewide WI	0.040	0.036	extr low	Panuska and Lillie, 1995
	statewide WI	0.090	0.080	most likely	Panuska and Lillie, 1995
	statewide WI	0.180	0.161	extr high	Panuska and Lillie, 1995
	Menominee River basin - VIII	0.058	0.052	wet year	Panuska and Lillie, 1995 based upon USGS data
	Menominee River basin - VIII	0.093	0.083	average year	Panuska and Lillie, 1995 based upon USGS data
	Menominee River basin - VIII	0.112	0.100	dry year	Panuska and Lillie, 1995 based upon USGS data
	Ontario - VIII	0.309	0.276	Kenora - mixed	reported in:Reckhow, et al,1980
	Minnesota - VIII	0.157	0.140		reported in:Reckhow, et al,1980
	National median	0.206	0.184		reported in:Reckhow, et al,1980
	Mean	**0.130**	**0.116**		
	Standard deviation	**0.079**	**0.070**		
	Number	**12**	**12**		
51 Shrubland / Transitional					
	Deciduous forest	0.151	0.135	calculated based upon average	
	Grassland	0.106	0.094	of deciduous forest and grassland	
	Calculated value	**0.129**	**0.115**		no literature values available
71 Grasslands/Herbaceous					
	Minnesota - VI	0.100	0.089	native pasture - high end of range	Timmons and Holt, 1977
		0.250	0.223	native pasture - low end of range	Timmons and Holt, 1977
		0.175	0.156	native pasture - mean of range	calculated from Timmons and Holt, 1977
	So WI -VII	0.169	0.151	restored prairie	calculated based upon Brye et al, 2000 water budget and [ave] from US ACE, 2001
	Eastern ND - VI	0.060	0.054	native grasses - prairie pothole region	calculated based upon Shjeflo, 1968 and Winter etal, 2001 water budgets and [ave] from US ACE, 2001
	Mean	**0.151**	**0.135**		
	Standard deviation	**0.073**	**0.066**		
	Number	**5**	**5**		
		Percent Impervious			
21 Low Intensity Residential	Runoff coefficient	32%		calculated based upon urban loadings	Zielinski, 2002; Barr Engineering, 2003
22 High Intensity Residential	Runoff coefficient	42%		calculated based upon urban loadings	Zielinski, 2002; Barr Engineering, 2003
23 Commercial / Industrial / Transportation	Runoff coefficient	57%		calculated based upon urban loadings	Zielinski, 2002; Barr Engineering, 2003
32 Quarries/ Strip Mines/ Gravel Pits				not calculated	
85 Urban/ Recreational Grasses	Runoff coefficient	32%		calculated based upon urban loadings	Zielinski, 2002; Barr Engineering, 2003

Table 7. Level III Aggregate Ecoregion specific phosphorus export rates for natural plant communities.

Land Use Type / Location	Level III Aggregate Ecoregion	kg P/ ha / yr	pounds P/ ac / yr
41 Deciduous Forest			
	41 Mean - Ecoregion VIII	0.155	0.139
	Standard deviation	0.100	0.089
	Number	6	6
	41 Mean - Ecoregion VII	0.075	0.067
	Standard deviation	0.035	0.031
	Number	3	3
	41 Mean - All Deciduous Forest	0.119	0.106
	Standard deviation	0.082	0.074
	Number	12	12
42 Evergreen Forest			
	42 Mean - Ecoregion VIII	0.123	0.110
	Standard deviation	0.111	0.099
	Number	4	4
	42 Mean - All Evergreen Forest	0.114	0.102
	Standard deviation	0.098	0.088
	Number	5	5
43 Mixed Forest			
	43 Mean - Ecoregion VIII	0.130	0.116
	Standard deviation	0.085	0.076
	Number	8	8
	43 Mean - All Mixed Forest	0.130	0.116
	Standard deviation	0.079	0.070
	Number	12	12
71 Grasslands/Herbaceous			
	71 Southern WI -VII	0.169	0.151
	71 Mean - Ecoregion VIII	0.146	0.130
	Standard deviation	0.084	0.075
	Number	4	4
	Mean - All Grasslands/Herbaceous	0.151	0.135
	Standard deviation	0.073	0.066
	Number	5	5

Table 8. Ecoregion export coefficients for phosphorus load calcualtions; **Applied export rate in bold**.

Watershed	Level III Aggregate Ecoregion	Ecoregion Land Use Class Export Coefficient - kg/ha/yr				
		Deciduous Forest	Evergreen Forest	Mixed Forest	Shrubland	Grasslands/ Herbaceous
Cedar River	VI - Corn Belt and Northern Great Plains	**0.119 (1)**	**0.114 (2)**	**0.130 (3)**	**0.129 (4)**	**0.151 (5)**
Des Moines River	VI - Corn Belt and Northern Great Plains	**0.119 (1)**	**0.114 (2)**	**0.130 (3)**	**0.129 (4)**	**0.151 (5)**
Lake Superior	VIII - Nutrient Poor Largely Glaciated Upper Midwest and Northeast	**0.155**	**0.123**	**0.130 (3)**	**0.129 (4)**	**0.146**
Lower Mississippi River	VI - Corn Belt and Northern Great Plains	0.119 (1)	0.114 (2)	0.130 (3)	0.129 (4)	**0.151 (5)**
	VII - Mostly Glaciated Dairy Region	**0.075**	**0.114 (2)**	**0.130 (3)**	**0.129 (4)**	0.169
Minnesota River	VI - Corn Belt and Northern Great Plains	**0.119 (1)**	**0.114 (2)**	**0.130 (3)**	**0.129 (4)**	**0.151 (5)**
	VII - Mostly Glaciated Dairy Region	0.075	0.114 (2)	0.130 (3)	0.129 (4)	0.169
Missouri River	VI - Corn Belt and Northern Great Plains	**0.119 (1)**	**0.114 (2)**	**0.130 (3)**	**0.129 (4)**	**0.151 (5)**
Rainy River	VIII - Nutrient Poor Largely Glaciated Upper Midwest and Northeast	**0.155**	**0.123**	**0.130 (3)**	**0.129 (4)**	**0.146**
Red River	VI - Corn Belt and Northern Great Plains	0.119 (1)	0.114 (2)	0.130 (3)	**0.129 (4)**	**0.151 (5)**
	VII - Mostly Glaciated Dairy Region	**0.075**	0.114 (2)	**0.130 (3)**	0.129 (4)	0.169
	VIII - Nutrient Poor Largely Glaciated Upper Midwest and Northeast	0.155	**0.123**	0.130 (3)	0.129 (4)	0.146
St. Croix River	VII - Mostly Glaciated Dairy Region	**0.075**	0.114 (2)	**0.130 (3)**	**0.129 (4)**	**0.169**
	VIII - Nutrient Poor Largely Glaciated Upper Midwest and Northeast	0.155	**0.123**	0.130 (3)	0.129 (4)	0.146
Upper Mississippi River	VII - Mostly Glaciated Dairy Region	**0.075**	0.114 (2)	**0.130 (3)**	**0.129 (4)**	**0.169**
	VIII - Nutrient Poor Largely Glaciated Upper Midwest and Northeast	0.155	**0.123**	0.130 (3)	0.129 (4)	0.146

Notes: Statewide Land Class Export Coefficient Used due to absence of ecoregion value

(1) All Deciduous Forests export rate
(2) All Conferous Forests export rate
(3) All Mixed Forests export rate
(4) All Shrublands export rate
(5) All Grasslands export rate

	Dry Conditions		Average Conditions		Wet Conditions	
Basin	Runoff (inches)	Basin Runoff Factor	Runoff (inches)	Basin Runoff Factor	Runoff (inches)	Basin Runoff Factor
Cedar River	5.6	0.57	9.8	1	17.5	1.79
Des Moines River	1.4	0.25	5.7	1	13.4	2.36
Lake Superior	7.9	0.63	12.4	1	16.7	1.35
Lower Mississippi River	7.1	0.70	10.3	1	15.6	1.51
Minnesota River	1.9	0.34	5.6	1	11.2	2.00
Missouri River	1.0	0.18	5.3	1	12.8	2.44
Rainy River	4.8	0.60	8.0	1	11.4	1.43
Red River	1.1	0.31	3.4	1	6.1	1.78
St. Croix River	5.6	0.58	9.7	1	14.3	1.47
Upper Mississippi River	3.6	0.52	6.9	1	10.4	1.52

Table 9. Basin runoff factor for non-agricultural rural land use phosphorus load calculations.

Results of Phosphorus Loading Computations and Assessments

Export rates were applied to each of the basins for the natural plant community lands uses are listed in Table 8. The export coefficients highlighted in bold were applied to the watershed areas in the basin.

Land use totals for the basins and the contributory areas for each basin were previously listed in Tables 4 and 5.

The results of the basin loading calculations for each basin and state-wide totals are listed in table 10.

Table 10. Phosphorus loading results for watershed contributory areas for Minnesota basins and state-wide totals for three hydrologic scenarios; loads in kg.

Basin	Hydrology Scenario	Low Intensity Residential	High Intensity Residential	Commercial/ Industrial/ Transportation	Bare Rock/Sand/ Clay	Quarries/ Strip Mines/ Gravel Pits	Transitional	Deciduous Forest	Evergreen Forest	Mixed Forest	Shrubland	Grasslands/ Herbaceous	Urban/ Recreational Grasses	Total Kg P
Cedar River	Dry Year	69.8	8.2	1263.7	2.7	Not Calculated	0.0	291.1	0.0	1.9	0.0	0.0	28.3	1,666
	Avg Year	73.9	8.7	1338.2	2.9	Not Calculated	0.0	510.7	0.0	3.3	0.0	0.0	30.0	1,968
	Wet Year	75.7	8.9	1369.6	2.9	Not Calculated	0.0	914.2	0.0	5.9	0.0	0.0	30.7	2,408
Des Moines River	Dry Year	35.8	1.1	1020.1	0.0	Not Calculated	0.0	117.5	2.7	3.0	0.1	0.0	98.3	1,279
	Avg Year	41.5	1.3	1183.0	0.0	Not Calculated	0.1	469.9	10.6	12.0	0.4	0.0	114.0	1,833
	Wet Year	46.7	1.5	1332.3	0.0	Not Calculated	0.3	1108.9	25.1	28.4	0.8	0.0	128.4	2,673
Lake Superior	Dry Year	178.4	93.3	4546.1	92.9	Not Calculated	559.1	23219.3	7883.2	10799.0	264.2	177.0	181.0	47,993
	Avg Year	190.7	99.7	4859.4	99.3	Not Calculated	887.4	36856.1	12513.1	17141.2	419.4	281.0	193.5	73,541
	Wet Year	204.1	106.7	5201.1	106.3	Not Calculated	1198.0	49755.7	16892.7	23140.7	566.2	379.3	207.1	97,758
Lower Mississippi River	Dry Year	214.9	53.6	4496.0	16.3	Not Calculated	1.2	4944.9	63.7	348.5	0.3	35.7	313.9	10,489
	Avg Year	238.6	59.6	4991.9	18.1	Not Calculated	1.8	7064.2	91.1	497.8	0.4	51.0	348.6	13,363
	Wet Year	252.5	63.0	5284.0	19.2	Not Calculated	2.7	10667.0	137.5	751.7	0.6	77.0	369.0	17,624
Minnesota River	Dry Year	539.2	61.4	5962.3	0.3	Not Calculated	2.3	3772.9	93.5	197.0	64.2	0.0	1603.9	12,297
	Avg Year	627.1	71.4	6934.2	0.4	Not Calculated	6.7	11096.9	274.9	579.3	188.8	0.0	1865.3	21,645
	Wet Year	695.7	79.2	7693.0	0.4	Not Calculated	13.4	22193.8	549.9	1158.6	377.6	0.0	2069.5	34,831
Missouri River	Dry Year	39.6	0.7	1412.6	0.0	Not Calculated	0.0	48.7	0.2	0.9	0.0	0.1	51.2	1,554
	Avg Year	46.6	0.9	1662.6	0.0	Not Calculated	0.0	270.5	0.9	5.1	0.1	0.6	60.3	2,047
	Wet Year	53.0	1.0	1890.4	0.0	Not Calculated	0.1	659.9	2.3	12.5	0.2	1.4	68.5	2,689
Rainy River	Dry Year	226.2	42.2	6770.8	189.7	Not Calculated	1394.9	27232.8	15260.7	17633.1	2445.7	25.1	199.9	71,421
	Avg Year	248.5	46.4	7436.2	208.3	Not Calculated	2324.8	45388.0	25434.5	29388.4	4076.2	41.8	219.6	114,813
	Wet Year	273.7	51.1	8191.5	229.5	Not Calculated	3324.4	64904.8	36371.4	42025.4	5829.0	59.8	241.9	161,503
Red River of the North	Dry Year	310.8	41.4	5839.0	122.5	Not Calculated	167.6	7806.5	343.6	357.4	396.2	0.1	849.9	16,235
	Avg Year	362.5	48.2	6810.6	142.8	Not Calculated	540.7	25182.4	1108.4	1153.0	1278.0	0.4	991.3	37,618
	Wet Year	410.0	54.6	7702.9	161.5	Not Calculated	962.4	44824.6	1973.0	2052.4	2274.8	0.7	1121.1	61,538
St. Croix River	Dry Year	252.4	71.7	2257.9	0.0	Not Calculated	83.9	9777.1	515.1	810.9	61.3	34.3	734.8	14,599
	Avg Year	293.4	83.3	2624.8	0.0	Not Calculated	144.6	16857.1	888.1	1398.2	105.7	59.1	854.2	23,308
	Wet Year	320.0	90.9	2863.2	0.0	Not Calculated	212.6	24779.9	1305.6	2055.3	155.4	86.8	931.7	32,801
Upper Mississippi River	Dry Year	2780.6	573.4	11562.3	30.5	Not Calculated	695.5	27379.7	5221.9	5762.3	1309.9	1.3	3386.8	58,704
	Avg Year	3181.9	656.2	13231.0	34.9	Not Calculated	1337.4	52653.3	10042.2	11081.4	2519.1	2.4	3875.6	98,615
	Wet Year	3509.1	723.6	14591.4	38.5	Not Calculated	2032.9	80033.1	15264.1	16843.8	3829.0	3.7	4274.1	141,143

	Hydrology Scenario	Low Intensity Residential	High Intensity Residential	Commercial/ Industrial/ Transportation	Bare Rock/Sand/ Clay	Quarries/ Strip Mines/ Gravel Pits	Transitional	Deciduous Forest	Evergreen Forest	Mixed Forest	Shrubland	Grasslands/ Herbaceous	Urban/ Recreational Grasses	Total Kg P
Statewide Totals	Dry Year	4,648	947	45,131	455	Not Calculated	2,904	104,591	29,385	35,914	4,542	274	7,448	236,238
	Avg Year	5,305	1,076	51,072	507	Not Calculated	5,244	196,349	50,364	61,260	8,588	436	8,552	388,751
	Wet Year	5,840	1,181	56,120	558	Not Calculated	7,747	299,842	72,522	88,075	13,034	609	9,442	554,968

Phosphorus Loading Variability and Uncertainty

The variability and uncertainty of these phosphorus loading computations and assessment is currently difficult to assess due to the lack of monitoring data that would allow a rigorous evaluation of the application of the concepts of contributory area and the use basin runoff factor.

The procedures used for the basin calculations were applied to the Brule River and South Fork Valley Creek watersheds and compared to the normalized loads determined from 2002 monitoring and 1997-98 monitoring data, respectively (MPCA, 2003a; Almendinger, et al, 1999; Zapp and Almendinger, 2001; Valley Branch Watershed District. 2002). The results are tabulated below in Table 11. The comparison shows that the method used to estimate the annual loadings over predicts the loadings by 28.7% in dry years and 100% in wet years. However, this predicted load for the Brule River is significantly lower than the calculated load that would result if phosphorus export rate coefficients were applied to the entire basin, which over-predicted observed loads by 347%. Results for the South Fork of Valley Creek using the contributory area approach under predicts the total load by 75% in dry years and 33% in wet years. The large volume of groundwater in the South Fork of Valley Creek's annual water budget most likely leads to the under prediction.

While the current estimation method used in this report still over or under predicts loads, the difference between calculated and gauged apparent loads is less, and there is no way to determine how much of the actual load has been retained in upstream water bodies in the Brule River Watershed (i.e., the gauged load is a net statistic). This load assessment's purpose was to estimate surface runoff loads to all surface waters of the state, and it should be recognized that retention of phosphorus in upstream water bodies will reduce the watershed output for all of the basins and phosphorus inputs from groundwater will not be accurately accounted.

Brule River Watershed

Land Cover	Contributory Area (hectares)	TP Export Rate (kg/ha/yr)	Calculated TP Load (kg P/yr) Dry Year	Average Year	Wet Year
Deciduous Forest	8,072	0.155	788	1,251	1,689
Evergreen Forest	8,469	0.123	656	1,042	1,406
Mixed Forest	10,561	0.130	865	1,373	1,853
Grasslands/Herbaceous	141	0.146	13	21	28
Quarries/Strip Mines/Gravel Pits	7	0.000	0	0	0
Transitional	498	0.129	40	64	87
Pasture/Hay	52	0.250	8	13	18
Row Crops	175	1.000	110	175	236
Commercial/Industrial/Transportat	2	1.250	2	3	3
Water	7,191	0.000	0	0	0
Wetland	8,094	0.000	0	0	0
Total	**43,262**		**2,483**	**3,941**	**5,320**
Normalized TP Load*			**1,929**	**2,202**	**2,656**
Percent Difference (calculated/normalized)			**128.7%**	**179.0%**	**200.3%**

* Nomalized load as per MPCA (2003)

Dry Year = 3 pounds of TP /square mile / inch runoff (3 # P x 265 sq.mi. x 5.4") as per MPCA (2003)

Average Year = 3 pounds of TP /square mile / inch runoff (3 # P x 265 sq.mi. x 6.1") as per MPCA (2003)

Wet Year = 3 pounds of TP /square mile / inch runoff (3 # P x 265 sq.mi. x 7.4") as per MPCA (2003)

Calculated TP Load = Export rate (kg/ha/yr) * Contributory area (ha) * Basin runoff multiplier

Contributory Area = all watershed area within 100m of surface waters

South Fork Valley Creek Watershed

Land Cover	Area (hectares)	TP Export Rate (kg/ha/yr)	Calculated TP Load (kg P/yr) Dry Year	Average Year	Wet Year
Forest	40	0.130	3	5	8
Urban	10	1.250	7	13	19
Grassland	10	0.169	1	2	3
Pasture	16	0.250	2	4	6
Agric, land	46	1.000	27	46	68
Roads	15	1.250	11	19	28
Water	3	0.000	0	0	0
Wetland	1	0.000	0	0	0
Total	**142**		**52**	**89**	**131**
Monitored TP Load (kg)			**195**	**195**	**195**
Percent Difference (calculated/monitored)			**26.48%**	**45.66%**	**67.12%**

Notes: Contributory area calculated for stream corridor and adjacent upland wetlands.
Total load does not account for ground water inputs of phosphorus.

Table 11. Comparison of calculated and normalized loads for the Brule River watershed and monitored and estimated phosphorus loads for South Fork Valley Creek Watershed, using the application of export rates to the contributory area of each watershed..

The annual loads to the basin derived using the contributory area approach to loads were compared to the loads that would be predicted using the watershed-wide application of export rates to assess the difference between the methods across all of the basins in Minnesota. This side-by-side method evaluation was completed on the non-agricultural land uses outside of incorporated areas only. Table 12 summarizes the phosphorus loading estimates for both methods and the percent differences. The loading totals for non-agricultural land uses from the entire basin is larger than would be expected due to the larger land areas, with the state-wide total loads being 56.4% greater in a dry year, 58.0% greater in an average year, and 58.9% greater in a wet year, with a mean difference of 57.8%.

Table 12. Phosphorus loading results for Minnesota basins and state-wide totals comparing application of export rates to contributory areas and all watershed rural land use areas for three hydrologic scenarios; loads in kg.

Basin	Hydrology Scenario	Total Kg P - Contributory Area Application of Export Rates	Total Kg P - Basin-wide Application of Export Rates	Percent Difference (Contributory Area Load/Basin Area Load)
Cedar River	Dry Year	1,666	5,407	30.8%
	Avg Year	1,968	6,115	32.2%
	Wet Year	2,408	7,011	34.3%
Des Moines River	Dry Year	1,279	4,650	27.5%
	Avg Year	1,833	5,996	30.6%
	Wet Year	2,673	7,804	34.2%
Lake Superior	Dry Year	47,993	86,529	55.5%
	Avg Year	73,541	132,606	55.5%
	Wet Year	97,758	176,283	55.5%
Lower Mississippi River	Dry Year	10,489	29,568	35.5%
	Avg Year	13,363	36,925	36.2%
	Wet Year	17,624	47,388	37.2%
Minnesota River	Dry Year	12,297	32,467	37.9%
	Avg Year	21,645	49,689	43.6%
	Wet Year	34,831	72,698	47.9%
Missouri River	Dry Year	1,554	5,005	31.1%
	Avg Year	2,047	6,318	32.4%
	Wet Year	2,689	7,893	34.1%
Rainy River	Dry Year	71,421	111,161	64.3%
	Avg Year	114,813	179,730	63.9%
	Wet Year	161,503	253,499	63.7%
Red River of the North	Dry Year	16,235	28,507	57.0%
	Avg Year	37,618	61,419	61.2%
	Wet Year	61,538	98,101	62.7%
St. Croix River	Dry Year	14,599	19,460	75.0%
	Avg Year	23,308	30,994	75.2%
	Wet Year	32,801	43,554	75.3%
Upper Mississippi River	Dry Year	58,704	95,883	61.2%
	Avg Year	98,615	159,965	61.6%
	Wet Year	141,143	228,174	61.9%

	Hydrology Scenario	Total Kg P - Contributory Area Application of Export Rates	Total Kg P - State-wide Application of Export Rates	Percent Difference (Contributory Area Load/Basin Area Load)
Statewide Totals	Dry Year	236,238	418,636	56.4%
	Avg Year	388,751	669,758	58.0%
	Wet Year	554,968	942,406	58.9%

Recommendations for Future Refinements

Refinement of the application of export coefficients to Minnesota watershed will require further monitoring and research into the development and application of transmission coefficients. This work will require more detail investigation into the relationships that exist between phosphorus-flux coefficients, land use export coefficients, and transmission factors and their impact on the effective contributory area for large watersheds. As was seen in the literature review, many of the export coefficients for natural vegetation were developed on very small sites. Larger scale studies, comparable to the work by Sartz and others in the driftless area should be undertaken.

The width of the effective contributory area has major implications for water quality management. Much of the research conducted on buffer systems provides some insight into contributory watershed area functions. However, refinement of the interactions of soil type, topography and vegetative cover on the transmission of phosphorus to surface waters needs further research. Research and monitoring efforts on this topic should include GIS modeling efforts to help define these relationships and allow for state-wide spatial database development.

Further investigation into ground water interactions in the Driftless area, Washington County and other high ground water recharge areas are needed to develop a better understanding of groundwater recharge and the impacts upon stream quality and quantity and how this impacts watershed nutrient loadings.

Recommendations for Lowering Phosphorus Export

The protection of natural areas is needed to insure they retain the hydrologic and ecologic functions that keep surface runoff volumes low, nutrient export low and groundwater recharge rates high. Many natural areas are under stress due to development pressures, invasion by exotic species and increased nutrient loading from adjacent land uses. While the overall percentage of land cover represented by these natural plant communities is only 23%, they provide valuable ecologic and hydrologic value.

Conservation easements, such as CREP and RIM, provide additional opportunities for reducing phosphorus export from contributory watershed areas. The impact of these easements on phosphorus export from converted agricultural lands is evaluated as part of the Agricultural Runoff Technical Memorandum.

All land use decisions will need to consider the loss of these functions, and provision of economic mechanisms that allow landowners to retain these functions is needed.

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BARR

Technical Memorandum

To: Marvin Hora, Minnesota Pollution Control Agency

Mark Tomasek, Minnesota Pollution Control Agency

Doug Hall, Minnesota Pollution Control Agency

From: Jeffrey Lee and Keith Pilgrim

Subject: Detailed Assessment of Phosphorus Sources to Minnesota Watersheds – Urban Runoff

Date: December 22, 2003

Project: 23/62-853 URBN 008

c: Greg Wilson

Henry Runke

The purpose of this memorandum is to provide a discussion of urban land use runoff as a source of phosphorus to Minnesota watersheds. This discussion is based on a review of the available literature, monitoring data and the results of phosphorus loading computations done for each of Minnesota's major watershed basins as part of this study. This memorandum is intended to:

- Provide an overview and introduction to this source of phosphorus
- Describe the results of the literature search and review of available monitoring data
- Discuss the characteristics of each watershed basin as it pertains to this source of phosphorus
- Describe the methodology used to complete the phosphorus loading computations and assessments for this study
- Discuss the results of the phosphorus loading computations and assessments
- Discuss the uncertainty of the phosphorus loading computations and assessment
- Provide recommendations for future refinements to phosphorus loading estimates and methods for reducing error terms
- Provide recommendations for lowering phosphorus export from this source

Overview and Introduction to Urban Runoff Sources of Phosphorus

The conversion of land areas to urban land uses leads to changes in watershed hydrology and pollutant load rates. The areal increase in impervious surfaces in urban areas over undeveloped rural and natural land uses leads to greater surface water runoff volumes. The increased runoff coupled with human activities increases the types of pollutants and delivery rate of these pollutants to surface waters. The impacts of the increased runoff volumes and pollutant mass to downstream waters often leads to declines in water quality and ecological function.

Urban land uses have higher percentages of impervious surfaces than natural land cover. The road and street infrastructure, parking lots and buildings all increase the area of hard surfaces. These impermeable surfaces shed water as surface runoff, lowering the infiltration and evapotranspiration components of the hydrologic cycle. Up to 90% of the annual precipitation may become surface runoff in high density urban environments (Center for Watershed Protection, 2003). This water is generally directed to storm sewers and other conveyance systems to rapidly move the large volumes to receiving waters and prevent flooding.

The intense human use in urban watersheds leads to a larger range of pollutants and large quantities of these pollutants when compared to natural vegetative land cover. Human activities related to automobiles, industrial uses, and the prevalence of turf grass as a groundcover provides a ready supply of pollutants. The storm water conveyance systems promote the rapid movement of water to receiving waters, increasing the efficiency of runoff water at entraining and removing pollutants from the landscape. The result is that urban landscapes generate a larger volume of surface runoff that transports a larger load of pollutants compared to pre-development conditions. This increase in runoff volumes reduces the infiltration volume and thus reduces stream base flows and shallow groundwater levels.

This resulting urban stormwater runoff channels large quantities of pollutants and water to lakes, streams and wetlands where the impact on ecological function is nearly always negative. The increased loading of nutrients, especially phosphorus, leads to eutrophication of lakes and wetlands, as well as stream systems. The resulting eutrophication leads to increased algal growth, decreased water clarity and loss of recreational uses, as well as human health concerns, increased periphyton growth and increased treatment costs for industrial uses of water. Remediation of the resulting water quality problems is costly and many times may not fully restore water to the pre-impacted conditions.

Results of Literature Search and Review of Available Monitoring Data

Initially, the literature review efforts attempted to document urban runoff studies within each of the basins in Minnesota, but it became readily apparent that the quality and quantity of the data available was insufficient for the use of quantifying basin-specific data for this assessment. See Table 1 for a listing and summary of the initial 31 data sets reviewed for this assessment. The need to quantify phosphorus loadings across basins with regard to three different hydrologic conditions (low, average and high flow conditions) required that a method be developed to model phosphorus loadings with regard to land use and hydrologic conditions. The scientific literature was thus reviewed to determine the hydrologic regimes, nutrient cycling mechanisms and phosphorus loading factors for each of the land use categories included in the Urban Runoff category. Phosphorus monitoring results for urban watersheds, the hydrologic and nutrient export relationships related to the urban land uses, runoff modeling techniques, and methods for assessing variability in stormwater modeling results were the main areas of investigation of the review.

Stormwater Runoff Monitoring

The variability in storm water runoff data is inherent in studies of this type, and storm water runoff data should always be subject to scrutiny to insure that the variability is not beyond the expected range. One recurring point noted during this review of the literature was agreement by all authors that runoff data is log-normally distributed and highly variable (Bannerman, 1983). In an attempt to determine the range of phosphorus concentrations in urban runoff, we reviewed summary data provided by investigators and wherever possible examined the site specific data from previous or ongoing monitoring studies. The monitoring data presented in Table 1 is a combination of flow-weighted mean concentrations, event mean concentrations, expressed as median geometric mean or arithmetic mean. The inconsistency in data reporting limited the use of many of the data sets found during the literature review process.

From all of the available published and unpublished urban runoff total phosphorus data that were assessed in the development of estimates of phosphorus concentrations in urban storm water runoff, only a limited number of data sets were used. The elimination of data from consideration was based upon information from various investigators related to bias and accuracy of load estimates (Schwartz and Naiman, 1999; Marsalek, 1991; Marsalek, 1990). Schwartz and Naiman (1999) reviewed the

Table 1. Storm event runoff total phosphorus concentrations (concentrations - mg P/L).*

Location	Concentration	Source of data	Notes:	
Nokomis/Hiawatha watersheds				
Hiawatha watersheds - 1996	0.510	Wenck/MCWD, 1998		
Minnehaha Creek 1997		Wenck/MCWD, 1998		
Storm event flows	0.380		[average] of overflows from MC to L.Nokomis following rain events	
Storm event flows	0.690		July 1, 1997 storm	
Minneapolis NPDES report (92 only)		City of Minneapolis, 1992		
Ave. EMC w/o Jimmy's	0.417			
White Bear Lake storm sewer FWMC	0.242	Schuler, 1998	arithmetic mean of annual FWMC for 12 years (1985-96)	
Metropolitan Area 208 Study	0.560	Oberts, 1983	median flow-weighted mean concentration	
Plymouth, MN	0.258	Barten, 1994	5 samples - July - Oct 1993	
TCMA - NURP site data		USGS, 1982 (from Brach, 1989)	mean FWMC values	
Yates watershed	0.630			
Iverson watershed	0.620			
Wisconsin storm-sewer samples	0.290	Bannerman *et al* , 1996	EMC median; n=204	
	0.450		EMC mean; n=204	
Madison, WI		Bannerman, *et al,* 1992	storm sewer outfalls - urban areas	
geometric mean	0.660		cv = 0.70	
arithmetic mean	0.860		cv = 0.70	
Michigan NPDES residential sites	0.380	Cave and Roesner, 1994	mean EMC 1992-93; n=34	
Marquette, MI	0.290	Steuer *et al* , 1997	geometric mean	
Minneapolis/St. Paul NPDES Monitoring				
Lake Harriet Parkway at W. 44th St., Minneap	0.541	MPRB 2002.	May-October	2001
Luella St. at Orange Ave, St. Paul, MN	0.652		May-October	2001
Vandalia St.-350 feet south of Capp Rd.,St. Pa	0.255		May-October	2001
Charles Ave-Mackubin to Arundel St., St. Pau	0.377		May-October	2001
E. 29th St. at 31st Ave. S., Minneapolis, MN	0.525		May-October	2001
Souix Falls SD		Niehus, 1997		
Site 1, Sioux Falls, SD	0.217		June 1995-July 1996	
Site 2, Sioux Falls, SD	0.613		June 1995-July 1996	
Site 3, Sioux Falls, SD	0.114		June 1995-July 1996	
Fish Lake Watershed - Eagan MN		City of Eagan, 1995		
I-2 inlet to Fish Lake Watershed, Eagan, MN	0.235		All Year	1993
I-3, Eagan, Fish Lake Watershed, MN	0.371		All Year	1993
Lake Harriet watershed, Minneapolis		MPRB unpublished		
Lake Harriet Parkway at W. 44th St., Minneap	0.934		April-October	1995
Lake Harriet Parkway at W. 44th St., Minneap	0.635		June-November	1996
Lake Harriet Parkway at W. 44th St., Minneap	0.466		June-August	1997
Lake Harriet Parkway at W. 44th St., Minneap	0.366		May-October	2002
Minneapolis/St. Paul NPDES Monitoring		MPRB 2003a		
Luella St. at Orange Ave, St. Paul, MN	0.344		May-October	2002
Vandalia St.-350 feet south of Capp Rd.,St. Pa	0.278		May-October	2002
Charles Ave-Mackubin to Arundel St., St. Pau	0.391		May-October	2002
E. 29th St. at 31st Ave. S., St. Paul, MN	0.305		May-October	2002
Tanners Lake Watershed, Maplewood, MN		Barr 1993		
G1AB, Tanners Lake Watershed, Maplewood,	0.240		All Year	1989
G4A, Tanners Lake Watershed, Maplewood, M	0.410		All Year	1989
G3, Tanners Lake Watershed, Maplewood, MN	0.340		All Year	1989
Minneapolis Chain of Lakes CWP project		Barr 1992		
LH1, Lake Harriet, Minneapolis, MN	0.224		April-October	1990-1991
LH8, Lake Harriet, Minneapolis, MN	0.213		April-October	1990-1991
LC15, Lake Calhoun, Minneapolis, MN	0.211		April-October	1990-1991
LC17, Lake Calhoun, Minneapolis,MN	0.179		April-October	1990-1991
LC20, Lake Calhoun, Minneapolis, MN	0.255		April-October	1990-1991
LC22, Lake Calhoun, Minneapolis, MN	0.224		April-October	1990-1991
LC26, Lake Calhoun, Minneapolis, MN	0.230		April-October	1990-1991
LI31, Lake of the Isles, Minneapolis, MN	0.232		April-October	1990-1991
CD36, Cedar Lake, Minneapolis, MN	0.211		April-October	1990-1991
CD37, Cedar Lake, Minneapolis, MN	0.173		April-October	1990-1991
TCMA golf course study		Barten 1995		
Baker Golf Course, Minneapolis, MN	0.479		April-October	1994
Meadowbrook Golf Course, Minneapolis, MN	0.892		April-October	1994
Woodhill Golf Course, Minneapolis, MN	0.476		April-October	1994
Plymouth MN		TRPD unpublished		
Three Rivers Park District	0.341		July-November	2001
Three Rivers Park District	0.195		April-October	2002
Three Rivers Park District	0.377		July-November	2001
Three Rivers Park District	0.254		April-October	2002
Three Rivers Park District	0.244		July-November	2001
Three Rivers Park District	0.219		April-October	2002
Three Rivers Park District	0.213		July-November	2001
Three Rivers Park District	0.249		April-October	2002
Three Rivers Park District	0.329		July-November	2001
Three Rivers Park District	0.290		April-October	2002
Tanners Lake Watershed, Maplewood, MN		Barr 2003		
G1AB Inlet (Dennys) to Tanners Lake, Oakdal	0.232		May-September	2002
G4A Inlet (Glenbrook) to Tanners Lake, Mapl	0.308		May-September	2002
G3 Inlet to Tanners Lake, Maplewood, MN	0.202		May-September	2002
Superior, WI		USGS 1996		
Urban Undeveloped Lot, Superior, WI	0.065		May-September	1996
Urban Undeveloped Lot, Superior, WI	0.115		July-September	1995
Golf Course, Superior, WI	0.247		June-October	1996
Madison WI		Waschbusch, etal 1999		
Monroe Neighborhood, Madison, WI	0.640		May-October	1994
Harper Neighborhood, Madison, WI	0.930		June-October	1995
Woodbury MN		RWMWD unpublished		
PFS Study Site, East Pond, Woodbury, MN	0.398		May-September	2001
PFS Study Site, East Pond, Woodbury, MN	0.332		May-September	2002
PFS Study Site, West Pond, Woodbury, MN	0.446		May-September	2001
PFS Study Site, West Pond, Woodbury, MN	0.322		May-September	2002
Minneapolis/St. Paul NPDES Monitoring		MPRB unpublished		
Lake Harriet Parkway at W. 44th St., Minneap	0.588		March-September	2003
Luella St. at Orange Ave, St. Paul, MN	0.539		May-September	2003
Vandalia St.-350 feet south of Capp Rd.,St. Pa	0.296		May-September	2003
Charles Ave-Mackubin to Arundel St., St. Pau	0.426		May-September	2003
St. Paul MN		Ramsey County Public Works, unpublished		
Como Lake Rain Water Garden, St. Paul, MN	0.253		April-September	2002
Hennepin County				
Storm Sewer at Torah School, St. Louis Park,	0.930		July-November	1989
Storm Sewer at Torah School, St. Louis Park,	0.470		April-October	1990
Keller Lake watershed		RWMWD unpublished		
Keller Lake Parkway and HWY 36, St. Paul, M	0.316		June-October	2002
Canadian Cities				
Sarnia, ON	0.299			
ult Ste. Marie, ON	0.309			
Windsor, ON	0.231			
		Marsalek, 1991		
Toronto, ON				
warm weather	0.280			
cold weather	0.230			
		Pitt and McLean, 1986		
Sault Ste. Marie, ON	0.246			
		Marsalek, 1990		
Summary statistics	**Mean**	**Standard deviation**		
	0.379	**0.195**		

*All values listed are for either mixed use urban watershed or urban residential, as provided by the author(s).

level and cause of uncertainty in planning level estimates of pollutant loads. They defined planning level estimates as methods that make use of an annual runoff volume and a representative pollutant concentration to estimate annual loads. The use of planning level estimates is widespread, but the authors note that very little work has been completed to measure the accuracy or confidence of these estimates. Schwartz and Naiman (1999) noted that errors in planning level pollutant loads have been reported to be in the range of 50 – 300%. Schwartz and Naiman (1999) suggest using the mean concentration as the representative concentration introduces significant bias into the annual load estimates and report that the use of flow-weighted mean concentration (FWMC) provides an unbiased estimate of annual load. They further note that the use of arithmetic means for event concentrations can yield a range of bias from -40% to 40%.

Data collected in the literature review, chosen for inclusion in the database, had to meet the following criteria:

1) phosphorus data was collected for the duration of individual storm events and was reported as Event Mean Concentration, (EMC)
2) numerous samples had to be collected at the same monitoring location throughout a given year,
3) land use was either reported in adequate detail or land use could be determined using ArcView with delineated watersheds and USGS National Land Cover Data (NLCD), and
4) a large fraction of the runoff generated from a monitored watershed was not routed through storm water treatment BMPs such as detention ponds.

With regard to criteria #4, the urban runoff dataset is intended to represent the concentration of phosphorus in untreated urban runoff. For a majority of the datasets (71 percent), the annual average total phosphorus concentration reported was weighted by the volume of runoff produced for each storm event (i.e. flow weighted mean concentration), the remainder of the annual total phosphorus concentrations reported were arithmetic averages. One study (Niehus, 1997) did not meet criterion #2 but was included in the dataset because of limited runoff data for small urban areas and the need to represent less populated urban areas in the dataset. All of the data included in this dataset are presented in Table 2. Precipitation data that is shown in Table 2 was gathered from the rain gage nearest to the monitoring site. Rain gage data was provided by the State Climatology Office Climatology Working Group web page.

Table 2. Dataset of flow-weighted annual total phosphorus concentration in urban runoff.

Location	Landuse[1]										
	% LIR	%CIT	%RG	%HIR	% Impervious	Watershed Size (ac)	Total Precipitation for Monitoring Year (in)	Monitoring Year	Sampling Period	Flow Weighted TP Concentration (ug/L)	Reference[2]
Lake Harriet Parkway at W. 44th St., Minneapolis,MN	100	0	0	0	32	143	36	2001	May-October	541	1
Luella St. at Orange Ave, St. Paul, MN	100	0	0	0	32	95	34	2001	May-October	652	1
Vandalia St.-350 feet south of Capp Rd.,St. Paul, MN	0	100	0	0	57	80	34	2001	May-October	255	1
Charles Ave-Mackubin to Arundel St., St. Paul, MN	60	40	0	0	42	63	34	2001	May-October	377	1
E. 29th St. at 31st Ave. S., Minneapolis, MN	50	45	5	0	43	100	36	2001	May-October	525	1
Site 1, Sioux Falls, SD	30	70	0	0	50	145	23	1995 to 1996	June 1995-July 1996	217	2
Site 2, Sioux Falls, SD	0	96	0	0	55	695	23	1995 to 1996	June 1995-July 1996	613	2
Site 3, Sioux Falls, SD	76	0	18	0	30	328	23	1995 to 1996	June 1995-July 1996	114	2
I-2 inlet to Fish Lake Watershed, Eagan, MN	80	20	0	0	37	124	34	1993	All Year	235	3
I-3, Eagan, Fish Lake Watershed, MN	100	0	0	0	32	40	34	1993	All Year	371	3
Lake Harriet Parkway at W. 44th St., Minneapolis, MN	100	0	0	0	32	143	26	1995	April-October	934	4
Lake Harriet Parkway at W. 44th St., Minneapolis, MN	100	0	0	0	32	143	26	1996	June-November	635	4
Lake Harriet Parkway at W. 44th St., Minneapolis, MN	100	0	0	0	32	143	34	1997	June-August	466	4
Lake Harriet Parkway at W. 44th St., Minneapolis, MN	100	0	0	0	32	143	39	2002	May-October	366	5
Luella St. at Orange Ave, St. Paul, MN	100	0	0	0	32	95	42	2002	May-October	344	5
Vandalia St.-350 feet south of Capp Rd.,St. Paul, MN	0	100	0	0	57	80	42	2002	May-October	278	5
Charles Ave-Mackubin to Arundel St., St. Paul, MN	60	40	0	0	42	63	42	2002	May-October	391	5
E. 29th St. at 31st Ave. S., St. Paul, MN	50	45	5	0	43	100	42	2002	May-October	305	5
G1AB, Tanners Lake Watershed, Maplewood, MN	0	82	18	0	53	65	27	1989	All Year	240	6
G4A, Tanners Lake Watershed, Maplewood, MN	0	83	17	0	53	43	27	1989	All Year	410	6
G3, Tanners Lake Watershed, Maplewood, MN	41	11	48	0	35	1354	27	1989	All Year	340	6
LH1, Lake Harriet, Minneapolis, MN	100	0	0	0	32	142	36	1991	April-October	224	7
LH8, Lake Harriet, Minneapolis, MN	82	18	0	0	37	50	36	1991	April-October	213	7
LC15, Lake Calhoun, Minneapolis, MN	81	12	7	0	35	232	36	1991	April-October	211	7
LC17, Lake Calhoun, Minneapolis,MN	26	42	25	0	40	1385	36	1991	April-October	179	7
LC20, Lake Calhoun, Minneapolis, MN	34	31	0	27	40	146	36	1991	April-October	255	7
LC22, Lake Calhoun, Minneapolis, MN	69	31	0	0	40	177	36	1991	April-October	224	7
LC26, Lake Calhoun, Minneapolis, MN	27	41	0	27	43	46	36	1991	April-October	230	7
LI31, Lake of the Isles, Minneapolis, MN	79	21	0	0	37	229	36	1991	April-October	232	7
CD36, Cedar Lake, Minneapolis, MN	100	0	0	0	32	115	36	1991	April-October	211	7
CD37, Cedar Lake, Minneapolis, MN	64	17	15	0	35	1714	36	1991	April-October	173	7
Baker Golf Course, Minneapolis, MN	0	0	100	0	32	47	30	1994	April-October	479	8
Meadowbrook Golf Course, Minneapolis, MN	0	0	100	0	32	94	30	1994	April-October	892	8
Woodhill Golf Course, Minneapolis, MN	0	0	100	0	32	31	30	1994	April-October	476	8
Three Rivers Park District	100	0	0	0	32	14	36	2001	July-November	341	9
Three Rivers Park District	100	0	0	0	32	14	41	2002	April-October	195	9
Three Rivers Park District	100	0	0	0	32	9	36	2001	July-November	377	9
Three Rivers Park District	100	0	0	0	32	9	41	2002	April-October	254	9
Three Rivers Park District	100	0	0	0	32	12	36	2001	July-November	244	9
Three Rivers Park District	100	0	0	0	32	12	41	2002	April-October	219	9
Three Rivers Park District	100	0	0	0	32	17	36	2001	July-November	213	9
Three Rivers Park District	100	0	0	0	32	17	41	2002	April-October	249	9
Three Rivers Park District	100	0	0	0	32	14	36	2001	July-November	329	9
Three Rivers Park District	100	0	0	0	32	14	41	2002	April-October	290	9
G1AB Inlet (Dennys) to Tanners Lake, Oakdale, MN	0	80	20	0	52	65	42	2002	May-September	232	10
G4A Inlet (Glenbrook) to Tanners Lake, Maplewood, MN	85	0	15	0	32	74	42	2002	May-September	308	10
G3 Inlet to Tanners Lake, Maplewood, MN	49	19	25	0	35	1368	42	2002	May-September	202	10
Urban Undeveloped Lot, Superior, WI	0	0	100	0	32	76	40	1996	May-September	65	11
Urban Undeveloped Lot, Superior, WI	0	0	100	0	32	76	32	1995	July-September	115	11
Golf Course, Superior, WI	0	0	100	0	32	12	40	1996	June-October	247	11
Monroe Neighborhood, Madison, WI	97	0	0	0	31	232	36	1994	May-October	640	12
Harper Neighborhood, Madison, WI	100	0	0	0	32	41	33.6	1995	June-October	930	12
PFS Study Site, East Pond, Woodbury, MN	100	0	0	0	32	21	36.0	2001	May-September	398	13
PFS Study Site, East Pond, Woodbury, MN	100	0	0	0	32	21	41.0	2002	May-September	332	13
PFS Study Site, West Pond, Woodbury, MN	100	0	0	0	32	15	36.0	2001	May-September	446	13
PFS Study Site, West Pond, Woodbury, MN	100	0	0	0	32	15	41.0	2002	May-September	322	13
Lake Harriet Parkway at W. 44th St., Minneapolis, MN	100	0	0	0	32	143	30.8	2003	March-September	588	14
Luella St. at Orange Ave, St. Paul, MN	100	0	0	0	32	95	26.8	2003	May-September	539	14
Vandalia St.-350 feet south of Capp Rd.,St. Paul, MN	0	100	0	0	57	80	26.8	2003	May-September	296	14
Charles Ave-Mackubin to Arundel St., St. Paul, MN	60	40	0	0	42	63	26.8	2003	May-September	426	14
Como Lake Rain Water Garden, St. Paul, MN	100	0	0	0	32	5	26.8	2002	April-September	253	15
Storm Sewer at Torah School, St. Louis Park, MN	100	0	0	0	32	31	26.8	1989	July-November	930	16
Storm Sewer at Torah School, St. Louis Park, MN	100	0	0	0	32	31	38.25	1990	April-October	470	16
Keller Lake Parkway and HWY 36, St. Paul, MN	27	53	20	0	45	53	42	2002	June-October	316	17

[1] LIR= Low Intensity Residential, CIT= Commercial, Industrial, Transportation, RG= Urban Recreation Grasses, HIR=High Intensity Residential

[2] References

1)Minneapolis Park and Recreation Board, 2002. National Pollutants Discharge Elimination System (NPDES) Monitoring
2)Niehus, C.A. 1997. Characterization of stormwater runoff in Sioux Falls, South Dakota, 1995-1996. USGS Water-Resources Investigations Report 97-4070.
3)City of Eagan. 1995. Diagnostic/feasibility study of Fish Lake, Eagan, MN.
4) Minneapolis Park and Recreation Board, 1997. Unpublished Data.
5)Minneapolis Park and Recreation Board, 2003a. National Pollutants Discharge Elimination System (NPDES) Monitoring
6)Barr Engineering. 1993. Diagnostic/feasibility study of water quality problems and restorative measures for Tanner's Lake. Prepared for the Ramsey Washington Metro Watershed District.
7)Barr Engineering. 1992. Minneapolis chain of lakes clean water partnership project. Prepared for Minneapolis Park and Recreation Board.
8)Barten, J. 1995. Quantity and quality of runoff from four golf courses in the twin cities metropolitan area. Suburban Hennepin Regional Park District.
9)Three River Park District, unpublished data
10) Barr Engineering. 2003. Tanners Lake CIP Performance Evaluation. Prepared for Ramsey-Washington Metro Watershed District.
11) USGS. 1996. Water resources data Wisconsin Water Year 1996. U.S. Geological Survey Water-Data Report WI-96-1.
12) Waschbusch, R.J., etal. 1999. Sources of phosphorus in stormwater and street dirt from two urban residential basins in Madison, Wisconsin. 1994-95. USGS Water-Resources Investigation Report 99-4021.
13) Ramsey Washington Metro Watershed District. Unpublished Data.
14) Minneapolis Park and Recreation Board, 2003b. Unpublished monitoring data for the 2003 NPDES permit.
15) Ramsey County Public Works. 2003. Unpublished data.
16) Hennepin Conservation District. 1991. Toxic and hazardous substances in urban runoff. February 1991.
17) Ramsey Washington Metro Watershed District. 2003. Unpublished data.

Hydrologic and nutrient export relationships

Driver and Tasker (1990) found that, in developing linear regression equations for the estimation of storm water loads, the total storm rainfall, and total contributory drainage area were the most significant factors, while impervious area, land-use and mean annual climatic characteristics were also significant.

The high level of correlation between land use type and effective impervious area has also been noted by many investigators (Schueler, 1987; Driver and Tasker, 1990; Beaulac and Rechkow, 1982). Likewise nutrient loadings increase with increasing impervious surface area, most likely due to the ease of washoff and transport in curb and gutter systems and on other hard surfaces (Brezonik, *et al*, 2002; Schueler, 1994). Higher impervious percentage watersheds yield lower phosphorus concentrations, but the larger volume of water leads to the higher phosphorus loading rates (Bannerman, *et al*, 1992; Swenson, 1998; Beaulac and Rechkow, 1982). Schwartz and Naiman (1999) propose that in small watersheds the pollutant and buildup functions may dominate the pollutant delivery patterns. Thus precipitation patterns can move the pollutant delivery between supply-limited and transport-limited conditions depending upon rainfall amounts. These conditions make the correlation of flow and concentration difficult. This transition between supply-limited conditions and transport-limited is also helpful in explaining the observed concentration and loading differences with annual rainfall amounts. Walker (1992) found similar relationships for runoff data for the Vadnais Lake watershed and noted that antecedent flow conditions are important, with high loads in years following drought. The regression analysis preformed for this assessment supports this theory, in that during wet years the phosphorus storm FWMC are lower and the annual loadings are higher.

Clesceri, et al, (1986) report that years (and seasons) that are wetter or dryer than average, or generally abnormal, can cause large deviations in the annual export rate. They suggest that more accurate loading estimates can be calculated if export rates used were determined from watersheds having similar watershed characteristics or at least from the same regions. Beaulac and Rechkow (1982) also suggest that there is wide variability in loading estimates due to watershed characteristics that influence runoff rates, pollutant sources and delivery. US EPA (1997) and Brezonik, *et al* (2002) provide information on the use of regression analysis for evaluating non-point source pollutant loads. Brezonik *et al* (2002) presented Walker's (1987) regression relationship between phosphorus export and percent urban cover, and the regression relationships between percent urban and percent impervious surface from Twin Cities watershed studies.

Runoff modeling techniques

Marsalek (1991) noted that the simplest methods for estimating annual loads is made by applying monitoring data expressed as annual unit loads to unmonitored watersheds, with the use of summary statistics from larger data bases, regression models and simulation models being progressively more complex. He felt that the best load estimates would be obtained through runoff sampling programs, and that the correlation between runoff volumes and event mean concentrations were critical to the accuracy of the estimates.

Export coefficients are commonly reported according to land use and are developed during a given year under a particular hydrologic condition, such as a wet year (Beaulac and Reckhow, 1982: Reckhow, et al, 1980; Panuska and Lillie, 1995; Clesceri, et al, 1986a; Clesceri, et al, 1986b; McFarland and Hauck, 2001). In some cases the export coefficient is adjusted to reflect a normal climatic year. The most common approach to estimating loads is based upon Schueler's (1987) regression of rainfall runoff volume and percentage imperviousness of a watershed combined with a flow-weighted mean concentration. The equation is widely used for loading estimates and is used in this assessment to determine runoff coefficient based upon impervious fraction:

$$\text{Runoff coefficient } (R_v) = 0.05 + 0.009\ (I)$$

where I = the percentage of site imperviousness.

Using the direct average method, the pollutant load is calculated by multiplying runoff volume with the pollutant concentration to obtain a mass load (Marsalek, 1990). The phosphorus export coefficients used for urban areas assume 100% of phosphorus transported from land will reach surface water due to developed conditions. The mass per unit area derived from the pollutant can be used to calculate the areal loading rate or export coefficient.

The phosphorous export coefficient is part of the total phosphorous loading equation:

$$L = \sum_{i=1}^{m} c_i \bullet A_i$$

> L is total phosphorus loading from land (in kilograms per year), m is number of land use types, c_i is the phosphorus export coefficient for land use i (in kilograms per hectare per year), and A_i is area of land use i (in hectares).

Over large watershed areas, the phosphorus export may not be proportional to watershed area and some attenuation of phosphorus occurs, especially in natural plant communities that have low runoff rates (Soranno, et al, 1996). Panuska and Lillie (1995) report that watershed phosphorus export rates are highly variable and are affected by many factors. Among the factors sited are watershed size, land use, soil types, annual rainfall and the drainage system efficiency.

Walker (1986) developed the FLUX program for the US Army Corps of Engineers (ACOE) to estimate watershed loads from monitoring data sets. The FLUX program allows for the estimation of tributary loadings from sample concentration data and continuous flow records. Five estimation methods are available and potential errors in estimates are quantified. This software is widely used where both flow and concentration data are available. FLUX was used by the Minneapolis Chain of Lakes Clean Water Partnership (and many other monitoring efforts) to estimate annual loads (MPRB, 1993). This data was examined and used in the development of the regression equations (see Approach and Methodology for Phosphorus Loading Computations section) and was used in the assessment of loading variability and uncertainty analysis undertaken for this assessment (see Phosphorus. Loading Variability and Uncertainty section).

McFarland and Hauck (2001) used a multiple regression approach to determine nutrient export coefficients for the Bosque River. They advise that the use of regression analysis using measured flows and water quality data for heterogeneous land uses allows the estimation of loads that represent average conditions accurately.

Methods for Assessing Variability

Schwartz and Naiman (1999) reviewed bias in planning level estimates of pollutant loads. They defined planning level estimates as methods that make use of an annual runoff volume and a representative pollutant concentration (literature derived or monitoring-based measure of central tendency) to estimate annual loads. The use of planning level estimates is widespread, but the authors note that very little work has been completed to measure the accuracy or confidence of these estimates. They noted that errors in planning level pollutant loads have been reported to be in the range of 50 – 300%. Schwartz and Naiman (1999) suggest using the mean event concentration as the representative concentration introduces significant bias into the annual load estimates and report that the use of flow-weighted mean concentration (FWMC) provides an unbiased estimate of annual load. They further note that the use of arithmetic means for EMCs can yield a range of bias from -40% to 40%.

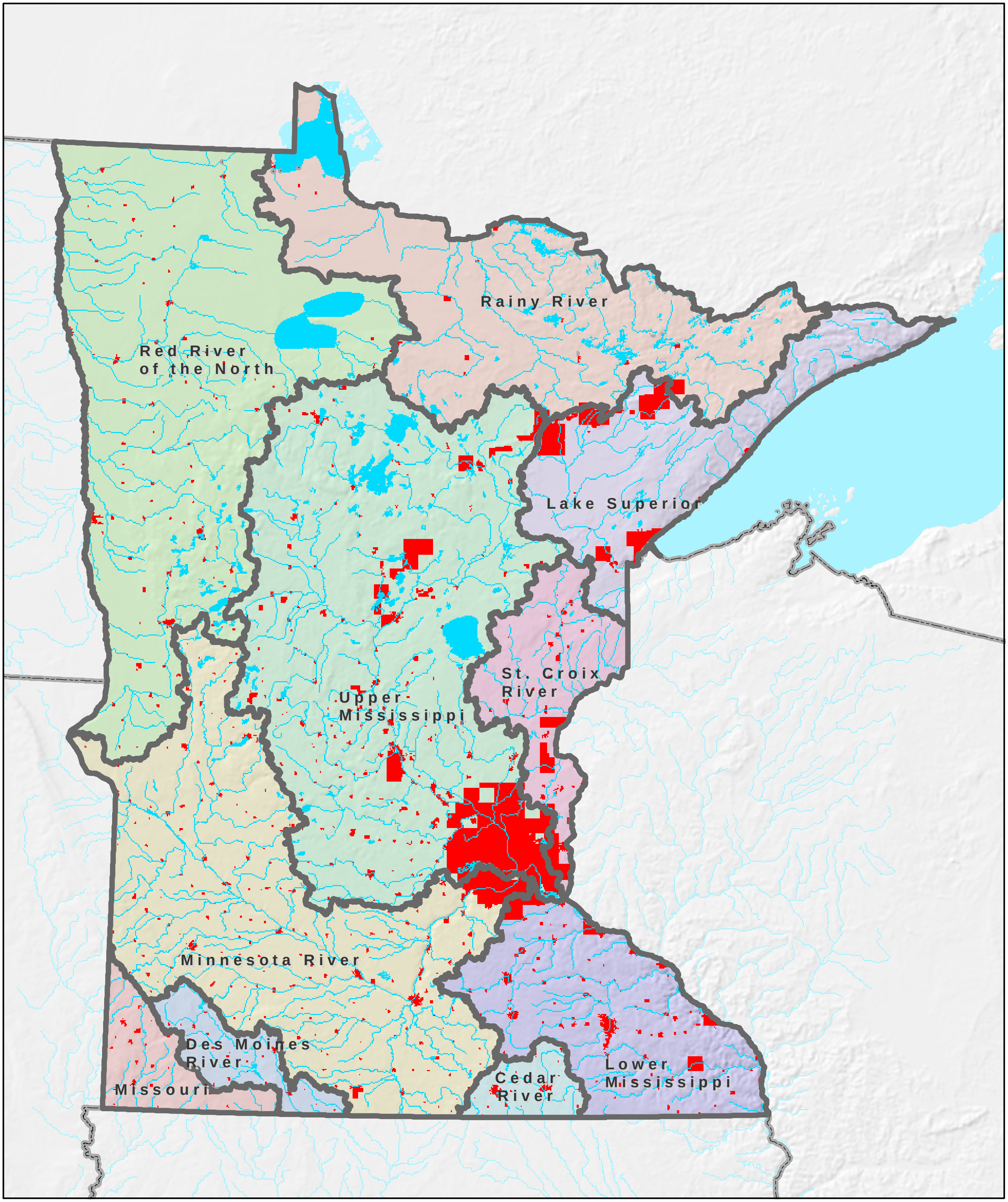
Watershed Basin Characteristics

For the purposes of defining and quantifying the phosphorus loads to Minnesota basins, the land uses within incorporated areas were classified and enumerated using the USGS National Land Cover Data (NLCD). Figure 1 shows the locations of the incorporated areas included in this assessment in relation to the basin boundaries. The National Land Cover Data Set for the Conterminous United States is derived from the Landsat thematic mapper data system (Vogelmann, 2001). The NLDC cover classes included in the land uses within incorporated areas assessed are:

- Urban Developed Areas
  - Low intensity residential
  - High intensity residential
  - Commercial/Industrial/Transportation
- Deciduous Forest
- Evergreen Forest
- Mixed Forest
- Shrubland
- Grasslands/Herbaceous
- Urban / Recreational Grasses
- Agricultural lands
  - Pasture/Hay
  - Row Crops
  - Small Grains
- Other
  - Quarries/Strip Mines/Gravel Pits
  - Transitional (new development)

Tables 3 and 4 provide an overview of the basin characteristics and basin hydrology for each of the ten basins.

Tables 5 and 6 present an overview of the land cover distribution within incorporated areas across the Minnesota basins. Table 5 provides a breakout of all the land cover classes found in the incorporated area boundaries, while Table 6 provides a detailed breakdown of only the urban land cover classes assessed for phosphorus loads.



Data Source: Minnesota Department of Transportation

Major Basins

Incorporated Areas

NORTH

0 12.5 25 50 75 100 Miles

FIGURE 1
Incorporated Areas and
Major Basins

Table 3. Basin watershed areas, precipitation, runoff and land cover percentages.

Basin	Area (Sq Miles)	Average Precipitation (1979-2002)	Average Runoff (1979-2002)	Land Cover Percentages*					
				Urban	Forested	Tilled Agricultural	Pasture/ Grassland	Wetland/Open Water	Other
Cedar River	1,028	32.06	9.80	3.4%	3.3%	83.4%	6.2%	3.7%	0.0%
Des Moines River	1,535	27.98	5.68	1.8%	1.8%	79.9%	11.0%	5.5%	0.0%
Lake Superior	6,149	29.11	12.44	1.4%	57.1%	2.6%	3.5%	33.3%	2.1%
Lower Mississippi	6,317	33.29	10.28	2.4%	15.4%	52.2%	24.8%	5.1%	0.1%
Minnesota River	14,943	28.14	5.61	2.2%	4.6%	72.7%	12.6%	7.8%	0.1%
Missouri	1,782	27.16	5.25	1.5%	1.0%	78.9%	16.0%	2.6%	0.0%
Rainy River	11,236	26.20	8.01	0.4%	41.4%	2.0%	2.3%	52.5%	1.3%
Red River	17,741	23.29	3.42	0.7%	12.0%	54.6%	8.8%	23.8%	0.2%
St. Croix River	3,528	30.61	9.71	1.3%	36.8%	10.8%	20.6%	30.1%	0.2%
Upper Mississippi	14,943	28.07	6.87	3.5%	29.1%	20.2%	16.7%	29.7%	0.7%
State Wide	**79,202**	**27.39**	**6.83**	**1.9%**	**22.7%**	**38.1%**	**12.0%**	**24.7%**	**0.6%**

*Based on USGS National Land Cover Database (1992)

Table 4. Basin hydrologic conditions for assessment scenarios.

			Dry Conditions		Average Conditions		Wet Conditions	
Basin	Total Watershed Area - Square Miles (at discharge point from State)	Minnesota Watershed Area	Rainfall (inches)	Runoff (inches)	Rainfall (inches)	Runoff (inches)	Rainfall (inches)	Runoff (inches)
Cedar River	1,028	1,028	27.5	5.6	32.1	9.8	41.3	17.5
DesMoines River	1,535	1,535	22.0	1.4	28.0	5.7	36.8	13.4
Lake Superior	6149*	6,149	25.5	7.9	29.1	12.4	35.1	16.7
Lower Mississippi	21,073	6,317	27.0	7.1	33.3	10.3	39.8	15.6
Minnesota River	16,879	14,933	22.1	1.9	28.1	5.6	34.8	11.2
Missouri River	1,782	1,782	21.1	1.0	27.2	5.3	35.6	12.8
Rainy River	>22,000*	11,236	22.4	4.8	26.2	8.0	32.1	11.4
Red River	38,183	17,741	18.6	1.1	23.3	3.4	28.9	6.1
St. Croix River	7,728	3,528	23.7	5.6	30.6	9.7	37.6	14.3
Upper Mississippi River	20,100	20,100	22.6	3.6	28.1	6.9	34.3	10.4

Table 5. All land use cover classes, total coverage (acres) and percent of land area for all urban land uses within incorporated areas.

WATERSHED	Open Water	Low Intensity Residential	High Intensity Residential	Commercial/ Industrial/ Transportation	Bare Rock/Sand/ Clay	Quarries/ Strip Mines/Gravel Pits	Transitional	Deciduous Forest	Evergreen Forest	Mixed Forest	Shrubland	Grasslands/ Herbaceous	Pasture/Hay	Row Crops	Small Grains	Urban/ Recreational Grasses	Woody Wetlands	Emergent Herbaceous Wetlands	Total
Cedar River	1,420	2,721	3,645	4,088	0	57	0	1,118	0	5	0	0	1,644	6,719	0	965	202	575	23,161
Des Moines River	880	3,712	657	2,038	0	0	0	497	9	6	0	0	1,759	6,248	0	1,558	87	309	17,762
Lake Superior	12,500	12,465	6,773	11,558	438	31,536	1,086	105,427	20,564	28,412	1,829	1,243	13,003	12,207	121	4,696	61,323	5,607	330,787
Lower Mississippi	11,364	26,611	11,619	13,993	0	803	324	39,953	583	1,957	4	1,026	52,126	72,531	21	14,634	8,125	6,887	262,562
Minnesota River	19,097	79,112	22,044	29,134	15	726	402	30,006	1,070	1,087	139	17	36,206	75,097	2,450	26,042	6,548	20,458	349,650
Missouri	874	3,102	601	1,458	2	45	0	380	0	4	0	25	3,529	9,065	193	1,323	16	320	20,938
Rainy River	2,578	2,883	1,054	2,073	174	8,154	418	17,004	5,305	7,896	513	45	4,148	1,939	493	818	13,491	2,192	71,179
Red River	7,046	15,745	6,701	10,168	0	196	32	7,348	219	130	10	0	14,212	31,002	4,604	6,178	1,782	3,497	108,869
St. Croix River	9,656	8,839	1,737	3,857	0	389	42	31,342	2,842	2,877	6	310	62,842	44,247	1,873	4,994	11,352	10,919	198,126
Upper Mississippi	112,290	172,383	82,717	61,800	50	17,791	2,293	203,942	15,688	19,224	2,476	859	218,513	152,854	15,440	55,046	64,030	103,844	1,301,239
Total Area in Acres by Category for All Basins (1)	177,705	327,573	137,548	140,168	679	59,698	4,598	437,017	46,280	61,598	4,978	3,526	407,981	411,910	25,196	116,253	166,956	154,609	2,684,274
Area Expressed as a Percent of Total Urban Land Use (1)	6.62%	12.20%	5.12%	5.22%	0.03%	2.22%	0.17%	16.28%	1.72%	2.29%	0.19%	0.13%	15.20%	15.35%	0.94%	4.33%	6.22%	5.76%	100.00%

Notes:
(1) Sum of each land use acreage within incorporated areas by cover class across all basins in Minnesota.
(2) Individual land use category expresses as a percent of the total statewide land use within incorporated areas.

Table 6. Land cover classifications, total land area coverage (acres) and percent of land area for all land areas within incoprorated areas included in Urban Runoff Sources.

WATERSHED	Low Intensity Residential	High Intensity Residential	Commercial/ Industrial/ Transportation	Bare Rock/Sand/ Clay	Quarries/ Strip Mines/ Gravel Pits	Transitional	Deciduous Forest	Evergreen Forest	Mixed Forest	Shrubland	Grasslands/ Herbaceous	Pasture/ Hay	Row Crops	Small Grains	Urban / Recreational Grasses	Total
Cedar River	2,721	3,645	4,088	0	57	0	1,118	0	5	0	0	1,644	6,719	0	965	20,964
Des Moines River	3,712	657	2,038	0	0	0	497	9	6	0	0	1,759	6,248	0	1,558	16,485
Lake Superior	12,465	6,773	11,558	438	31,536	1,086	105,427	20,564	28,412	1,829	1,243	13,003	12,207	121	4,696	251,358
Lower Mississippi River	26,611	11,619	13,993	0	803	324	39,953	583	1,957	4	1,026	52,126	72,531	21	14,634	236,186
Minnesota River	79,112	22,044	29,134	15	726	402	30,006	1,070	1,087	139	17	36,206	75,097	2,450	26,042	303,547
Missouri River	3,102	601	1,458	2	45	0	380	0	4	0	25	3,529	9,065	193	1,323	19,728
Rainy River	2,883	1,054	2,073	174	8,154	418	17,004	5,305	7,896	513	45	4,148	1,939	493	818	52,918
Red River	15,745	6,701	10,168	0	196	32	7,348	219	130	10	0	14,212	31,002	4,604	6,178	96,544
St. Croix River	8,839	1,737	3,857	0	389	42	31,342	2,842	2,877	6	310	62,842	44,247	1,873	4,994	166,199
Upper Mississippi River	172,383	82,717	61,800	50	17,791	2,293	203,942	15,688	19,224	2,476	859	218,513	152,854	15,440	55,046	1,021,075
Land Uses within Incorporated Areas - Land Use Category Total in Acres for All Basins (1)	327,573	137,548	140,168	679	59,698	4,598	437,017	46,280	61,598	4,978	3,526	407,981	411,910	25,196	116,253	2,185,004
Land Uses within Incorporated Areas expressed as Percent of State Total for Each Land Use Category (2)	91.29%	97.06%	42.79%	33.96%	55.10%	2.37%	5.14%	2.86%	3.33%	1.79%	19.97%	6.38%	2.19%	2.03%	67.68%	4.10%
Land Uses within Incorporated Areas expressed as Percent of All Incorporated Area Land Uses Statewide (3)	14.99%	6.30%	6.42%	0.03%	2.73%	0.21%	20.00%	2.12%	2.82%	0.23%	0.16%	18.67%	18.85%	1.15%	5.32%	100.00%

Notes:
(1) Sum of each land use acres by land cover category across all basins in the state of Minnesota.
(2) Individual land use category area expressed as percent total statewide coverage for that land use category, i.e., a percentage of all low intensity residential land use, both urban and rural.
(3) Incorporated land use area total in (1) expressed as a precent of the state total area for all urban lands uses, including natural vegetation, agricultural, surface waters and developed areas.

The NLCD system of land cover classification defines each of these land use categories as follows:

Developed areas characterized by a high percentage (30 percent or greater) of constructed materials (e.g. asphalt, concrete, buildings, etc).

21. Low Intensity Residential - Includes areas with a mixture of constructed materials and vegetation. Constructed materials account for 30-80 percent of the cover. Vegetation may account for 20 to 70 percent of the cover. These areas most commonly include single-family housing units. Population densities will be lower than in high intensity residential areas.

22. High intensity residential urban areas - Includes highly developed areas where people reside in high numbers. Examples include apartment complexes and row houses. Vegetation accounts for less than 20 percent of the cover. Constructed materials account for 80 to 100 percent of the cover. Population densities will be higher than in low intensity residential areas.

23. Commercial/Industrial/Transportation - Includes infrastructure (e.g. roads, railroads, etc.) and all highly developed areas not classified as High Intensity Residential. Phosphorus in gasoline (1.2 – 2.0 ppm) and the resulting automobile emissions can contribute to the phosphorus load from roads. This load is included in the Atmospheric Deposition Technical Memorandum (Barr, 2003c)) and likewise would be reflected in the urban loads as part of the runoff concentration. Based upon an annual gasoline consumption in Minnesota of 6.8 million gallons the resulting phosphorus input would be 34 kilograms per year (Mike Hensel, personal communication, 2003).

Barren - Areas characterized by bare rock, gravel, sand, silt, clay, or other earthen material, with little or no "green" vegetation present regardless of its inherent ability to support life. Vegetation, if present, is more widely spaced and scrubby than that in the "green" vegetated categories; lichen cover may be extensive.

32. Quarries/Strip Mines/Gravel Pits - Areas of extractive mining activities with significant surface expression. Runoff from these sites is either covered under NPDES permitted discharges under the point source category, or any overland runoff has been considered to be internal and thus does not leave the site.

33. Transitional - Areas of sparse vegetative cover (less than 25 percent of cover) that are dynamically changing from one land cover to another, often because of land use activities. Examples include forest clear cuts, a transition phase between forest and agricultural land, the temporary clearing of vegetation, and changes due to natural causes (e.g. fire, flood, etc.). This land use classification has been treated in the same manner as the Commercial/Industrial/Transportation class for loading calculations, as in most urban areas this class represents land undergoing development. Only 2% of the land use in this category is found within incorporated areas.

Undeveloped areas with forested upland - Areas characterized by tree cover (natural or semi-natural woody vegetation, generally greater than 6 meters tall); tree canopy accounts for 25-100 percent of the cover.

41. Deciduous Forest - Areas dominated by trees where 75 percent or more of the tree species shed foliage simultaneously in response to seasonal change.

42. Evergreen Forest - Areas dominated by trees where 75 percent or more of the tree species are coniferous, i.e., they maintain their leaves all year. Canopy is never without green foliage in most locations.

43. Mixed Forest - Areas dominated by trees where neither deciduous nor evergreen species represent more than 75 percent of the cover present. Clear-cut and burned areas are classified as “Transitional Bare” areas,

Shrubland - Areas characterized by natural or semi-natural woody vegetation with aerial stems, generally less than 6 meters tall, with individuals or clumps not touching to interlocking. Both evergreen and deciduous species of true shrubs, young trees, and trees or shrubs that are small or stunted because of environmental conditions are included.

51. Shrubland - Areas dominated by shrubs; shrub canopy accounts for 25-100 percent of the cover. Shrub cover is generally greater than 25 percent when tree cover is less than 25 percent. Shrub cover may be less than 25 percent in cases when the cover of other life forms

(e.g. herbaceous or tree) is less than 25 percent and shrubs cover exceeds the cover of the other life forms.

Herbaceous upland areas characterized by natural or semi-natural herbaceous vegetation; herbaceous vegetation accounts for 75-100 percent of the cover.

71. Grasslands/Herbaceous - Areas dominated by upland grasses and forbs. In rare cases, herbaceous cover is less than 25 percent, but exceeds the combined cover of the woody species present. These areas are not subject to intensive management, but they are often utilized for grazing.

Planted/Cultivated - Areas characterized by herbaceous vegetation that has been planted or is intensively managed for the production of food, feed, or fiber; or is maintained in developed settings for specific purposes. Herbaceous vegetation accounts for 75-100 percent of the cover.

81. Pasture/Hay - Areas of grasses, legumes, or grass-legume mixtures planted for livestock grazing or the production of seed or hay crops.

82. Row Crops - Areas used for the production of crops, such as corn, soybeans, vegetables, tobacco, and cotton.

83. Small Grains - Areas used for the production of graminoid crops such as wheat, barley, oats, and rice.

85. Urban / Recreational Grasses – Vegetation (primarily grasses) planted in developed settings for recreation, erosion control, or aesthetic purposes. Examples include parks, lawns, golf course, airport grasses and industrial grass sites.

The percent imperviousness applied to each of these urban land uses and then used in calculation of the runoff coefficient for this assessment are as follows:

Land cover class	Percent impervious
Low intensity residential	32%
High intensity residential	42%
Commercial/Industrial/Transportation	57%
Urban / Recreational Grasses	32%
Transitional	57%

(adapted from Zielinski, 2002 and analysis of TCMA GIS coverage)\

Approach and Methodology for Phosphorus Loading Computations for Incorporated (Urban) Areas

The development of nutrient loading estimates in the absence of direct monitoring has generally been completed by applying areal based nutrient export rates to the watershed area to calculate the annual nutrient mass (Beaulac and Reckhow, 1982: Reckhow, et al, 1980; Panuska and Lillie, 1995; Clesceri, et al, 1986a; Clesceri, et al, 1986b; McFarland and Hauck, 2001). Inherent in the export coefficient is the climatic condition under which the coefficient was developed and the difficulty lies in trying to adjust this export coefficient to reflect loading under dry, normal, and wet climatic conditions because it is not known for a particular site what the relationship is between precipitation and runoff. The phosphorus export coefficients used for land uses within incorporated area boundaries assume 100% of phosphorus transported from land will reach surface water due to developed conditions. The phosphorous export coefficient is part of the total phosphorous loading equation:

$$L = \sum_{i=1}^{m} c_i \bullet A_i$$

where: L is total phosphorus loading from land (in kilograms per year),
m is number of land use types,
c_i is the phosphorus export coefficient for land use i (in kilograms per hectare per year),
A_i is area of land use i (in hectares).

Over large watershed areas, the phosphorus export may not be proportional to watershed area and some attenuation of phosphorus occurs, especially in natural plant communities that have low runoff rates. Recently, authors who have examined the nutrient export issue on landscape level scales have raised concerns over the applicability of export coefficients across large watershed areas (Birr and Mulla, 2001; Cammermeyer, et al, 1999; Johnson and gage, 1997; Jones, et al, 2001; Mattson and Isaac, 1999; McFarland and Hauck, 1998; Richards, et al, 2001; Sharpley, et al, 1993; Soranno, et al, 1996; Worrall and Burt, 1999). The underlying issue related to this concern is that not all areas in a large watershed contribute nutrients and sediment equally. For this assessment, all of the developed urban uses are assumed to have storm water conveyance systems in place – minimally drainage ditches and conveyance channels up to full curb and gutter with piping.

An alternative approach is to estimate the phosphorus load from urban sources using annual estimates of the average flow-weighted total phosphorus concentration in urban runoff. There are several variables that may potentially affect the concentration of phosphorus in storm water runoff, however, development of a relationship between phosphorus concentration and these variables is limited by the variables that are typically reported. The most common variables are land use and precipitation.

For this assessment of monitoring data an evaluation was completed for data that were collected at the same location for multiple years and under different hydrologic conditions. These data shows that the concentration of phosphorus in stormwater at the same site is often higher during dry years compared to an average year, and is lower during a wet year compared to an average year (Table 2). From the available studies that had multiple years of monitoring data, a ratio was developed by dividing the concentration of total phosphorus in runoff for a wet year by the average year, and by dividing the concentration of total phosphorus in runoff for a dry year by the average year (Table 7). Overall, the wet to average ratio was 0.8 and the dry to average ratio was 1.18. This qualitatively shows that less precipitation leads to higher total phosphorus concentrations in runoff, and more precipitation leads to lower phosphorus concentrations in runoff.

To quantify the relationship between annual precipitation, land use (the four urban NLCD land uses: low intensity residential, high intensity residential, commercial-industrial-transportation, and urban recreational grasses), percent impervious area, and the annual flow-weighted total phosphorus concentration, single variable and multivariate linear regressions were performed. The percent impervious area for the watershed that contributed runoff to each monitoring point was calculated from the land use data collected for each watershed (see Table 2), based on a 32 percent impervious area for low density residential, 47 percent for high density residential, 42 percent for commercial-industrial-transportation, and 32 percent for urban/recreational grasses. There was a significant relationship ($P<0.1$ for each variable, $R^2=0.19$ for the overall model) between annual flow-weighted mean total phosphorus concentration, percent impervious area, and annual precipitation (Table 8). Although the overall R^2 was slightly greater for the regression that included annual precipitation and land use composition expressed as a percent, no single land use variable was significant when considered as a separate variable. This may have been because many of the watersheds that were tributary to the monitoring locations reported for each study were not uniform or singular land uses. The land use was often mixed resulting in the effective "canceling out" of one land use versus another. It was determined that the only way to determine the aggregate effect of land use on phosphorus concentration for a particular watershed was to express that land use as percent impervious.

Table 7. Effect of precipitation on annual total phosphorus EMC

Location	Flow-Weighted Average Annual Concentration (ug/L)	Year	Annual Precipitation	Wet,Dry, or Average Precipitation Year	Ratio (Wet/Average, or Dry/Average)	Reference	
G3 Inlet to Tanners Lake, Maplewood, MN	340	1989	27	Dry	0.83	1	0.80
G3 Inlet to Tanners Lake, Maplewood, MN	411	2001	32	Average	--	2	1.18
G3 Inlet to Tanners Lake, Maplewood, MN	202	2002	42	Wet	0.49	2	
G4A, Tanners Lake Watershed, Maplewood, MN	410	1989	27	Dry	--	1	
G4A, Tanners Lake Watershed, Maplewood, MN	308	2002	42	Wet	0.75[1]	2	
Lake Harriet Parkway at W. 44th St., Minneapolis,MN	245	1991	37	Wet	0.49	3	
Lake Harriet Parkway at W. 44th St., Minneapolis,MN	935	1995	26	Dry	1.86	4	
Lake Harriet Parkway at W. 44th St., Minneapolis,MN	635	1996	26	Dry	1.26	4	
Lake Harriet Parkway at W. 44th St., Minneapolis,MN	466	1997	34	Average	--	4	
Lake Harriet Parkway at W. 44th St., Minneapolis,MN	541	2001	34	Average	--	5	
Lake Harriet Parkway at W. 44th St., Minneapolis,MN	373	2002	39	Wet	0.74	6	
Lake Harriet Parkway at W. 44th St., Minneapolis,MN	588	2003	31	Dry	1.17	7	
MG1, Three Rivers Park District, Maple Grove, MN	341	2001	36	Average	--	8	
MG1, Three Rivers Park District, Maple Grove, MN	223	2002	41	Wet	0.65	8	
MG2, Three Rivers Park District, Maple Grove, MN	329	2001	36	Average		8	
MG2, Three Rivers Park District, Maple Grove, MN	252	2002	41	Wet	0.77	8	
P1, Three River Park District, Plymouth, MN	238	2001	36	Average	--	8	
P1, Three River Park District, Plymouth, MN	219	2002	41	Wet	0.92	8	
P2, Three River Park District, Plymouth, MN	213	2001	36	Average	--	8	
P2, Three River Park District, Plymouth, MN	245	2002	41	Wet	1.15	8	
P3, Three River Park District, Plymouth, MN	256	2001	36	Average	--	8	
P3, Three River Park District, Plymouth, MN	233	2002	41	Wet	0.91	8	
Luella St. at Orange Ave, St. Paul, MN	652	2001	34	Average	--	5	
Luella St. at Orange Ave, St. Paul, MN	344	2002	42	Wet	0.53	6	
Luella St. at Orange Ave, St. Paul, MN	539	2003	27	Dry	0.83	7	
Vandalia St.-350 feet south of Capp Rd.,St. Paul, MN	255	2001	34	Average	--	5	
Vandalia St.-350 feet south of Capp Rd.,St. Paul, MN	278	2002	42	Wet	1.09	6	
Vandalia St.-350 feet south of Capp Rd.,St. Paul, MN	296	2003	27	Dry	1.16	7	
Charles Ave-Mackubin to Arundel St., St. Paul, MN	377	2001	34	Average	--	5	
Charles Ave-Mackubin to Arundel St., St. Paul, MN	391	2002	42	Wet	1.04	6	
Charles Ave-Mackubin to Arundel St., St. Paul, MN	426	2003	27	Dry	1.13	7	
E. 29th St. and 31st Ave. S., Minneapolis, MN	525	2001	36	Average	--	5	
E. 29th St. and 31st Ave. S., Minneapolis, MN	305	2002	39	Wet	0.58	6	
PFS Study Site, East Pond, Woodbury, MN	398	2001	32	Average	--	9	
PFS Study Site, East Pond, Woodbury, MN	332	2002	42	Wet	0.83	9	
PFS Study Site, West Pond, Woodbury, MN	446	2001	32	Average	--	9	
PFS Study Site, West Pond, Woodbury, MN	322	2002	42	Wet	0.72	9	

[1] Ratio of wet/dry year.
[2] References

1)Barr Engineering. 1993. Diagnostic/feasibility study of water quality problems and restorative measures for Tanner's Lake. Prepared for the Ramsey Washington Metro Watershed District.
2) Barr Engineering. 2003. Tanners Lake CIP Performance Evaluation. Prepared for Ramsey-Washington Metro Watershed District.
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8)Three River Park District: Lawn Fertilizer Experiment, unpublished data
9) Ramsey Washington Metro Watershed District. Unpublished Data.

Table 8. Regression results between flow-weighted TP concentration in runoff and land use, percent imperviousness, and total preciptiation recorded during the monitoring year.

Multple Variable Regressions:

Set 1: R^2=0.23

Variables	Coefficient	P-Value
Intercept	-978	0.49
%LIR	19.0	0.18
%CIT	17.5	0.22
%RG	18.3	0.20
%HIR	19.9	0.27
Total Precipitation (in) in Monitoring Year	-14.7	0.001

Set 2: R^2=0.19

Variables	Coefficient	P-Value
Intercept	1075	0.000001
% Impervious	-14.4	0.06
Total Precipitation (in) in Monitoring Year	-5.7	0.001

Single Variable Regression

Set 1: R^2=0.13

Variable	Coefficient	P-Value
Intercept	802.3	0.000001
Total Precipitation (in) in Monitoring Year	-12.6	0.003

The number of acres for each of the four developed urban land uses was determined for the incorporated areas in each of the ten basins. In the incorporated areas the total area of each land cover was considered to be contributory. To calculate the expected concentration of total phosphorus in urban runoff for each basin, the average percent imperious area for the four developed urban land uses (high and low intensity residential, commercial/industrial/transportation and urban/recreational grasses) in each basin and the annual precipitation for the dry, average, and wet year were used as inputs to the regression model.

Phosphorus loading from the four developed urban land uses in each basin was then calculated according to the following equation:

*Basin load = Concentration * Contributory area * Runoff coefficient * Annual Rainfall Depth*

where: concentration is based upon the concentration regression equations developed for urban runoff in each of the basins,
contributory area is equal to the total area for each land use class,
runoff coefficient = 0.05 + 0.009 * impervious percentage,
annual rainfall depth is the annual precipitation for the loading flow condition scenario by basin.

The phosphorus load for each of the other non-agricultural land uses within incorporated areas (natural vegetation within incorporated areas) were calculated by multiplying the phosphorus export coefficient by the contributory area and basin runoff factor. The basin runoff factor is based upon the percent differences between the wet and dry precipitation scenarios compared to the average conditions for each basin (Barr Engineering, 2003a). The basin runoff factor was developed to account for the changes in runoff volumes due to increased precipitation and higher loadings due to longer overland flow lengths and thus larger contributory areas. This information was generated from the basin hydrology technical memorandum (Barr Engineering, 2003b). The basin hydrology technical memorandum reported significant variability of runoff and precipitation across the state. That technical memorandum examined the precipitation patterns and developed the basin-wide precipitation conditions used for each of the loading scenarios assessed. The basin runoff factor used for each of the three scenarios for natural areas within incorporated areas is present in Table 9 of the Non-Agricultural Rural Land use Technical Memorandum (Barr Engineering, 2003a).

The calculation formula for the natural areas was:

*Basin natural area load (kg) = Export rate (kg/ha/yr) * Contributory area (ha) * Runoff factor*

Phosphorus loads from agricultural land uses within incorporated areas were calculated using the same methodology as for other agricultural areas statewide as per Mulla (2003).

The export rates used for natural areas within the incorporated area boundaries are listed in Table 9.

Table 9. Natural vegetation ecoregion and agricultural land use export coefficients for phosphorus load calculations applied to urban areas.

Watershed	Land Use Export Coefficient - kg/ha/yr				
	Deciduous Forest (3)	**Evergreen Forest (3)**	**Mixed Forest (3)**	**Shrubland (3)**	**Grasslands/ Herbaceous (3)**
Cedar River	0.119	0.114	0.130	0.129	0.151
Des Moines River	0.119	0.114	0.130	0.129	0.151
Lake Superior	0.155	0.123	0.130	0.129	0.146
Lower Mississippi River	0.075	0.114	0.130	0.129	0.151
Minnesota River	0.119	0.114	0.130	0.129	0.151
Missouri River	0.119	0.114	0.130	0.129	0.151
Rainy River	0.155	0.123	0.130	0.129	0.146
Red River	0.075	0.123	0.130	0.129	0.151
St. Croix River	0.075	0.123	0.130	0.129	0.169
Upper Mississippi River	0.075	0.123	0.130	0.129	0.169

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(2) Panuska, J.C. and Lillie, R.A. 1995. Phosphorus loadings from Wisconsin watersheds: Recommended phosphorus export coefficients for agricultural and forested watersheds. Research Management Findings, Number 38. Wisconsin Department of Natural Resources.

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Results of Phosphorus Loading Computations and Assessments

The percentage of imperviousness and export rates, as applicable for urban land use for each of the basins are listed on page 19 and in Table 9, respectively.

Land use totals for the basins and the phosphorus contributory areas for each basin were previously listed in Table 6.

The results of the basin loading calculations for each basin and state-wide totals are listed in Table 10.

Table 10. Phosphorus loading results from incorporated urban areas for Minnesota basins and state-wide totals for three hydrologic scenarios; loads in kg/yr.

Basin	Hydrology Scenario	Low Intensity Residential	High Intensity Residential	Commercial/ Industrial/ Transportation	Bare Rock/Sand/ Clay	Quarries/ Strip Mines/ Gravel Pits	Transitional	Deciduous Forest	Evergreen Forest	Mixed Forest	Shrubland	Grasslands/ Herbaceous	Urban/ Recreational Grasses	Agricultural Lands in Incorporated Areas	Total Kg P
Cedar River	Dry Year	738.7	1,251.5	1,827.8	0.0	Not Calculated	0.0	46.2	0.0	0.2	0.0	0.0	262.1	413	4,539
	Avg Year	782.3	1,325.3	1,935.6	0.0	Not Calculated	0.0	53.9	0.0	0.3	0.0	0.0	277.5	1,002	5,377
	Wet Year	800.6	1,356.4	1,981.0	0.0	Not Calculated	0.0	69.4	0.0	0.3	0.0	0.0	284.0	1,278	5,770
Des Moines River	Dry Year	1,097.6	245.8	992.7	0.0	Not Calculated	0.0	18.8	0.3	0.2	0.0	0.0	460.6	351	3,167
	Avg Year	1,272.8	285.0	1,151.1	0.0	Not Calculated	0.0	23.9	0.4	0.3	0.0	0.0	534.1	537	3,805
	Wet Year	1,433.5	321.0	1,296.4	0.0	Not Calculated	0.0	31.5	0.6	0.4	0.0	0.0	601.6	1,042	4,727
Lake Superior	Dry Year	3,598.6	2,472.8	5,495.7	320.0	Not Calculated	516.4	5,794.7	896.9	1,309.8	83.7	64.3	1,355.6	1,060	22,969
	Avg Year	3,846.7	2,643.3	5,874.5	342.1	Not Calculated	552.0	6,613.3	1,023.6	1,494.8	95.5	73.4	1,449.0	1,824	25,832
	Wet Year	4,117.2	2,829.2	6,287.6	366.1	Not Calculated	590.8	7,966.8	1,233.2	1,800.7	115.0	88.5	1,550.9	3,134	30,080
Lower Mississippi River	Dry Year	9,032.4	4,987.8	7,823.2	0.4	Not Calculated	181.1	983.8	21.8	83.5	0.2	50.9	4,967.4	5,291	33,423
	Avg Year	10,028.5	5,537.9	8,685.9	0.4	Not Calculated	201.1	1,212.7	26.9	103.0	0.2	62.7	5,515.2	10,535	41,909
	Wet Year	10,615.5	5,862.0	9,194.3	0.5	Not Calculated	212.8	1,449.9	32.2	123.1	0.2	74.9	5,838.0	12,809	46,212
Minnesota River	Dry Year	24,477.9	8,625.8	14,846.9	11.6	Not Calculated	205.0	1,135.2	38.8	44.9	5.7	0.8	8,057.5	5,723	63,173
	Avg Year	28,467.9	10,031.9	17,267.0	13.5	Not Calculated	238.4	1,445.1	49.4	57.2	7.2	1.1	9,371.0	11,275	78,225
	Wet Year	31,583.3	11,129.8	19,156.6	15.0	Not Calculated	264.5	1,786.3	61.0	70.7	8.9	1.3	10,396.5	16,541	91,015
Missouri River	Dry Year	913.6	223.8	707.4	1.8	Not Calculated	0.0	14.2	0.0	0.2	0.0	1.2	389.7	614	2,866
	Avg Year	1,075.3	263.4	832.6	2.1	Not Calculated	0.0	18.3	0.0	0.2	0.0	1.6	458.7	1,000	3,652
	Wet Year	1,222.7	299.5	946.7	2.3	Not Calculated	0.0	24.0	0.0	0.3	0.0	2.0	521.5	1,859	4,878
Rainy River	Dry Year	800.7	370.1	948.4	122.1	Not Calculated	191.4	913.8	226.2	355.9	23.0	2.3	227.1	218	4,399
	Avg Year	879.4	406.5	1,041.6	134.1	Not Calculated	210.2	1,066.6	264.1	415.4	26.8	2.7	249.5	502	5,199
	Wet Year	968.7	447.8	1,147.4	147.7	Not Calculated	231.6	1,305.2	323.1	508.3	32.8	3.3	274.8	874	6,265
Red River of the North	Dry Year	3,978.4	2,141.3	4,231.8	0.0	Not Calculated	13.2	177.9	8.7	5.4	0.4	0.0	1,561.0	1,229	13,347
	Avg Year	4,640.4	2,497.6	4,936.0	0.0	Not Calculated	15.4	223.0	10.9	6.8	0.5	0.0	1,820.7	3,599	17,750
	Wet Year	5,248.4	2,824.8	5,582.7	0.0	Not Calculated	17.5	277.1	13.5	8.5	0.7	0.0	2,059.3	5,101	21,133
St. Croix River	Dry Year	2,888.4	718.1	2,076.0	0.0	Not Calculated	22.8	735.7	109.4	117.1	0.3	16.4	1,631.9	3,397	11,713
	Avg Year	3,357.8	834.7	2,413.3	0.0	Not Calculated	26.6	951.3	141.5	151.4	0.3	21.2	1,897.1	7,309	17,104
	Wet Year	3,662.7	910.5	2,632.5	0.0	Not Calculated	29.0	1,168.2	173.7	185.9	0.4	26.1	2,069.3	13,421	24,279
Upper Mississippi River	Dry Year	53,550.4	32,497.7	31,620.6	38.9	Not Calculated	1,173.4	4,982.4	628.5	814.1	104.1	47.3	17,099.9	21,243	163,800
	Avg Year	61,278.5	37,187.6	36,183.9	44.5	Not Calculated	1,342.7	6,190.1	780.9	1,011.4	129.3	58.8	19,567.7	38,038	201,813
	Wet Year	67,579.4	41,011.4	39,904.5	49.1	Not Calculated	1,480.8	7,560.0	953.7	1,235.2	157.9	71.8	21,579.7	68,981	250,565

	Hydrology Scenario	Low Intensity Residential	High Intensity Residential	Commercial/ Industrial/ Transportation	Bare Rock/Sand/ Clay	Quarries/ Strip Mines/ Gravel Pits	Transitional	Deciduous Forest	Evergreen Forest	Mixed Forest	Shrubland	Grasslands/ Herbaceous	Urban/ Recreational Grasses	Agricultural Lands in Incorporated Areas	Total Kg P
Statewide Totals	Dry Year	101,077	53,535	70,570	495	Not Calculated	2,303	14,803	1,931	2,731	217	183	36,013	39,539	323,397
	Avg Year	115,630	61,013	80,321	537	Not Calculated	2,586	17,798	2,298	3,241	260	221	41,140	75,621	400,667
	Wet Year	127,232	66,992	88,130	581	Not Calculated	2,827	21,638	2,791	3,933	316	268	45,176	125,040	484,924

Phosphorus Loading Variability and Uncertainty

In an effort to define the accuracy of the pollutant loading estimates derived from the regression equations, a comparison was completed using FLUX calculated loads for the Minneapolis Chain of Lakes watershed. This assessment was completed on the residential watersheds that had direct storm water flow from the 1991 monitoring stations. All of the sites had continuous flow measurement and flow-composite runoff samples; the data was reduced to a flow-weighted mean concentration using FLUX (MPRB, 1993; Walker, 1986). Not all of the watersheds assessed in the Chain of Lakes project are included in Table 11, as a number of them had upstream wetlands or large areas of natural land cover that attenuated the phosphorus loadings.

For purposes of this loading variability and uncertainty discussion, the loading regression equation developed for this assessment was used to calculate loads to the eight watersheds. All of the load estimates were calculated using the 1991 monitored flow volumes. The 1991 FLUX-derived loadings based upon FWMC concentrations are, for this discussion considered, the baseline loadings. Annual loadings were also estimated using the mean 1991 EMC for each specific watershed, using a national EMC for residential watersheds of 320 ug/L (Center for Watershed Protection, 2003) and the regression equation result of 326 ug/L.

The results of those calculations and assessments are presented in Table 12. The loads calculated with the national EMC for residential watersheds and the regression equation were 100.6% and 102.5% of the FLUX model loadings, respectively. The results of the regression equation are very similar to the monitored loads.

Stormwater monitoring results are highly variable and the 102.5% average variance from the 1991 monitored loads is quite good. The variance range for the Minneapolis 1991 FWMC and EMC stormwater data of 168% to 456% reflects that variability. The regression equation developed for the urban land use loads estimation explains 19% of the variance for stormwater using precipitation and impervious percentage (see Table 8).

Table 11. Chain of Lakes CWP project monitored watersheds, FLUX loadings and comparisons for alternative load estimate methodologies.

	1991 Flow Weighted Mean Concentrations (MPRB, 1993) FLUX - UNSTRATIFIED				1991 Flow Weighted Mean Concentrations (MPRB, 1993) FLOW - 2 STRATA				1991 Subwatershed Event Mean Concentrations (MPRB, 1993)				Literature Values - Residential Land Uses Mean EMC (Center for Watershed Protection, 2003)			Regression Equation Based Values Assessment of Phosphorus Sources (Barr 2003)		
Subwatershed	Q	FWMC	CV	LOAD - P kg	Q	FWMC	CV	MASS-P kg	Q	FWMC	CV	MASS-P kg	Q	EMC	LOAD kg	Q	FWMC	LOAD kg
S57-020	0.019	245	0.640	4.7	**0.019**	**338**	**0.376**	**6.4**	0.019	559	0.33	10.6	0.019	320	6.1	0.019	326	6.2
S57-100	**0.252**	**694**	**0.168**	**174.9**	0.252	688	0.299	173.4	0.252	480	0.25	121.0	0.252	320	80.6	0.252	326	82.2
S57-120	**0.041**	**219**	**0.456**	**9.0**	0.041	182	0.291	7.5	0.041	267	0.41	10.9	0.041	320	13.1	0.041	326	13.4
S54-080	0.171	263	0.407	45.0	**0.171**	**343**	**0.158**	**58.7**	0.171	413	0.33	70.6	0.171	320	54.7	0.171	326	55.7
S54-040	0.162	225	0.398	36.5	**0.162**	**156**	**0.305**	**41.5**	0.162	1360	0.38	220.3	0.162	320	51.8	0.162	326	52.8
S53-120	**0.085**	**320**	**0.303**	**27.2**	0.085	320	0.353	27.2	0.085	633	0.35	53.8	0.085	320	27.2	0.085	326	27.7
S53-160	0.212	194	0.444	41.1	**0.212**	**285**	**0.413**	**63.6**	0.212	359	0.35	76.1	0.212	320	67.8	0.212	326	69.1
S53-150	0.082	350	0.453	28.7	**0.082**	**345**	**0.434**	**28.3**	0.082	555	0.35	45.5	0.082	320	26.2	0.082	326	26.7

Notes:
Q = hm3/yr, FWMC = ug/L; Watershed land uses = mixed urban residential
Center for Watershed Protection. 2003. Impacts of Impervious Cover on Aquatic Systems. Watershed Protection Research Monograph No. 1. Center for Watershed Protection, Ellicott City, MD. Table 16.
Minneapolis Park and Recreation Board, 1993. Minneapolis Chain of Lakes Clean Water Partnership Project Phase I – Diagnostic Report. Minneapolis Park & Recreation Board, Minneapolis, MN
1991 was an wet year based upon Barr Engineering, 2003b.
Bold values used in 1991 modeling results for Chain of Lakes Phase I CWP Project

Table 12. Comparison of percent difference for FLUX derived (FWMC) loads and other load estimation methods.

SITE	FLUX LOAD - P kg	1991 EMC LOAD - P kg	% Difference vs. FLUX Load	CWP, 2003 LOAD - P kg	% Difference vs. FLUX Load	Regression LOAD - P kg	% Difference vs. FLUX Load
S57-020	6.4	10.6	165.4%	6.1	94.7%	6.2	96.4%
S57-100	174.9	121.0	69.2%	80.6	46.1%	82.2	47.0%
S57-120	9.0	10.9	121.9%	13.1	146.1%	13.4	148.9%
S54-080	58.7	70.6	120.4%	54.7	93.3%	55.7	95.0%
S54-040	41.5	220.3	531.3%	51.8	125.0%	52.8	127.3%
S53-120	27.2	53.8	197.8%	27.2	100.0%	27.7	101.9%
S53-160	63.6	76.1	119.7%	67.8	106.7%	69.1	108.7%
S53-150	28.3	45.5	160.9%	26.2	92.8%	26.7	94.5%
	Mean % Difference for Method		185.8%		100.6%		102.5%

Recommendations for Future Refinements

Refinement of the load estimate for phosphorus in urban runoff will require that additional, long-term monitoring sites be established across the state. Most of the long-term monitoring locations used for the regression equation development were located within the Twin Cities metropolitan area or other large cities. There were some out-state sites but most lacked multiple years of data or were quite old and therefore were not usable in this assessment. The lack of data for out-state sites could introduce some bias into the results due to differing watershed conditions and characteristics.

Recommendations for Lowering Phosphorus Export

The design, construction and maintenance of watershed BMPs will help reduce pollutant loads to surface waters. However, the current dependence of watershed managers and regulators upon "NURP-type" ponds will not prevent the degradation of surface water resources due to increased phosphorus loadings. While the NURP-style ponds can remove particulate phosphorus, they are relatively ineffective at removing soluble phosphorus (which can comprise up to 50% of the phosphorus in urban runoff). The phosphorus removal efficiency of ponds are also only in the 40 – 50% range, so that in many urban developments, the phosphorus load increase exceed the removal effciency of ponds. The ponds required by regulators to mediate the increased runoff therefore do not fully mitigate the increases in runoff loads. In essence the BMP treatment, whether ponds or otherwise, never keeps the post-development loadings at pre-development levels once impervious area surpasses 40 – 50% (Schueler, 1995). Another critical flaw is that many urban planners assume that urban turf grass is an effective infiltrator of runoff, when in actuality most urban turf grows on highly compacted soils and can have a runoff rate of up to 45% during large storm events (Schueler, 1996a, 1996b; Legg, *et al*, 1996). Urban soils need to be protected from compaction during development/construction activities and likewise need to be actively managed to reduce compaction and increase infiltration over the long term.

Water quality protection requires that all urban development design use a water budget approach, where the preservation of the infiltration and evapotranspiration components of the hydrologic cycle are primary considerations. Site planning that reduces impervious surface area and preserves infiltration will help attain water quality protection. Caraco, et al (1998) recommends that site design in urban areas create urban spaces that:

- reduce impervious cover
- spread runoff over pervious areas
- utilize open channel drainage
- conserve forests and natural areas
- reduce the amount of managed turf and lawn
- create more effective stream buffers and riparian areas

A number of stormwater management and urban best management practices manuals are available that provide design guidance for controlling the impacts of urban runoff and promoting infiltration (Metropolitan Council, 2001; Schueler, 1995; Brach, 1989; US EPA. 2001)

The National Pollutant Discharge Elimination System (NPDES) permit administered by the MPCA regulates runoff from construction sites, industrial facilities and municipal separate storm sewer systems to reduce the pollution and ecological damage. Phase I focused on large construction sites, 11 categories of industrial facilities, and major metropolitan MS4s. Phase II broadened the program to include smaller construction sites, small municipalities (populations of less than 100,000) that were exempted from Phase I regulations, industrial activity, and MS4s.

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Technical Memorandum

To: Hal Runke, Barr Engineering
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From: Hans Holmberg, LTI
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Subject: Assessment of Bioavailable Fractions of Phosphorus and Annual Phosphorus Discharge for Each Major Basin

Date: January 16, 2004

Project: MNBAP

cc: Dave Dilks, LTI

The purpose of this memorandum is to provide a discussion about the bioavailable phosphorus fraction of individual point and nonpoint sources of phosphorus. This discussion is based on a review of the available literature, results of POTW-specific and basin-specific sampling and analysis, and the results of basin-specific total and bioavailable phosphorus annual discharge calculations. This memorandum is intended to:

- Provide an introduction to the forms of phosphorus in the aquatic environment.
- Describe the results of the literature review for each category of point and nonpoint sources.
- Present the results of POTW-specific and basin-specific sampling and analysis for bioavailable phosphorus.
- Compare and summarize estimates of bioavailable phosphorus fraction for each source type.
- Describe methods used for developing estimates of annual phosphorus discharge for each of Minnesota’s major watershed basins.
- Present the results of the basin-specific annual discharge calculations.
- Discuss the uncertainty of the bioavailable phosphorus fraction estimates and basin-specific discharge calculations.
- Provide recommendations for future refinements of bioavailable phosphorus fraction estimates and basin-specific discharge calculations.

Introduction to Forms of Phosphorus in the Aquatic Environment

Under natural conditions, phosphorus is typically scarce in the aquatic environment. Human activities, however, have resulted in excessive loading of phosphorus into many freshwater systems. A portion of the total phosphorus concentration in surface waters is available to plants to support their growth. The available portion is commonly called bioavailable phosphorus. Excess bioavailable phosphorus in freshwater systems can result in accelerated plant growth. Phosphorus is the principal nutrient causing excessive growth of algae and other aquatic plants in Minnesota's surface waters.

Phosphorus exists in water in either a dissolved phase or a particulate phase. Dissolved phosphorus is operationally-defined as passing a 0.45 µm filter. Dissolved phosphorus in natural waters is usually found in the form of phosphates (PO_4^{-3}). Dissolved phosphates exist in three forms: inorganic (commonly referred to as orthophosphate or soluble reactive phosphorus- SRP), inorganic polyphosphate (or metaphosphate) and organically bound phosphate. Particulate phosphorus contains phosphorus sorbed to inorganic (mineral) and organic particles, including phosphorus contained within algae. Dissolved inorganic phosphate (orthophosphate) is the form required by plants for growth. Animals can utilize either organic or inorganic phosphate. The analytical procedure for measuring total phosphorus, which includes a sulfuric acid extraction, accounts for all forms of phosphorus, both dissolved and particulate, including phosphorus contained in algae.

Orthophosphates are immediately available in the aquatic environment for algal uptake. Natural processes produce orthophosphates, but major man-influenced sources include: partially treated and untreated sewage; runoff from agricultural sites; and application of some lawn fertilizers. Orthophosphate concentrations in a water body vary widely over short periods of time as plants take it up and release it.

Polyphosphates are used for treating boiler waters and in detergents. Also, polyphosphates are used in drinking water treatment in many municipalities. In water, polyphosphates are unstable and will eventually convert to orthophosphate and become available for plant uptake.

Organic phosphates (particulate and dissolved) are bound or tied up in plant or animal tissue, waste solids, or associated with other organic matter. Organic phosphates are formed primarily by biological processes. They are contributed to sewage by body waste and food residues, and also may be formed from orthophosphates in biological treatment processes or by receiving water biota. After decomposition, the organic form can be converted to orthophosphate as a result of microbially-induced mineralization of phosphorus-containing organic matter.

Not all forms of phosphorus are utilized to the same degree or at the same rate by plants and microbial communities. Association of phosphorus with particulate or organic matter reduces bioavailability; such forms of phosphorus are immediately unavailable for uptake by algae. While a significant amount of phosphorus can enter water bodies in an immediately unavailable form, there is the potential for this unavailable phosphorus to undergo physical or chemical cycling process that may convert it (all or partially) to the readily bioavailable form of phosphorus, orthophosphate. For example, the decomposition of organic matter by microbial activities can result in mineralization of phosphorus to orthophosphate. Desorption or dissolution of particle-associated phosphate represents another mechanism of conversion from unavailable to bioavailable forms.

In an assessment of the biological effects of phosphorus, it is important to consider the rate at which unavailable forms of phosphorus become bioavailable within the receiving waters. This is true, since the rate of conversion of unavailable but potentially-bioavailable phosphorus to readily bioavailable phosphorus competes in time with the rate of other processes, for example: adsorption; precipitation; sedimentation; and dilution. Though readily bioavailable phosphorus, orthophosphate, is directly responsible for plant growth, total phosphorus is an equally important indicator of a water body's nutrient status because of these internal cycling processes.

DePinto *et al*. (1986) characterized phosphorus into three forms: orthophosphate – immediately bioavailable for algal uptake; external ultimately-available phosphorus – not immediately available but ultimately converted to orthophosphate at a specific rate; and external refractory phosphorus – not available while in the water column. Total bioavailable phosphorus is then comprised of orthophosphate and the external ultimately-available phosphorus. It is indeed the bioavailable phosphorus that affects the algal production in the aquatic environment in combination with other nutrients (e.g. nitrogen and silicon), light, and temperature. Methodologies for the analysis of the bioavailable phosphorus content of water samples are presented in Attachment A.

Within the aquatic environment, plants, algae, and animals take in orthophosphate and convert it to organic phosphorus as it becomes part of their tissues. After algal death, the phosphorus associated with the minimum cell quota becomes unavailable and the phosphorus that is in excess of internal level becomes readily bioavailable (Bierman *et al.*, 1980). The unavailable form can remain in water or can settle to the bottom, where bacterial decomposition converts it back to inorganic phosphorus. This inorganic phosphorus re-enters the water column when the bottom gets stirred up by animals, chemical interactions, and water currents. Then it is taken up by plants and the cycle begins again.

Bioavailable Phosphorus Fractions in Individual Point and Nonpoint Sources of Phosphorus

Different sources provide water bodies with a variety of the forms of phosphorus described above, in variable proportions. Phosphorus in lakes and streams comes from both point and nonpoint sources. Point sources are typically publicly-owned wastewater treatment plants (POTWs) and permitted industrial discharges. Point sources usually have distinct pipe discharges to surface water and are regulated under state and federal water pollution permit programs. Phosphorus discharged from wastewater treatment plants may come into the plant from a variety of sources. Nonpoint sources are typically polluted runoff from cities and farmland, erosion and sedimentation, atmospheric deposition, direct input by animals and wildlife, and natural decomposition of rocks and minerals. Nonpoint sources do not have distinct discharge points and are not typically regulated under State water pollution permit programs.

A comprehensive literature search and review was conducted to compile available information on the bioavailable phosphorus fractions of individual point and nonpoint sources of phosphorus to surface waters. The results of this literature review are presented in the following discussion.

Bioavailable Phosphorus in POTW Effluent

The bioavailable phosphorus fraction in POTW effluent is generally assumed to be high compared to that of other sources to surface waters (Lee *et al.*, 1980). Young *et al*. (1982) sampled the effluent from four municipal treatment plants in the vicinity of the Great Lakes during the summer of 1979 for bioavailable phosphorus. They conducted bioassays where measurement of phosphorus taken up by *Scenedesmus* sp. provided the measure of bioavailable phosphorus fraction. They developed a series of relationships among different forms of phosphorus. The following is a summary of those relationships.

On average, 82% of the dissolved phosphorus was bioavailable in the short term (less than 30 days from sample collection). The relationship was:

$$BADP = 0.82\ TDP - 0.03$$

where: *BADP* is the bioavailable dissolved phosphorus and *TDP* is the total dissolved phosphorus.

Orthophosphate was a major component of the dissolved phosphorus (69% on average). Moreover, the regression coefficient relating bioavailable dissolved phosphorus to orthophosphate was unity, indicating that the orthophosphate fraction was totally available.

For particulate phosphorus, they found that the bioavailable particulate phosphorus correlated closely with the total particulate phosphorus fractions. On average (with the samples taken from the effluent of the four wastewater treatment plants), 55% of the total particulate phosphorus was bioavailable in the short term (again, less than 30 days). The relationship was:

$$BAPP = 0.55\ TPP + 0.02$$

where: *BAPP* is the bioavailable particulate phosphorus and *TPP* is the total particulate phosphorus.

The relationship between the ultimately bioavailable dissolved phosphorus (became bioavailable after 30 days) and total dissolved phosphorus was:

$$UADP = 0.99\ TDP - 0.04$$

where: *UDAP* is the ultimately bioavailable dissolved phosphorus and *TDP* is the total dissolved phosphorus.

The relationship between the ultimately bioavailable particulate phosphorus and total particulate phosphorus was:

$$UAPP = 0.63\ TPP + 0.013$$

where: *UAPP* is the ultimately bioavailable particulate phosphorus and *TPP* is the total particulate phosphorus. This relationship was obtained when bioavailable phosphorus was regressed on total particulate phosphorus for raw influent, biological effluent, and final effluent of the wastewater treatment plants.

The relationship between the ultimately available phosphorus and total phosphorus was:

$$UAP = 0.83\ TP + 0.035$$

where: *UAP* is the ultimately available phosphorus and *TP* is the total phosphorus.

Data from the wastewater treatment plants indicated that 83% of the total wastewater phosphorus in those effluent samples was ultimately available.

Results of Bioavailable Phosphorus Sampling of Minnesota POTWs

In addition to the information gathered from the literature review, effluent from eight Minnesota POTWs was sampled between October 13 and October 17, 2003. Grab samples were collected by Barr Engineering with facilitation from the MPCA. The samples were analyzed for total phosphorus and orthophosphate. The ultimately bioavailable particulate phosphorus was estimated using the relationship developed by Young *et al*. (1982) described above.

The results of this analysis are presented in Table 1. The bioavailable phosphorus fraction in these samples ranged from 75-96%, with an average of 85.5%, which is typical for POTW effluents based on the results of the literature review. Measured particulate phosphorus concentrations also are consistent with expected range based on the literature. Chemical and biological phosphorus removal is implemented at all of these POTWs with the exception of Albert Lea and Wilmar. Albert Lea and Wilmar also have industrial discharges to the POTW that contain high phosphorus levels.

Table 1: Estimated bioavailable phosphorus (BAP) fractions of samples collected from the final effluent of eight Minnesota POTWs.

City	TSS (mg/L)	Total P mg/L)	Orthophosphate (mg/L)	Particulate P (mg/L)	Ultimately Bioavailable Particulate P (mg/L) [0.63TPP+0.013]	Particulate BAP fraction	Total BAP fraction
Albert Lea	<5.0	5.32	4.31	1.01	0.65	0.64	0.93
Alexandria	<5.0	0.187	0.102	0.085	0.07	0.78	0.90
St. Cloud	<5.0	0.250	0.068	0.182	0.13	0.70	0.78
Fergus Falls	<5.0	0.166	0.019	0.147	0.11	0.72	0.75
Mankato	11	2.04	1.57	0.47	0.31	0.66	0.92
MCES-Metro	<5.0	0.293	0.130	0.163	0.12	0.71	0.84
Rochester	13	0.948	0.286	0.662	0.43	0.65	0.76
Wilmar	10	7.24	6.41	0.83	0.54	0.65	0.96

Bioavailable Phosphorus in Runoff

The contribution of phosphorus from nonpoint sources of runoff has rarely been clearly defined, largely because point sources are often the major and more controllable source of phosphorus loads (Sharpley *et al*., 2000). In addition, phosphorus losses in land runoff are difficult to quantify due to their diffuse nature. The transfer of phosphorus from terrestrial to aquatic systems in runoff can occur in dissolved and particulate forms. Phosphorus loading from nonpoint sources depends on a large number of factors, such as geology and hydrology of the region, land use, and population density. For example, sandy soils have less retention of phosphorus than clays and high slope and high runoff lead to lower retention.

Caraco (1995) found that population density was related to orthophosphate export from watersheds and predicted 47% of the variation in orthophosphate export in the dataset from 32 large rivers. Other variations could be related to the geochemical factors that alter orthophosphate in rivers or could be due to variability in human behaviors that lead to variable phosphorus export. For example, human agricultural practices, soil composition, diets, detergent use, and extent of sewer services and sewage treatment can vary greatly between different areas. Phosphorus loss from land not only affects the surface runoff, but also gets transferred in subsurface flow (Gaynor and Findley, 1995; Lennox *et al*., 1997; Haygarth *et al*., 1998; and Withers *et al*., 1999).

It has been shown that the orthophosphate concentration in surface runoff is related to the soil phosphorus concentration in the topsoil (McDowell and Sharpley, 2001). For example, Pote *et al*. (1996) found that that the orthophosphate concentration in surface runoff was linearly related to phosphorus extracted by Mehlich-3 (r^2 of 0.72), Bray-I (r^2 of 0.75), Olsen (r^2 of 0.72), distilled water (r^2 of 0.82), iron oxide paper (r^2 of 0.82), acidified ammonium oxalate (r^2 of 0.85), and phosphorus sorption saturation (r^2 of 0.77).

Surface runoff from grassland, forest land or nonerosive soils carries little sediment and is generally dominated by dissolved phosphorus, although phosphorus transport attached to colloidal material also may be important where land is overstocked (Haygarth and Jarvis, 1997; Simrad *et al*., 2000). Sharpley *et al*. (1995) also reported that runoff from grass and forestland carries little sediments, and is therefore, generally dominated by orthophosphate.

As reported by Sharpley *et al*. (1995), the discharge of organic and inorganic phosphorus in runoff from several Atlantic Coastal Plain watersheds was related to soil phosphorus composition. The high organic phosphorus content of forest soils (331 mg/kg; 70% of total phosphorus) contributed 51% of total phosphorus loss in runoff (0.31 kg/ha/y) as particulate organic phosphorus and 10% as dissolved organic phosphorus. For agricultural soils of lower organic phosphorus content (161 mg/kg, 25% of total phosphorus), only 32% of total phosphorus loss in runoff (2.41 kg/ha/y) was particulate organic phosphorus and 1% was dissolved organic phosphorus (Vaithiyanathan and Correll, 1992). Similarly, from 16 to 38% of phosphorus in runoff from Polish meadows and cultivated fields and as much as 70% of lake water phosphorus was bound to organic compounds (Szpakowska and Zyczynska-Baloniak, 1989). These losses varied seasonally, with both inorganic and organic phosphorus concentrations in canal and lake water decreasing during summer months (Ryszkowski *et al.*, 1989).

Estimates for urban runoff particulates, tributary particulates and lake sediments in the lower Great Lakes basins by bioassay methods have reported an average of 30% bioavailable phosphorus (Cowen and Lee, 1976; Williams *et al*., 1980).

Bioavailable Phosphorus in Agricultural Runoff

The sources of phosphorus from agricultural land can include soil phosphorus, manure or fertilizer applications. Those sources of phosphorus emanate from a number of source areas within the landscape and their amount, form, and timing are very variable as a result of short-term and often unpredictable changes in hydrological conditions and farming practices, including crop rotation, the application of fertilizers and manures, or the movement of animals from one field to another (Lennox *et al.*, 1997).

Phosphorus may be transported to a water body from agricultural lands by leaching, runoff or erosion. The loss of phosphorus in surface runoff from agricultural lands occurs as particulate and dissolved forms (Haygarth and Sharpley, 2000). Particulate phosphorus includes phosphorus associated with soil particles and large molecular-weight or organic matter eroded during flow events and constitute the major proportion of phosphorus transported from most cultivated lands (60-90%, Pietilainen and Rekolainen, 1991).

Several studies have reported that the loss of dissolved phosphorus in surface runoff from agricultural land depends on the phosphorus content of surface soil (STP- soil test P concentration), but that the relationship varies with soil type, tillage, and crop management (Pote *et al.*, 1996; Sharpley *et al.*, 1996). Moreover, it will depend on the topography and soil hydrology.

James *et al.* (2002) used fractionation procedures and phosphorus adsorption-desorption assays to delineate bioavailable forms and refractory or unavailable forms of phosphorus in the runoff of the Redwood River basin, an agriculturally-dominated tributary of the Minnesota River. Over several storm periods monitored in 1999, 75% of the phosphorus load originating from the watershed was in bioavailable forms while only 25% was in refractory forms. Bioavailable particulate forms included phosphorus loosely bound to suspended sediments (19%), phosphorus bound to iron (11%), and bioavailable particulate organic phosphorus (14%). After runoff discharges to receiving waters, the former two forms of bioavailable particulate phosphorus can be transformed to dissolved forms that are available to biota for uptake via eH and pH reactions and kinetic processes, while the latter form can be mineralized via decomposition processes. Bioavailable dissolved forms included orthophosphate and dissolved organic phosphorus.

Several studies have suggested that agricultural management may influence the bioavailability of phosphorus transported in runoff (McDowell and McGregor, 1980; Wendt and Corey, 1980). Concentration and amounts of bioavailable phosphorus in runoff from corn (*Zeamays* L.) were lower from no till compared to conventionally tilled plots under simulated rainfall (Andraski *et al.*, 1985; Mueller *et al.*, 1984). Bioavailable phosphorus in these studies was measured by resin extraction of unfiltered runoff, and thus includes dissolved phosphorus plus phosphorus desorbed from sediment (Huettl *et al*., 1979). However, Andraski *et al*. (1985) calculated that bioavailable phosphorus averaged 20% of total phosphorus and was not affected by tillage treatment.

Sharpley *et al*. (1992) assessed the impact of agricultural practices on phosphorus bioavailability in runoff by determining dissolved phosphorus, bioavailable particulate phosphorus, and particulate phosphorus in runoff from 20 watersheds (in the Southern Plains region of Oklahoma and Texas) unfertilized and fertilized, grassed and cropped watersheds over a 5-yr period. Although bioavailable phosphorus and bioavailable particulate phosphorus losses in runoff were reduced by agricultural practices minimizing runoff and erosion, the proportion of phosphorus transported in bioavailable forms increased. Both total phosphorus (14-88% as bioavailable phosphorus) and particulate phosphorus (9-69% as bioavailable particulate phosphorus) bioavailability varied appreciably with agricultural practices. Thus, bioavailable phosphorus is a dynamic function of physical and chemical processes controlling both dissolved phosphorus and bioavailable particulate phosphorus transport. Dissolved phosphorus transport depends on desorption-dissolution reactions controlling phosphorus release from soil, fertilizer reaction products, vegetative cover, and decaying plant residues. Bioavailable particulate phosphorus is a function of physical processes controlling soil loss and particle-size enrichment and chemical properties of the eroded soil material governing phosphorus sorption availability. The authors also found that the percent bioavailability of particulate phosphorus transported in runoff from each of these watersheds decreased with an increase in sediment concentration of runoff averaged for each watershed. They found a linear regression relationship between particulate phosphorus availability and logarithm of sediment concentration (with r^2 =0.84):

$$\textit{Particulate Phosphorus Bioavailabilty}\ (\%) = 82 - 15 \log \textit{sediment conc.}\ (g/L)$$

This relationship may be attributed to an increased transport of silt- and sand-sized (>2 μm) particles, of lower phosphorus content than finer clay-sized (<2 μm) particles, as sediment concentration of runoff increases. Further, particulate phosphorus bioavailability may decrease with an increase in size of eroded soil particles, which contain less sorbed phosphorus and more primary mineral phosphorus (i.e., apatite) of lower availability compared with finer clay-sized particles (Dorich *et al*., 1984; Sharpley *et al*., 1981; Syers *et al*., 1973).

O'Connor *et al*., (2002) compared phosphorus bioavailability of biosolids, manures and fertilizer. They found that phosphorus bioavailability was greater for phosphorus-fertilizer than manures and biosolids. However, if biological phosphorus removal is implemented in the treatment process, phosphorus in biosolids tends to be as bioavailable (74% to 132%) as fertilizer phosphorus. Note that values greater 100% are a result of the uncertainty in the analytical methods used to measure phosphorus forms.

A study conducted by Ekholm and Krogerus (2003), with samples from different sources, concluded that phosphorus in agricultural runoff appeared to be more bioavailable to algae (31%) than phosphorus in forest runoff (16%).

Bioavailable Phosphorus in Atmospheric Deposition

The contribution of phosphorus in rainfall can play an important part in the phosphorus cycle of oligotrophic sites (Carlisle *et al*. 1966; Miller 1961). For Lake Michigan, Murphy and Doskey (1975) reported a 30-fold greater total phosphorus concentration in rainfall than in lake water. Since 25-50% of the total phosphorus in rainfall is soluble, it is directly available to organisms in the lake (Murphy and Doskey 1975; Peters 1977). As a result, most of the enrichment of Clear Lake, Ontario (Schindler and Nighswander 1970) and of several Wisconsin Lakes (Lee 1973) has been attributed to rainfall (Sharpley *et al*. 1995).

The bioavailability of dry deposition or the particulate fraction of wet deposition can be characterized by the bioavailability of phosphorus in the soils in the region.

Increases in the atmospheric deposition of phosphorus may result from annual climatic changes (Sharpley *et al*. 1995). For example, the input of phosphorus in rainfall to an Oklahoma watershed in 1981 (208 g/ha/yr) was much greater than that in either 1982 (49 g/ha/yr) or 1983 (41 g/ha/yr) (Sharpley *et al*. 1985). This increase was attributed to the low annual rainfall in 1980 (642 mm, 105 mm below average). The drier soil was more susceptible to wind erosion and the airborne material increased the phosphorus content of subsequent rainfall and dry deposition.

Comparison of Phosphorus Bioavailability from Different Sources

Many forms of particulate matter in the waters of the State of Minnesota contain a certain amount of bioavailable phosphorus, the actual rate and extent of release of the bioavailable component depends on the physical and chemical characteristics of the material. It also depends on the biological characteristics as well, as the population of the micro-organisms in the suspended material mineralizes the organic detritus material. Young *et al*. (1995) have compared the relative bioavailability of particulate phosphorus from various sources to the Great Lakes by comparing the bioavailable phosphorus in particulate matter from point sources (wastewater suspended solids), and nonpoint sources (suspended solids and bottom sediments from tributaries, lake bottom sediments, and eroding bluff solids from the region). A wastewater treatment plant at Ely, Minnesota was also sampled and it showed the highest rate of release of bioavailable particulate phosphorus (0.27 grams released/gram particulate phosphorus/day, or 0.27/day) among the point and nonpoint sources sampled in that study (Young and DePinto, 1982). The release rate did appear to decline in magnitude as treatment of wastewater progressed from the raw influent → biologically treated effluent → final effluent (i.e., 0.30 /day → 0.27 /day → 0.20 /day). Young and DePinto (1982) summarized the results on relative bioavailability of particulate phosphorus for the point and nonpoint sources (Table 2).

Table 2: Relative bioavailability of particulate phosphorus from various sources to the lower Great Lakes (Young and DePinto 1982)

With respect to total particulate phosphorus:
Wastewater (≤ 80%)
Bottom sediments (≤ 50%)
Tributary suspended sediment (≤ 40%)
Eroding bluff (~0)
With respect to rate of release:
Wastewater (≤ 0.4 /day)
Tributary suspended sediment (≤ 0.2 /day)
Bottom sediment (≤ 0.1 /day)
Eroding bluffs (~ 0)

Ekholm and Krogerus (2003) analyzed 172 samples (during 1990-2000) representing phosphorus in point and nonpoint sources and in lacustrine matter. The bioavailability of phosphorus expressed as the proportion of potentially bioavailable phosphorus ranged from 3.3 to 89% (Table 3).

Table 3: Proportion of bioavailable phosphorus in total phosphorus by different sources (Ekholm and Krogerus 2003).

	Bioavailable P (% of Tot-P)	
Source	**Mean**	**Min.-Max.**
Wastewater effluent from rural population	89	74-98
Biologically treated urban wastewater effluent	83	61-103
Dairy house wastewater	69	27-93
Biologically and chemically treated wastewater effluent	36	0-67
Field runoff	31	15-50
Industrial wastewater effluent	30	4-89
Fish fodder and feces	29	9-72
Large Rivers water	20	3-45
Agricultural rivers	20	12-30
Field surface soils	19	6.8-24
Forest runoff	16	0-55
Lake settling matter	7.9	1.6-21
Lake bottom sediments	3.3	0.1-11

Summary of Literature Review

The above review covers as much research and data from phosphorus bioavailability studies as could be found in the available time and resources. There is a desire to estimate the fraction of phosphorus in each potential source category identified by the MPCA as contributing phosphorus to Minnesota waters. However, the bioavailability of some of these individual source categories has not been studied; therefore, we were not able to find directly applicable estimates for bioavailable fractions in the literature. The general categories for which data are available include: municipal wastewater treatment plants, agricultural, forest and urban runoff, and atmospheric deposition.

While the dissolved phosphorus from any of these sources can generally be assumed to be 100% bioavailable, the particulate phosphorus associated with these various source categories in general exhibit a wide range of bioavailability.

For point sources, the fraction of total phosphorus in the discharge that is bioavailable is not only governed by the sources of phosphorus to the treatment plant influent (e.g., human wastes, household cleaners, groundwater infiltration, etc.) but it will be dependent on the treatment train being employed within the plant. Data are generally available for wastewater treatment plant influent and effluent, however not for all individual phosphorus source categories. Knowing, however, that household cleaners and detergents are amended with polyphosphates, it is reasonable to assume that virtually 100% of these categories will ultimately become available by hydrolysis to orthophosphates.

For nonpoint sources, the input of total phosphorus and bioavailable phosphorus will be strongly dependent on the land use from which the phosphorus load is derived (e.g., agricultural runoff will be different from forestland runoff). Furthermore, agricultural practices can affect bioavailable phosphorus appreciably. Another determinant is the surficial geology within the watershed. We have seen, for example, that phosphorus associated with calcareous minerals like apatite is much less bioavailable than phosphorus adsorbed to iron-oxide minerals. At any rate the particulate phosphorus in non-point sources derived from land runoff tends to be less bioavailable than point source particulate phosphorus.

Bioavailable phosphorus fractions for each of the specific source categories of interest were estimated by combining the results of the literature review with best professional judgment to specify a most likely value for a number of the phosphorus source categories listed by the MPCA as being of interest. A range was also estimated in an attempt to cover the potential range site-specific determinations might show. These estimates are presented in Table 4. These estimates of bioavailable fraction should be used with care, understanding the uncertainty inherent in each estimate. Nevertheless, they can be used to assess relative contributions of bioavailable phosphorus from the source categories to assist in planning additional data collection or targeting specific sources for control.

As evident from the literature review, wide ranges of bioavailable fractions were noted for runoff sources, while estimation techniques for the bioavailable fraction from POTW effluent were better quantified. Future refinements to the estimation of bioavailable fractions of various phosphorous sources would be benefited by additional sample collection and analysis to best represent the source of interest.

Table 4. Estimates of Bioavailable Phosphorus Fractions for Specific Source Categories.

Phosphorus Sources			Fraction of PP that is Bioavailable (Range)	Fraction of PP that is Bioavailable (Most Likely)	Fraction of DP that is Bioavailable (Most Likely)	Fraction of TP that is Particulate (Most Likely)	Estimate of TP that is Bioavailable (Most Likely)
Point Sources	Phosphorus Sources to POTWs	Automatic Dishwasher Detergent	NA	NA	1.0	0.0	1.0
		Dentifrices (toothpastes)	0 – 0.1	0.05	NA	1.0	0.05
		Other Household Cleaners or Non-ingested Sources	NA	NA	1.0	0.0	1.0
		Food Soils/Garbage Disposal Wastes	0.7 – 0.9	0.8	1.0	0.9	0.8
		Human Waste Products	0.7 - 0.9	0.8	1.0	0.3	0.94
		Raw/Finished Water Supply	0.4 - 0.6	0.5	1.0	0.1	0.95
		Groundwater Intrusion (I&I)	0.2 - 0.5	0.3	1.0	0.5	0.65
		Process Water	0.2 - 1.0	0.7	1.0	0.1	0.97
		Noncontact Cooling Water	0.4 - 0.8	0.6	1.0	0.3	0.88
		Car Washes	0.2 - 0.8	0.5	1.0	0.3	0.85
	POTW Effluent		0.6 – 0.8	0.7	1.0	0.5	0.855
	Privately Owned Wastewater Treatment Systems for Domestic Use (effluent)		0.6 - 0.9	0.8	1.0	0.3	0.94
	Commercial/Industrial Wastewater Treatment Systems (effluent)		0.2 - 0.8	0.6	1.0	0.3	0.88

Phosphorus Sources			**Fraction of PP that is Bioavailable (Range)**	**Fraction of PP that is Bioavailable (Most Likely)**	**Fraction of DP that is Bioavailable (Most Likely)**	**Fraction of TP that is Particulate (Most Likely)**	**Estimate of TP that is Bioavailable (Most Likely)**
Non-Point Sources	Individual Sewage Treatment Systems		0.6 - 0.9	0.8	1.0	0.2	0.96
	Agricultural Runoff	Improperly Managed Manure	0.5 - 0.7	0.6	1.0	0.5	0.80
		Crop Land Runoff	0.2 - 0.7	0.4	1.0	0.7	0.58
	Urban Runoff	Turfed Surfaces	0.2 - 0.7	0.4	1.0	0.7	0.58
		Impervious Surfaces	0.10 - 0.5	0.2	1.0	0.5	0.60
	Forested Land		0.2 - 0.5	0.3	1.0	0.8	0.44
	Roadway and Sidewalk Deicing Chemicals	salt	0.2 - 0.8	0.6	1.0	0.2	0.92
		sand	0.1 - 0.3	0.2	1.0	0.8	0.36
	Stream Bank Erosion		0.1 - 0.5	0.3	1.0	0.8	0.44
	Atmospheric Deposition	Dry	0.05 – 0.4	0.2	NA	1.0	0.2
		Wet	0.05 – 0.4	0.2	1.0	0.6	0.5

Basin-wide Annual Phosphorus Discharge Calculations

Basin-specific analyses of existing hydrologic and water quality data were conducted to develop estimates of the annual total and bioavailable phosphorus discharge for each of the major Minnesota surface water basins. All annual calculations were based on the water year (October-September). While these calculations do not provide direct information on the specific point and nonpoint sources contributing to each basin, they can be used in a number of ways: 1) provide a check on the sum of point and nonpoint phosphorus loads for each basin; 2) provide a relative comparison between basins of annual phosphorus loads, yields, and ambient surface water concentrations and compare to land uses in the basins; and 3) provide some initial understanding of the relative water quality benefits to be gained by phosphorus source controls.

Methodology

For each major basin, basin-specific characteristics and data were compiled and analyzed. This information included drainage area and approximate land cover percentages as presented in separate technical memorandums for this project. Land uses were taken from USGS National Land Cover Database (1992). Soil phosphorus content for each major basin was estimated from soil phosphorus data compiled by Dr. Mulla at the University of Minnesota, Department of Soil, Water and Climate. Bray phosphorus values for all counties except Anoka (no data available there) were available in GIS format. Bray-P values were converted to soil total phosphorus content using the following two-step conversion provided by Dr. Mulla:

To covert to Bray-P to soil total phosphorus content:

$$\text{Olsen-P} = 0.7117 * (\text{Bray-P})$$

$$\text{Soil Total Phosphorus Content [mg/kg]} = 3.3173 * (\text{Olsen-P}) + 453.79$$

The conversion of Bray-P to total phosphorus is applicable on a state-wide basis. Soil total phosphorus content values were then area-weighted and used to calculate area-weighted average soil total phosphorus content for each major basin. The results of this analysis are presented in Table 5.

Table 5: Average soil phosphorus content for each Basin in Minnesota.

Major Basin	Area (sq. mi.)	Area-weighted Bray-P	Area-weighted Average Soil Total Phosphorus Content (mg/kg)
Cedar River	1,028	32.21	529.84
Des Moines River	1,535	23.04	508.18
Lake Superior	6,149	28.91	522.04
Lower Mississippi (Below St. Croix)	6,317	39.35	546.69
Minnesota River	14,933	24.37	511.33
Missouri	1,782	13.69	486.10
Rainy River	11,236	25.65	514.36
Red River	17,741	18.02	496.34
St. Croix River	3,528	41.19	551.03
Upper Mississippi (Above St. Croix)	20,100	29.70	523.90
Statewide	84,349	26.48	516.30

Representative USGS flow gauges were selected for each basin. These gauges are a subset of the gauges selected for analyses of hydrologic conditions, as presented in the Basin Hydrology Technical Memorandum. Flow rate and water quality data were compiled for these gauges. Water quality data available from the Minnesota Pollution Control Agency (MPCA) was also compiled for water quality sampling locations at or near the representative USGS gauging stations. This data included results of queries of the Environmental Data Access (EDA) database, available on-line and containing data for calendar years 1985-1992. MPCA queries of recent STORET data provided a third source of water quality data. Finally, data from the USGS Long Term Resource Monitoring Program (LTRMP) were compiled for stations in the Lower Mississippi basin. Parameters of interest included suspended sediment (analyzed as either suspended sediment concentrations (SSC)), total nonfilterable residue or total suspended solids (TSS)), total phosphorus (TP), and total dissolved phosphorus or orthophosphate (both assumed to represent total dissolved phosphorus (TDP) for this analysis). Water quality data collected from 1979 to the present were considered for use in these analyses.

When available data permitted, concurrent flow suspended sediment, total phosphorus, and total dissolved phosphorus data were plotted and a simple power function was fit to the data ($y=aQ^b$). While more complex methods are available for developing rating curves, the power function has proven to be an efficient means of relating suspended sediment and phosphorus concentrations to flow (Dolan *et al*., 1981; Asselman, 2000; and Horowitz, 2002). Best professional judgment was used to determine whether the relationship was better represented by a simple average of the water quality parameter when the correlation coefficient for the fitted power function was very small (typically less than 0.1).

Following the development of rating curves for solids, total phosphorus, and total dissolved phosphorus, the fitted power equations, and in some cases simple averages, were applied to calculate concentrations for daily flow values for the water years identified as representing low, average and high flow conditions in each watershed. Particulate phosphorus was calculated as the difference between the total phosphorus and total dissolved phosphorus predictions. If sufficient total dissolved phosphorus or orthophosphate measurements had not been available to develop a rating curve, particulate phosphorus concentrations could have been estimated by multiplying the predicted suspended sediment concentration by the soil total phosphorus content for that basin, and then adjusting the resulting value with a potency factor. The potency factor is a site-specific calibration parameter accounting for such things as land use and agricultural practices.

When sufficient data was available for TP and TDP rating curves:

Total Particulate Phosphorus (TPP) = TP – TDP

When insufficient data for TDP rating curves:

*TPP = Suspended Sediment (SS) * Soil Phosphorus Content * Potency Factor (PF)*

Bioavailable fraction of particulate phosphorus was estimated based on the results of the literature review and the recent water quality data collected as part of this project. The literature review produced values ranging from 5% to 40% of suspended sediment particulate phosphorus being bioavailable (see Attachment B for more details). Between September 24, 2003 and October 21, 2003, MPCA, with facilitation from Barr, collected one 10-liter stream sample from each of the ten major watersheds and analyzed the samples using a base-extractable inorganic P testing procedure adapted from Young *et al*. (1988). The results of these analyses are presented in Table 6.

These watershed-specific samples resulted in a range of 3%-31% of particulate phosphorus as bioavailable, consistent with the literature review results. Because a single sample from each watershed does not provide much certainty, a statewide average value of 18% was applied in the calculations.

Subsequent to calculating the solids and phosphorus concentrations and fractions bioavailable, the daily mass loading rates were calculated using flow and concentration and then summed over the water years of interest.

Table 6: Estimated BAP fractions of samples collected from ten Minnesota rivers.

Basin/Date/ Location/ID	Solids, total suspended (mg/L)	Phosphorus, total (mg/l)	Particulate Phosphorus (mg total P/g dry weight solids)	Orthophosphate (mg/L)	Particulate Phosphorus, NaOH Extractable (mg/l)	Particulate NaOH Extractable Phosphorus (mg of NaOH extractable P/g dry weight solids)	Bioavailable Particulate P (mg P/g) [(Ultimately avail PP = 1.08 NaOH -P-0.008)]	Bioavailable Particulate Phosphorus Fraction
Lake Superior Basin								
Date: 10/13/2003								
BRULE R UPSTRM OF US-61 AT JUDGE CR MAGNEY PARK								
BRU-0.4	<5.0	**0.014**		<0.006	--			
BRU-0.4 Solids	<100	**0.185**	**2.8**	--	**0.012**	**0.106**	0.11	0.038
BRU-0.4 Solids	<100	**0.149**	**2.25**	--	**0.007**	**0.063**	0.06	0.027
BRU-0.4 Solids	<100	**0.169**	**2.55**	--	**0.007**	**0.063**	0.06	0.024
							Average =	3%
Cedar River Basin								
Date: 10/08/2003								
CEDAR RIVER AT CSAH-4, 3 MILES SOUTH OF AUSTIN								
CD-10	**48**	**0.694**		**0.570**	--			
CD-10 Solids	**740**	**7.69**	**10.4**	--	**0.171**	**1.4**	1.49	0.143
CD-10 Solids	**830**	**7.71**	**9.3**	--	**0.217**	**1.6**	1.69	0.182
CD-10 Solids	**1300**	**7.47**	**5.7**	--	**0.435**	**2.0**	2.16	0.376
							Average =	23%
Minnesota River Basin								
Date: 10/14/2003								
MINNESOTA R UNDER LANDING LIGHTS FT. SNELLING PK								
MI-3.5	**18**	**0.124**	**--**	**0.037**	--			
MI-3.5 Solids	**1200**	**5.43**	**4.5**	--	**0.089**	**0.4**	0.47	0.104
MI-3.5 Solids	**1100**	**5.29**	**4.8**	--	**0.079**	**0.4**	0.46	0.095
MI-3.5 Solids	**1100**	**5.40**	**4.9**	--	**0.080**	**0.4**	0.46	0.094
							Average =	10%

Basin/Date/ Location/ID	Solids, total suspended (mg/L)	Phosphorus, total (mg/l)	Particulate Phosphorus (mg total P/g dry weight solids)	Orthophosphate (mg/L)	Particulate Phosphorus, NaOH Extractable (mg/l)	Particulate NaOH Extractable Phosphorus (mg of NaOH extractable P/g dry weight solids)	Bioavailable Particulate P (mg P/g) [(Ultimately avail PP = 1.08 NaOH -P-0.008)]	Bioavailable Particulate Phosphorus Fraction
Red River Basin								
Date: 10/12/2003								
OTTER TAIL R BRIDGE ON 4TH ST N AT BRECKENRIDGE								
OT-RIV	**12**	**0.036**	**--**	<0.006	--			
OT-RIV Solids	**1400**	**1.61**	**1.2**	--	**0.073**	**0.3**	0.33	0.287
OT-RIV Solids	**1300**	**1.60**	**1.2**	--	**0.037**	**0.2**	0.18	0.143
OT-RIV Solids	**1300**	**1.62**	**1.2**	--	**0.037**	**0.2**	0.18	0.142
							Average =	14%
Lower Mississippi River Basin								
Date: 09/24/2003								
ROOT RIVER AT BRIDGE ON MN-26 3 MI EAST OF HOKAH								
RT-3	**15**	**0.054**	**--**	**0.037 h**	--			
RT-3 Solids	**1500**	**2.12**	**1.4**	--	**0.044**	**0.2**	0.18	0.129
RT-3 Solids	**1600**	**2.12**	**1.3**	--	**0.048**	**0.2**	0.19	0.141
RT-3 Solids	**1600**	**2.00**	**1.3**	--	**0.042**	**0.2**	0.16	0.130
							Average =	13%
Lake Superior Basin								
Date: 10/13/2003								
ST LOUIS RIVER AT BRIDGE ON MN-23 AT FOND DU LAC								
SL-9	<5.0	**0.029**	**--**	**0.006**	--			
SL-9 Solids	**190**	**0.508**	**2.7**	--	**0.024**	**0.8**	0.81	0.303
SL-9 Solids	**140**	**0.479**	**3.4**	--	**0.023**	**1.0**	1.06	0.309
SL-9 Solids	**140**	**0.515**	**3.7**	--	**0.025**	**1.1**	1.15	0.312
							Average =	31%
St. Croix River Basin								
Date: 10/06/2003								
SN-10: SNAKE R BRIDGE AT CSAH-9, 2 MI NE OF PINE CITY								
SN-10	**9**	**0.051**	**--**	<0.006	--			
SN-10 Solids	**980**	**4.99**	**5.1**	--	**0.228**	**1.4**	1.50	0.295
SN-10 Solids	**1000**	**4.87**	**4.9**	--	**0.241**	**1.4**	1.55	0.319
SN-10 Solids	**1100**	**5.01**	**4.6**	--	**0.232**	**1.3**	1.36	0.298

Basin/Date/ Location/ID	Solids, total suspended (mg/L)	Phosphorus, total (mg/l)	Particulate Phosphorus (mg total P/g dry weight solids)	Orthophosphate (mg/L)	Particulate Phosphorus, NaOH Extractable (mg/l)	Particulate NaOH Extractable Phosphorus (mg of NaOH extractable P/g dry weight solids)	Bioavailable Particulate P (mg P/g) [(Ultimately avail PP = 1.08 NaOH -P-0.008)]	Bioavailable Particulate Phosphorus Fraction
							Average =	30%
Upper Mississippi River Basin								
Date: 10/14/2003								
MISSISSIPPI R MPLS WATERWORKS INTAKE AT FRIDLEY								
UM-859	**8**	**0.041**	**--**	**0.006**	--			
UM-859 Solids	**410**	**1.81**	**4.4**	--	**0.086**	**1.3**	1.35	0.306
UM-859 Solids	**390**	**1.81**	**4.6**	--	**0.087**	**1.3**	1.44	0.310
UM-859 Solids	**420**	**1.85**	**4.4**	--	**0.088**	**1.3**	1.35	0.306
							Average =	31%
Missouri River Basin								
Date: 10/21/2003								
ROCK RIVER BR ON STATELINE RD 10 MI S OF LUVERNE								
RO-0	**5**	**0.055**	**--**	**0.012**	--			
RO-0 Solids	**560**	**3.49**	**6.2**	--	**0.121**	**1.3**	1.39	0.223
RO-0 Solids	**520**	**3.44**	**6.6**	--	**0.119**	**1.4**	1.47	0.223
RO-0 Solids	**540**	**3.34**	**6.2**	--	**0.119**	**1.3**	1.42	0.230
							Average =	23%
Des Moines River Basin								
Date: 10/21/2003								
W FK DES MOINES R CSAH-23 BRIDGE S OF PETERSBURG								
WDM-3	**34**	**0.331**	**--**	<0.006	--			
WDM-3 Solids	**2300**	**16.3**	**7.1**	--	**0.164**	**0.4**	0.45	0.064
WDM-3 Solids	**2400**	**16.8**	**7.0**	--	**0.136**	**0.3**	0.36	0.051
WDM-3 Solids	**2400**	**16**	**6.7**	--	**0.142**	**0.4**	0.38	0.056
							Average =	6%

-- Not analyzed.

h EPA sample extraction or analysis holding time was exceeded.

Results of Basin Discharge and Bioavailable Fraction Calculations

The results of the basin discharge calculations and resulting bioavailable fractions are presented in Tables 7, 8 and 9 and Figures 1-17. Attachment C contains summary sheets for each major basin and additional sheets when multiple locations were included in developing an estimate for an individual basin. Only one location was used in the Minnesota River, Upper Mississippi River and Des Moines River basins. In these cases, the discharge calculations were adjusted using a drainage area ratio multiplier (basin area:drainage area at monitoring location). No monitoring locations with sufficient water quality data were identified in either the Cedar River or Missouri River basins. For these cases, water quality relationships to flow from the Des Moines River basin were applied. The Des Moines, Cedar and Missouri River basins in Minnesota share similar land use characteristics and are located relatively close to each other. Multiple stations were used in the following basins: Lower Mississippi River; St. Croix River; Lake Superior; Rainy River; and Red River. In these cases, discharge calculations were conducted at monitoring locations in subwatersheds. The discharge calculations at each location were adjusted using a drainage area multiplier and then added within a basin such that the entire basin area was represented. In the case of the St. Croix River basin, the discharge calculations at the Snake and Kettle Rivers were used equally to represent the entire basin. In the case of the Lake Superior basin, a monitoring location on the St. Louis River represented the St. Louis River drainage area while a monitoring location on the Baptism River represented the remainder of the basin. In the case of the Rainy River basin, monitoring locations on the Rainy River and Little Fork Rivers were assumed to equally represent the entire basin. In the case of the Red River basin, monitoring locations in the Red Lake River and Otter Tail River watersheds represented their respective drainage areas, while a monitoring location on the Wild Rice River represented the remainder of the basin. All drainage area multipliers are presented in the summary sheets in Attachment C.

Annual suspended sediment yields ranged from 6.2 lbs/acre/yr for low flow years in the St. Croix River basin, to 73.9 lbs/acre/yr in the Minnesota River basin, and a statewide average of 31.4 lbs/acre/yr. During high flow years, suspended sediment yields were considerably higher, ranging from 21 lbs/acre/yr in the Lake Superior basin to 528 lbs/acre/yr in the Lower Mississippi River basin, and a statewide average of 215 lbs/acre/yr. Average flow conditions produced a statewide-suspended sediment area-weighted average of 104 lbs/acre/yr.

Annual total phosphorus yields ranged from 0.023 lb/acre/yr during low flow years in the Lake Superior basin, to 1.056 lbs/acre/yr during high flow years in the Lower Mississippi River basin. The unusually high phosphorus yield in the Lower Mississippi River was based on two USGS gauging stations, one on the Cannon River at Welch, MN. Water quality data were somewhat limited at this site (28 total phosphorus samples) and showed no correlation with flow. An average total phosphorus concentration of 0.21 mg/l was applied in the discharge calculations. This site is influenced by an upstream discharge and may not be representative of other areas of the Lower Mississippi River basin. The other site was on the Root River near Beaver, MN. This site was selected to represent the remainder of the Lower Mississippi River basin outside of the Cannon River. USGS Long Term Monitoring Program (LTRMP) water quality data were available and showed a very strong response to increasing flows, with rapidly increasing solids and phosphorus concentrations with increases in flow. Water quality data were not available for significantly high flows and, therefore, extrapolation of the rating curves to higher flows than what were monitored is questionable. LTRMP data at a site on the Whitewater River were also evaluated and here too a very strong response to increasing flows was observed. Data at locations on the Zumbro River in the Lower Mississippi River basin were also evaluated but insufficient data were available to develop rating curves. Average flow conditions produced a statewide total phosphorus yield of 0.202 lb/acre/yr.

Total dissolved phosphorus yields were estimated as low as 0.005 lb/acre/yr in the Des Moines River, Cedar River, Missouri River, and Lake Superior basins during low flow years. The Cedar and Missouri River basins did not contain sufficient data to produce basin-specific estimates, but because of their proximity to the Des Moines River basin and similar land covers, the same rates were applied to these basins. High flow years produced total dissolved phosphorus yields as high as 0.312 lb/acre/yr in the Lower Mississippi River basin. Average flow conditions produced a statewide total dissolved phosphorus yield of 0.066 lb/acre/yr.

Particulate phosphorus yields during low flow conditions were lowest in the Red River basin at 0.024 lb/acre/yr. Particulate phosphorus yields were highest in the Lower Mississippi River basin at 0.744 lb/acre/yr during high flow years. Average flow conditions produced a statewide total particulate phosphorus yield of 0.136 lb/acre/yr.

All dissolved phosphorus was considered bioavailable, and 18% of the particulate phosphorus was considered bioavailable as discussed previously. Total bioavailable phosphorus yields were estimated as low as 0.008 lb/acre/yr in the Lake Superior basin during low flow years. High flow years produced total bioavailable phosphorus yields as high as 0.446 lb/acre/yr in the Lower Mississippi River basin. Average flow conditions produced a statewide total bioavailable phosphorus yield of 0.090 lb/acre/yr.

The resulting bioavailable fraction of total phosphorus ranged from 27% to 53% at low flow, with the lowest fraction in the Des Moines, Cedar and Missouri River basins, and the highest fraction in the Lower Mississippi River basin. During high flow conditions the range for total bioavailable phosphorus was 34% (Des Moines River, Cedar River, Missouri River, and Lake Superior basins) to 54% (Minnesota River basin). At average flow conditions the statewide bioavailable fraction was estimated at 45%.

Table 7: Summary of estimated annual basin discharge for low, average and high flow conditions.

Estimated Annual Basin Discharge (metric tons/year)							
Basin	**Area (sq. mi.)**	**Suspended Sediment**	**Total Phosphorus**	**Total Dissolved Phosphorus**	**Total Particulate Phosphorus**	**Total Bioavailable Phosphorus**	**Fraction Bioavailable**
Low Flow Year							
Minnesota River	14,939	321,201	475	151	324	210	44%
Upper Mississippi River	20,100	85,110	508	179	329	238	47%
Lower Mississippi River	6,317	48,612	238	102	135	127	53%
Des Moines River	1,535	4,566	20	2.2	18	5	27%
*Cedar River**	1,028	3,058	14	1.4	12	4	27%
*Missouri River**	1,782	5,300	24	2.5	21	6	27%
St. Croix River	3,528	6,355	85	29	56	39	46%
Lake Superior	6,149	13,537	42	8	33	14	35%
Rainy River	11,236	132,422	223	85	137	110	49%
Red River	17,741	151,146	188	66	122	88	47%
Statewide	84,355	771,306	1,816	627	1,188	841	46%
Average Flow Year							
Minnesota River	14,939	958,291	1,254	458	796	601	48%
Upper Mississippi River	20,100	212,614	997	365	632	478	48%
Lower Mississippi River	6,317	342,383	789	237	552	336	43%
Des Moines River	1,535	36,052	161	26	135	50	31%
*Cedar River**	1,028	24,144	108	17	90	34	31%
*Missouri River**	1,782	41,853	187	30	157	58	31%
St. Croix River	3,528	12,426	155	52	103	70	45%
Lake Superior	6,149	27,768	78	15	62	26	34%
Rainy River	11,236	217,316	346	129	217	168	49%
Red River	17,741	683,510	884	287	597	395	45%
Statewide	84,355	2,556,355	4,957	1,616	3,341	2,217	45%
High Flow Year							
Minnesota River	14,939	2,110,290	2,330	1,030	1,299	1,264	54%
Upper Mississippi River	20,100	409,504	1,545	584	961	757	49%
Lower Mississippi River	6,317	971,031	1,940	573	1,368	819	42%
Des Moines River	1,535	77,843	347	66	281	116	34%
*Cedar River**	1,028	52,132	233	44	188	78	34%
*Missouri River**	1,782	90,369	403	76	327	135	34%
St. Croix River	3,528	28,605	254	78	176	110	43%
Lake Superior	6,149	37,152	100	19	81	34	34%
Rainy River	11,236	467,087	528	176	352	239	45%
Red River	17,741	1,038,447	1,359	420	938	589	43%
Statewide	84,355	5,282,460	9,038	3,067	5,971	4,142	46%

*Based on water quality data for the Des Moines River basin.

Table 8: Summary of estimated annual basin yields for low, average and high flow conditions.

Estimated Annual Basin Yield (lbs/acre/yr)					
Basin	**Suspended Sediment**	**Total Phosphorus**	**Total Dissolved Phosphorus**	**Total Particulate Phosphorus**	**Total Bioavailable Phosphorus**
Low Flow Year					
Minnesota River	73.9	0.109	0.035	0.074	0.048
Upper Mississippi River	14.6	0.087	0.031	0.056	0.041
Lower Mississippi River	26.5	0.129	0.056	0.074	0.069
Des Moines River	10.2	0.046	0.005	0.041	0.012
*Cedar River**	10.2	0.046	0.005	0.041	0.012
*Missouri River**	10.2	0.046	0.005	0.041	0.012
St. Croix River	6.2	0.083	0.029	0.054	0.038
Lake Superior	7.6	0.023	0.005	0.019	0.008
Rainy River	40.5	0.068	0.026	0.042	0.034
Red River	29.3	0.036	0.013	0.024	0.017
Statewide	31.4	0.074	0.026	0.048	0.034
Average Flow Year					
Minnesota River	221	0.288	0.105	0.183	0.138
Upper Mississippi River	36	0.170	0.062	0.108	0.082
Lower Mississippi River	186	0.430	0.129	0.301	0.183
Des Moines River	81	0.360	0.058	0.302	0.112
*Cedar River**	81	0.360	0.058	0.302	0.112
*Missouri River**	81	0.360	0.058	0.302	0.112
St. Croix River	12	0.151	0.050	0.100	0.068
Lake Superior	16	0.043	0.008	0.035	0.015
Rainy River	66	0.106	0.040	0.066	0.051
Red River	132	0.171	0.056	0.116	0.076
Statewide	104	0.202	0.066	0.136	0.090
High Flow Year					
Minnesota River	486	0.536	0.237	0.299	0.291
Upper Mississippi River	70	0.264	0.100	0.164	0.130
Lower Mississippi River	528	1.056	0.312	0.744	0.446
Des Moines River	174	0.778	0.147	0.630	0.261
*Cedar River**	174	0.778	0.147	0.630	0.261
*Missouri River**	174	0.778	0.147	0.630	0.261
St. Croix River	28	0.247	0.076	0.171	0.107
Lake Superior	21	0.056	0.011	0.045	0.019
Rainy River	143	0.162	0.054	0.108	0.073
Red River	201	0.263	0.081	0.182	0.114
Statewide	215	0.368	0.125	0.243	0.169

*Based on water quality data for the Des Moines River basin.

Table 9. Summary of estimated annual flow weighted mean concentrations for low, average and high flow conditions.

Estimated Annual Flow Weighted Mean Concentration (mg/l)					
Basin	**Suspended Sediment**	**Total Phosphorus**	**Total Dissolved Phosphorus**	**Total Particulate Phosphorus**	**Total Bioavailable Phosphorus**
Low Flow Year					
Minnesota River	152.7	0.226	0.072	0.154	0.100
Upper Mississippi River	14.3	0.085	0.030	0.055	0.040
Lower Mississippi River	24.9	0.100	0.038	0.063	0.049
Des Moines River	66.7	0.298	0.031	0.266	0.079
*Cedar River**	66.7	0.298	0.031	0.266	0.079
*Missouri River**	66.7	0.298	0.031	0.266	0.079
St. Croix River	4.4	0.068	0.024	0.045	0.032
Lake Superior	10.6	0.030	0.011	0.019	0.014
Rainy River	28.3	0.047	0.018	0.029	0.023
Red River	77.0	0.095	0.036	0.058	0.047
Average Flow Year					
Minnesota River	187	0.245	0.089	0.155	0.117
Upper Mississippi River	21	0.100	0.037	0.064	0.048
Lower Mississippi River	81	0.186	0.055	0.131	0.079
Des Moines River	67	0.298	0.048	0.249	0.093
*Cedar River**	67	0.298	0.048	0.249	0.093
*Missouri River**	67	0.298	0.048	0.249	0.093
St. Croix River	5	0.071	0.024	0.047	0.032
Lake Superior	14	0.033	0.011	0.022	0.015
Rainy River	30	0.048	0.018	0.030	0.023
Red River	104	0.133	0.044	0.089	0.060
High Flow Year					
Minnesota River	244	0.270	0.119	0.150	0.146
Upper Mississippi River	30	0.114	0.043	0.071	0.056
Lower Mississippi River	150	0.286	0.079	0.207	0.116
Des Moines River	67	0.298	0.056	0.242	0.099
*Cedar River**	67	0.298	0.056	0.242	0.099
*Missouri River**	67	0.298	0.056	0.242	0.099
St. Croix River	8	0.075	0.024	0.052	0.033
Lake Superior	15	0.035	0.011	0.023	0.015
Rainy River	47	0.054	0.018	0.036	0.024
Red River	124	0.164	0.051	0.113	0.071

*Based on water quality data for the Des Moines River basin.

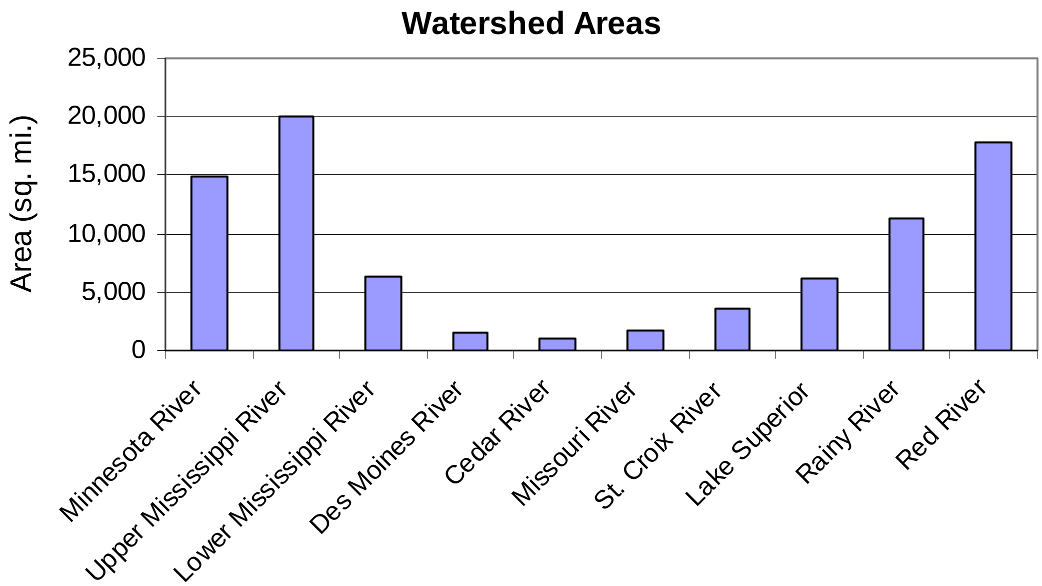

Figure 1: Watershed areas for each of the ten major watersheds.

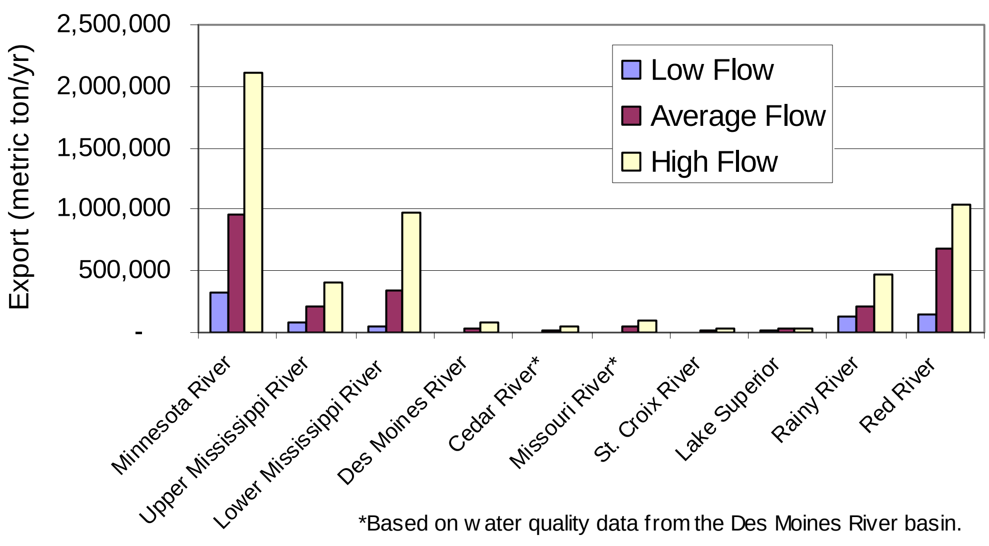

Figure 2: Estimated annual suspended sediment discharge for each of the ten major basins.

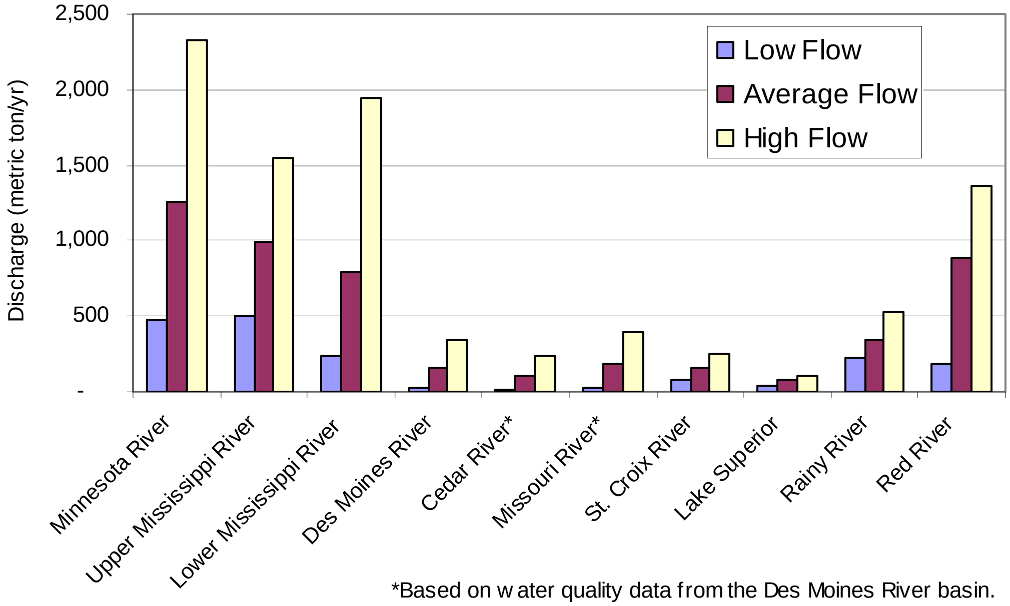

Figure 3: Estimated annual total phosphorus discharge for each of the ten major basins.

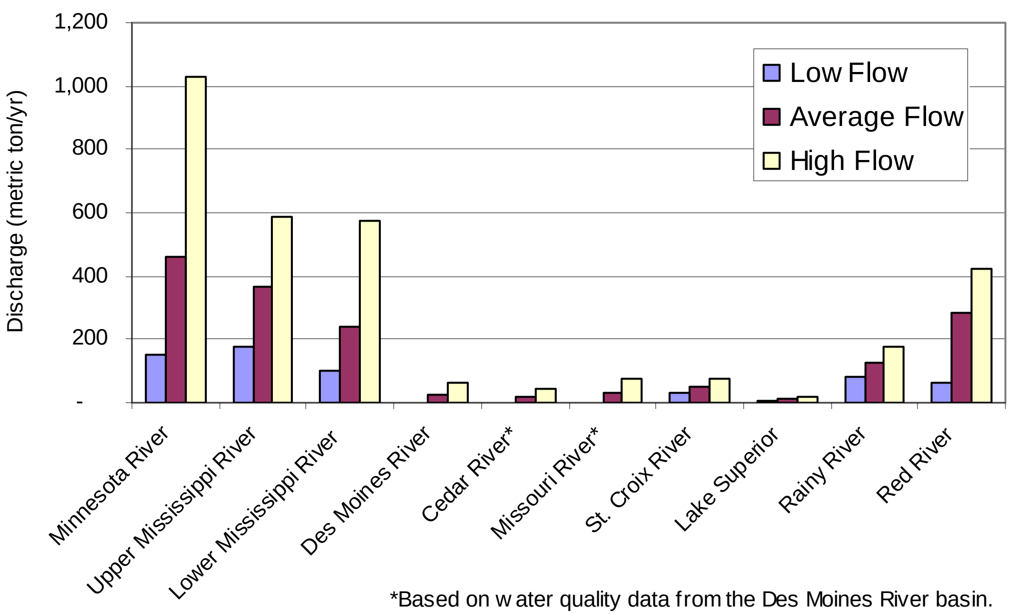

Figure 4: Estimated annual total dissolved phosphorus discharge for each of the ten major basins.

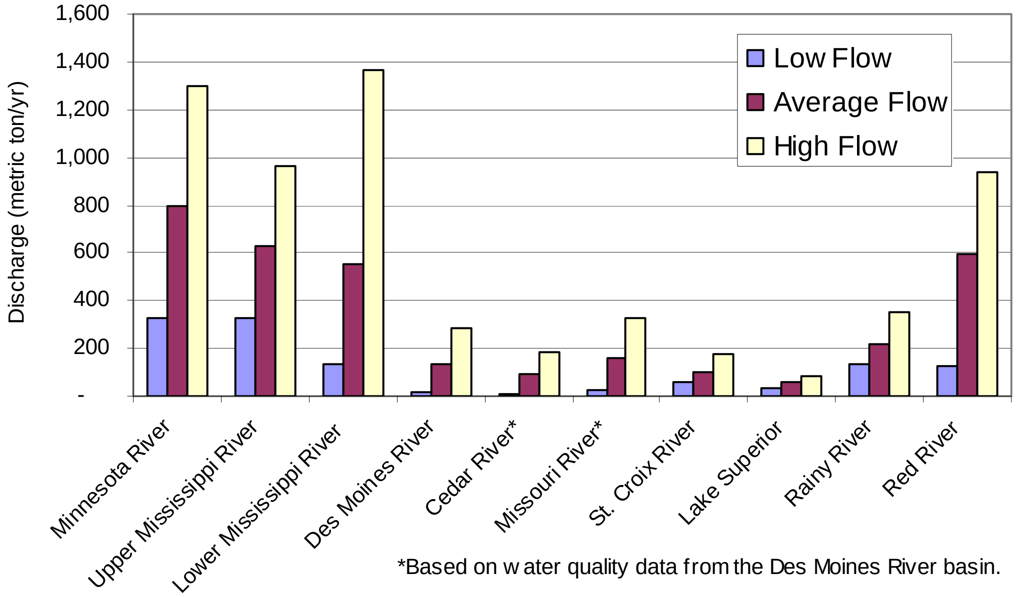

Figure 5: Estimated annual total particulate phosphorus discharge for each of the ten major basins.

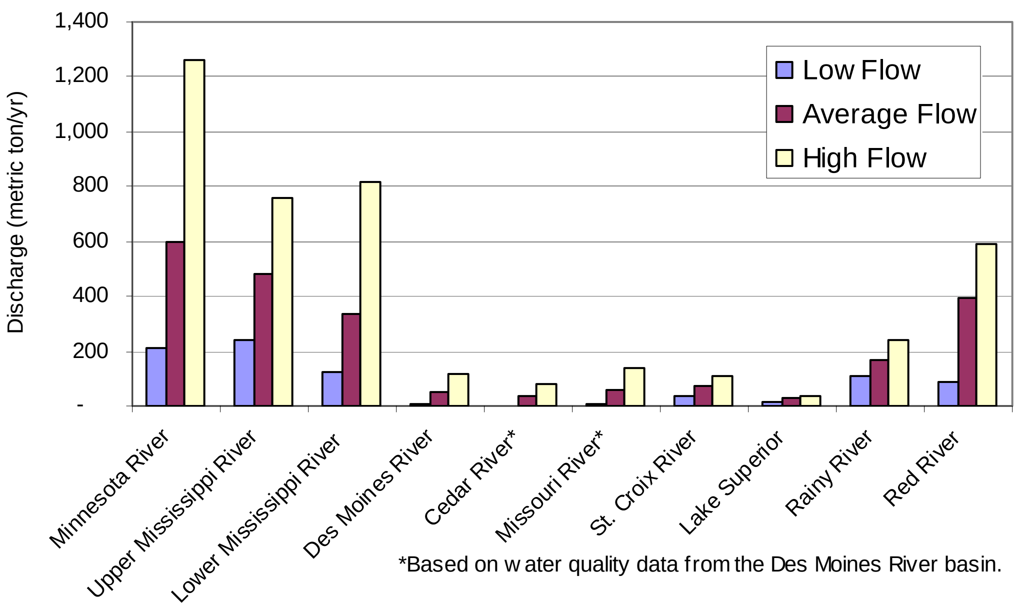

Figure 6: Estimated annual bioavailable phosphorus discharge for each of the ten major basins.

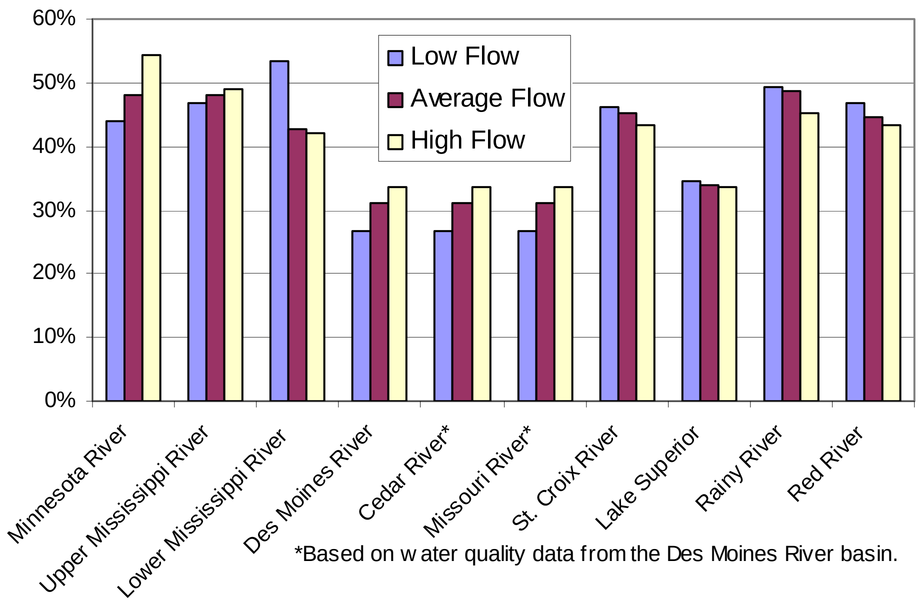

Figure 7: Estimated annual bioavailable phosphorus fractions for each of the ten major basins.

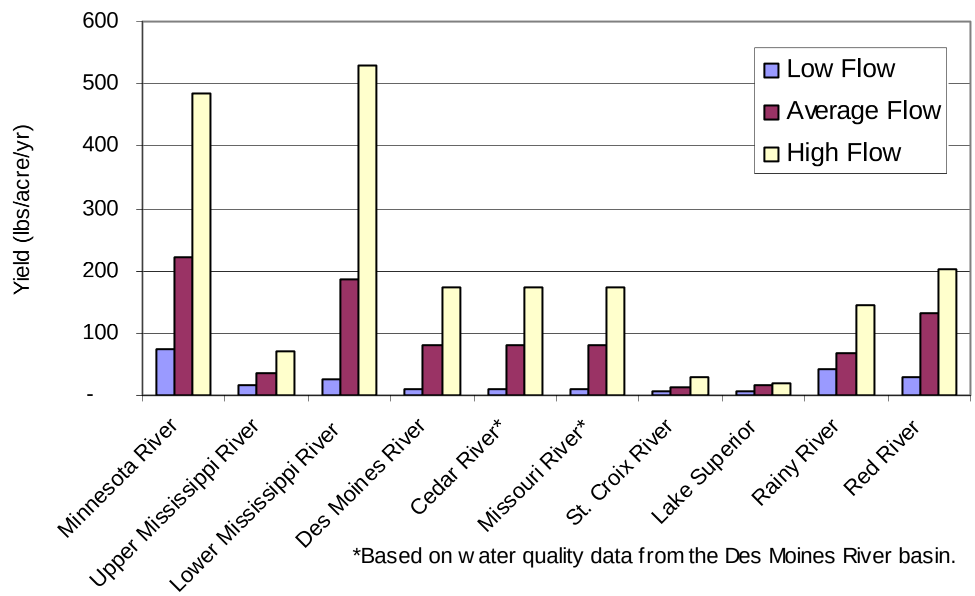

Figure 8: Estimated annual suspended sediment yields for each of the ten major basins.

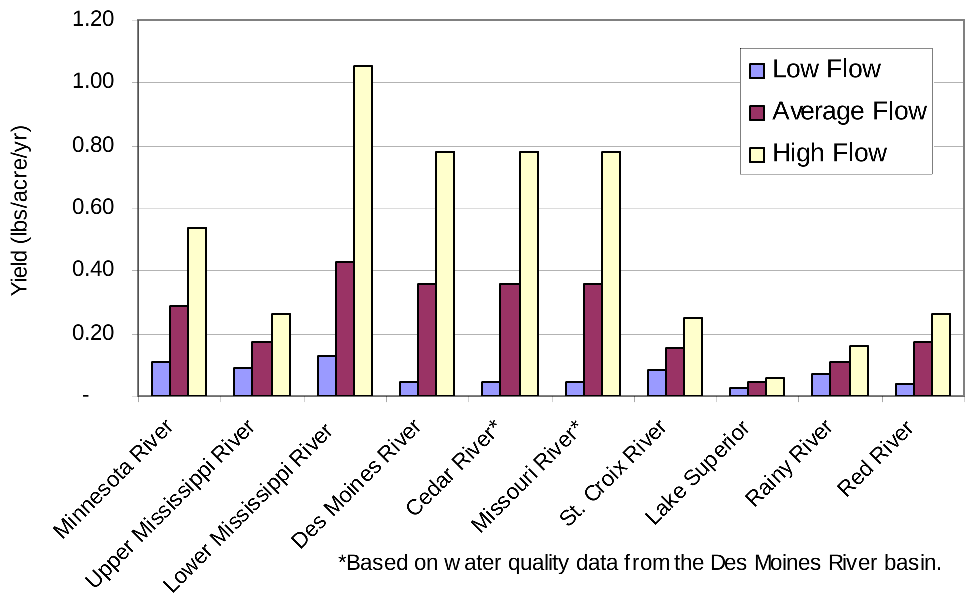

Figure 9: Estimated annual total phosphorus yields for each of the ten major basins.

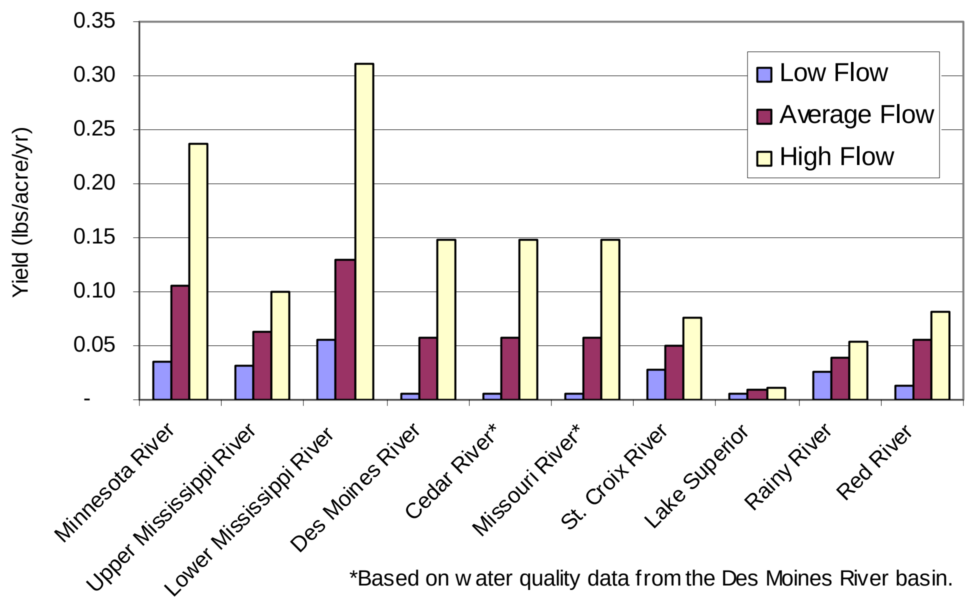

Figure 10: Estiamted annual total dissolved phosphorus yields for each of the ten major basins.

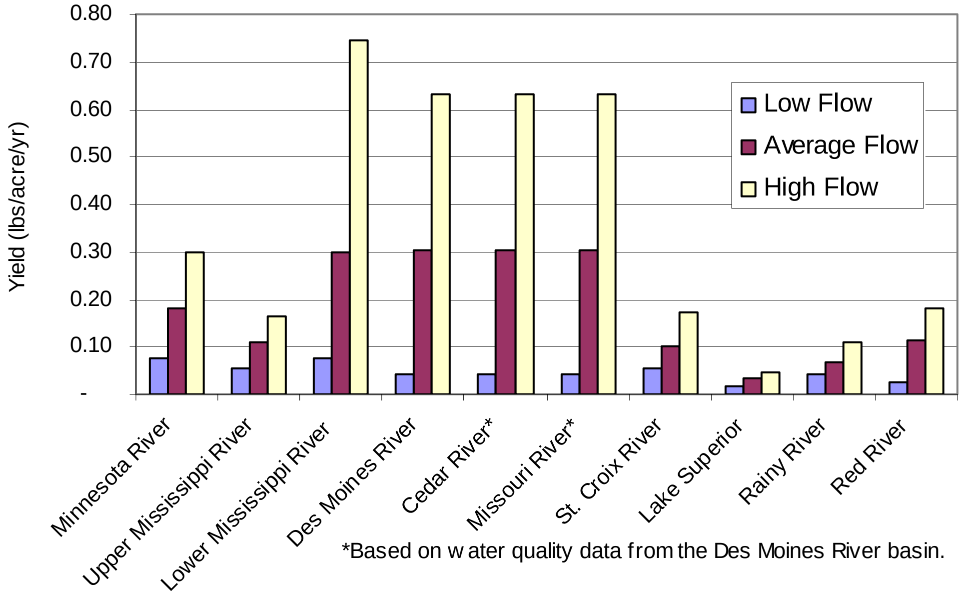

Figure 11: Estimated annual total particulate phosphorus yields for each of the ten major basins.

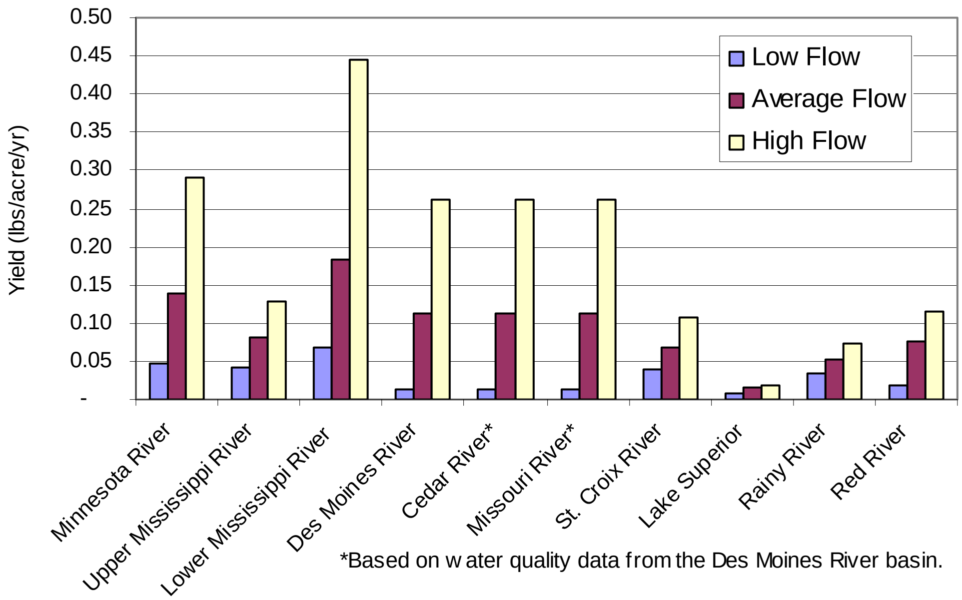

Figure 12: Estimated annual bioavailable phosphorus yields for each of the ten major basins.

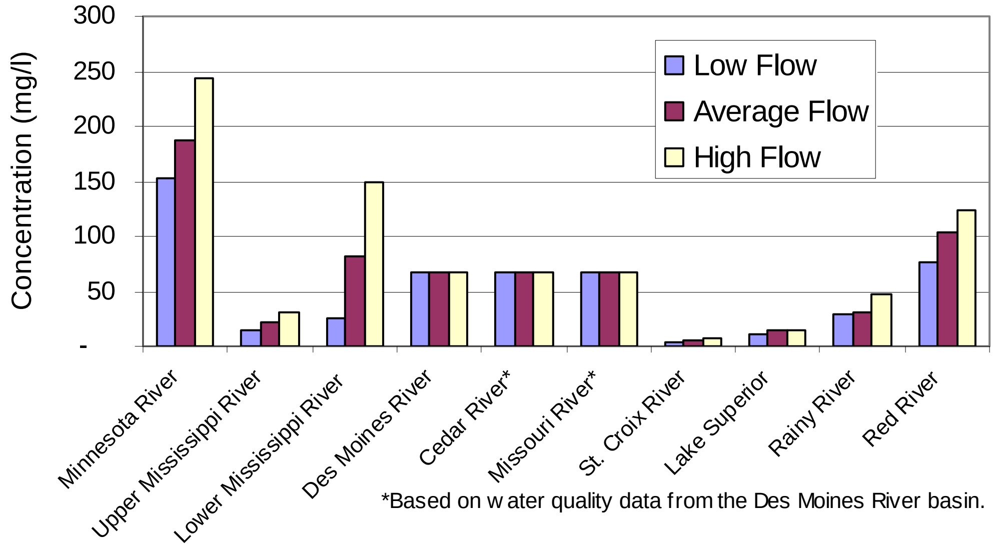

Figure 13: Estimated annual flow weighted mean concentration for suspended sediment for each of the ten major basins.

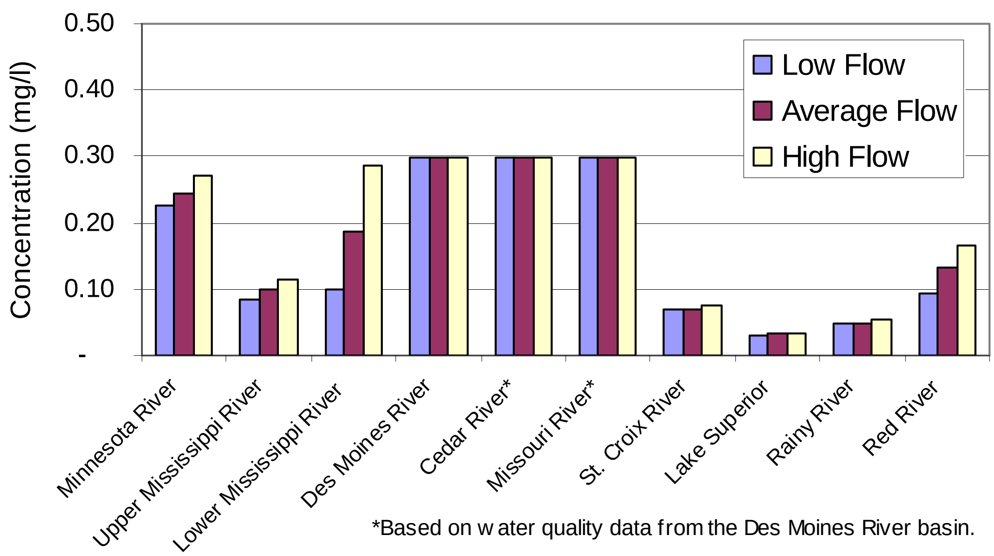

Figure 14: Estimated annual flow weighted mean concentration for total phosphorus for each of the ten major basins.

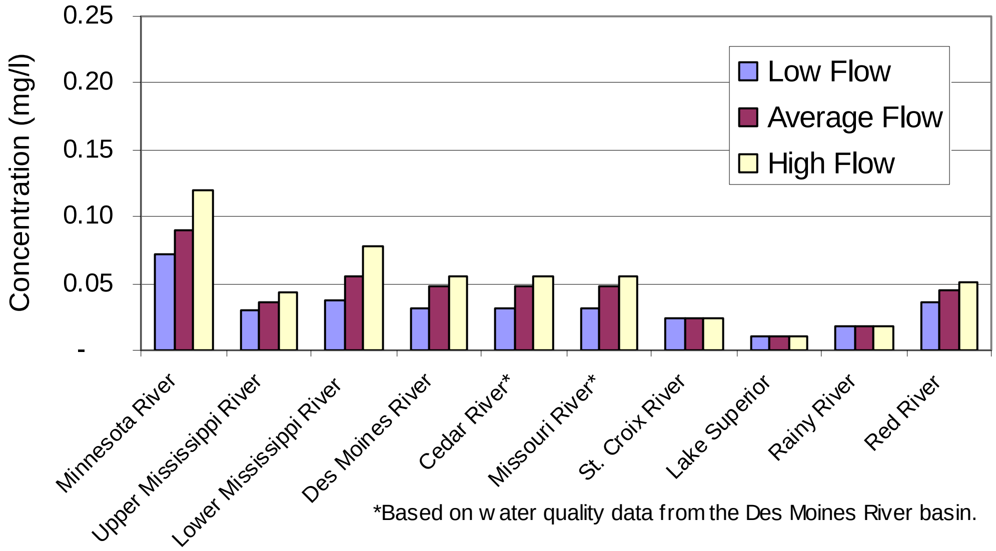

Figure 15: Estimated annual flow weighted mean concentration for total dissolved phosphorus for each of the ten major basins.

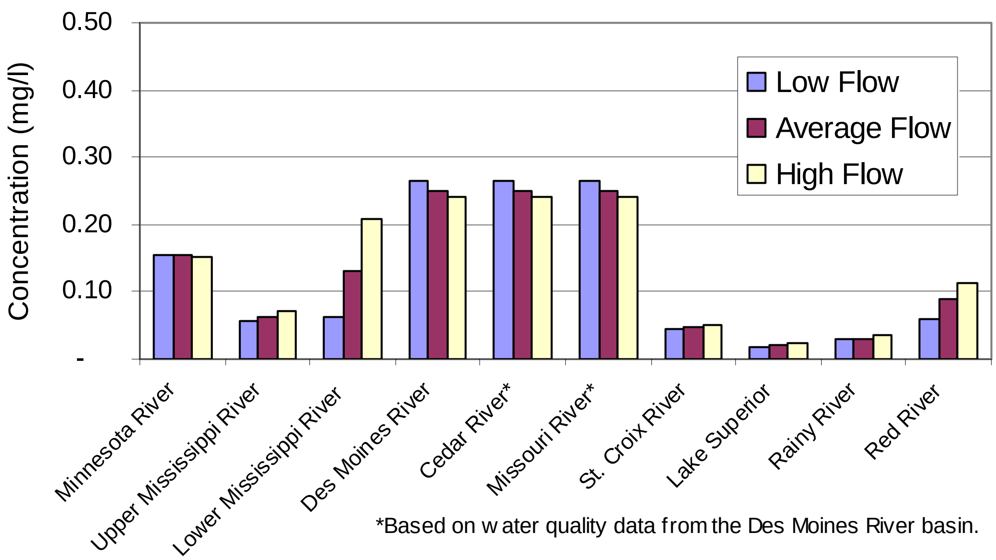

Figure 16: Estimated annual flow weighted mean concentration for total particulate phosphorus for each of the ten major basins.

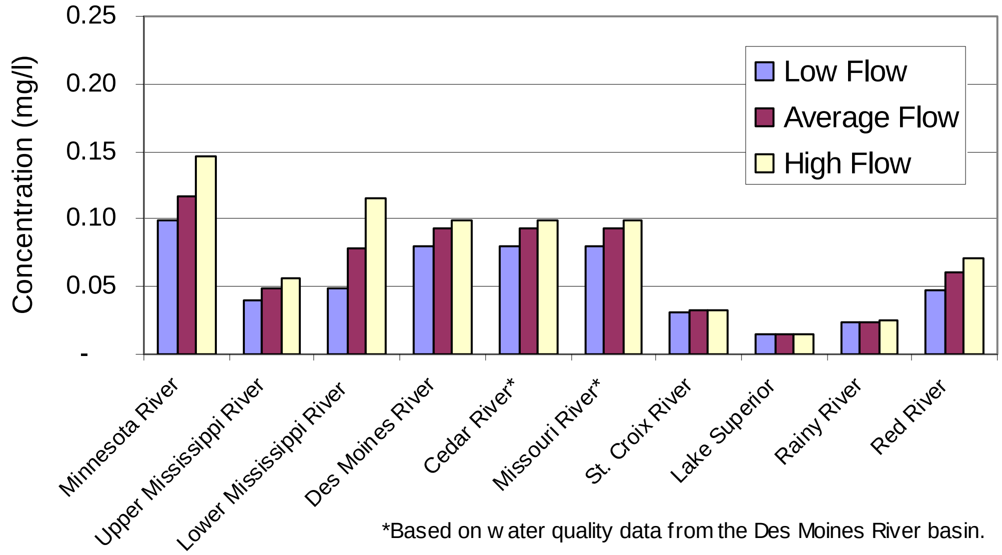

Figure 17: Estimated annual flow weighted mean concentration for total bioavailable phosphorus for each of the ten major basins.

Bioavailable Phosphorus Variability and Uncertainty

The uncertainty associated with the basin scale export estimates was not quantified, but is expected to be significant. Results from USGS studies of the St. Croix River Basin (Lenz *et al.*, 2001 and Lenz and Robertson, 2002) were compared to the results of this study as a check on the accuracy of the methods applied. In the USGS studies, more complex methods were applied in the development of suspended sediment and total phosphorus loads at the Snake and Kettle River gauging stations for the 1999 water year. Comparisons of the results are presented in Table 10. The results of this study generally fall within the 95^{th} percent confidence interval as calculated and reported in the USGS study. Also, as is typical with the simple approach to the development of rating curves used in this study, the results are generally lower. Note that even with the more complex methods applied in the USGS study, the range associated with the 95^{th} percent confidence interval is approximately ±40% for the sediment load estimates and ±20% on the total phosphorus estimates for this single year.

Table 10. Comparison of annual loads from USGS St. Croix River study and this study.

Gauging Station	Annual load, water year 1999 (metric tons/yr)			
	Sediment		Total Phosphorus	
	USGS	*Results of this Study*	*USGS*	*Results of this Study*
Snake River	3,050 (95^{th}-percent confidence interval = 1,780 to 4,320)	2,017	37.4 (95^{th}-percent confidence interval = 29.5 to 45.4)	38
Kettle River	5,970 (95^{th}-percent confidence interval = 3,660 to 8,290)	3,732	43.4 (95^{th}-percent confidence interval = 34.94 to 51.8)	34

As part of the USGS Long Term Resource Monitoring Program (LTRMP), the USGS has also calculated annual loads for suspended sediment, total phosphorus, and dissolved phosphorus at locations on the Minnesota River and the Mississippi River. Results of loading estimates are presented on the USGS Upper Midwest Environmental Sciences Center (http://www.umesc.usgs.gov/data_library/sediment_nutrients/streams/streams.html). These estimates are compared to the results of this study in Table 11. The comparison shows the results of this study again being generally less than the USGS results.

While there is significant uncertainty associated with the basin discharge calculations, the estimates presented are useful in assessing the relative discharge of the different forms of phosphorus from the basins and at different flow conditions, but care should be taken in using these estimates as predictors of absolute magnitudes of phosphorus loads.

Table 11. Comparison of annual loads from USGS LTRMP study and this study.

Monitoring Location	Water year	Annual load (metric tons/yr)					
		Sediment		Total Phosphorus		Dissolved Phosphorus	
		USGS	*Results of this Study*	*USGS*	*Results of this Study*	*USGS*	*Results of this Study*
Minnesota River near Jordan	Low Flow (1981)	472,868-500,863	300,858	584-589	465	194-211	141
	Average Flow (1985)	1,185,567-1,215,541	1,014,532	1,232-1,290	1,334	588-730	485
	High Flow (1986)	2,486,545-2,592,112	2,077,906	2,223-2,353	2,478	1,211-1,613	1,004
Mississippi River near Anoka	Low Flow (1989)	102,286-105,213	77,347	651-673	448	322-330	158
	Average Flow (1995)	195,394-204,458	188,759	1,253-1,273	935	757-794	339
	High Flow (1986)	517,356-549,192	486,458	2,521-2,586	1,850	1,255-1,373	701

Point Sources Not Accounted for in Basin Discharge Calculations

The method used for calculating basin discharge depended on an assumption that the gauge(s) chosen represented the discharge for the entire basin, including both point and non-point source contributions. This assumption is likely adequate for representation of the non-point sources as they are spread out over large areas. But because of the specific placement of point source discharges and the potential for relatively large phosphorus contributions, this assumption may not hold true. To evaluate this concern, point sources were located when latitude and longitude data were readily available. A determination was then made whether or not the point source discharged within the drainage area of the representative gauge(s). Unfortunately, of the 820 point sources identified in this study, only 480 had readily available latitude and longitude information. Of these 480, 252 were within the drainage areas of the representative gauges and 228 discharged outside. The estimated annual phosphorus loads for the point sources in each basin were tabulated to assess the magnitude of the loads represented by the gauges, those not represented by the gauges, and those of unknown location. This information is presented in Table 12. The results show the significance of both the point sources outside of the discharge calculation and those with unknown location.

The calculated basin discharges include upstream point sources, and to some extent account for point source loads below the representative gauge as the discharge at the gauge is multiplied by a drainage ratio factor. But the point sources below the gauge are adequately represented only to the degree that the point sources below a gauge discharge a similar load per area as those above the gauge. Where they are different, care needs to be taken in how the basin discharge estimates are used.

Table 12. Point source phosphorus loads inside and outside of gauged drainage areas.

Basin	Annual total phosphorus load (metric ton/year)			
	Total point source load	Located within discharge calculation	Located outside of discharge calculation	Unknown
Minnesota River	372	117.9	45.4	208.4
Upper Mississippi River	1,180[1]	194.9	897.1[1]	88.1
Lower Mississippi River	267	83.3	129.8	54.2
Des Moines River	56	42.4	-	13.1
Cedar River	57	19.3	-	37.5
Missouri River	13	6.7	-	6.4
St. Croix River	22	4.6	16.0	1.5
Lake Superior	35	9.1	23.4	2.5
Rainy River	44	2.7	0.7	40.8
Red River	63	17.5	35.6	9.6
Statewide	2,109	499	1,148	462

[1] Includes 868 metric tons/yr from the MCES Metro WWTF. This load is expected to be reduced by approximately 581 metric tons/yr associated with a 1 mg P/l effluent discharge limit effective 12/31/05.

Recommendations for Future Refinements of Basin Discharge Calculations

Phosphorus discharge estimates on a basin scale may be improved by application of more complex rating curve estimation techniques, for example including flow and seasonal stratification. Also, additional assessment of the portion of discharge at each gauge that can be attributed to POTW discharges would help understanding the observed differences. The assessment conducted focused on gauges and data at the downstream reaches of the watershed, therefore quantifying the cumulative impacts of all sources within the watershed, both point and non-point and from the various land cover types. Assessment of gauges and data representing small drainage areas with a homogeneous land cover might prove useful in isolating the phosphorus loadings from a particular land cover.

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Attachment A

Methods for Bioavailable Phosphorus Analysis

Two approaches are generally used to estimate bioavailable phosphorus fractions in the aquatic environment, bioassay and chemical extraction. These two methodologies are briefly discussed. Methods for measuring the bioavailability of phosphorus in soils are also presented.

Bioassay

A bioassay can be used to measure the bioavailable phosphorus content of water samples. A bioassay quantifies either growth (assuming constant phosphorus stoichiometry) or uptake of phosphorus by the test organism, usually a phosphorus-starved planktonic alga, to estimate bioavailability. The bioassay technique provides a direct measurement of phosphorus taken up by the test algal species (DePinto *et al*., 1981). This method has been used for estimating the bioavailability of phosphorus in Lake Ontario tributary and urban runoff samples (Cowan and Lee, 1976), soil runoff suspensions (Sagher, 1976), Lake Ontario sediment samples (Williams *et al*., 1980), and sediment samples from other lakes (Golterman *et al*., 1977).

Young *et al*. (1982) conducted bioassays on the particulate phosphorus in wastewater samples collected from four municipal treatment plants. They used a two-chamber device, with one side lighted (assay side) for the test algae and one darkened (decay side) for the wastewater particulates and 1-1 glass bottles for the dissolved phosphorus bioassays.

To separate the dissolved and the particulate phases of phosphorus, the sample is filtered generally using a 0.45 μm pore diameter membrane filter. The filtering process separates the filtrate from the residual remaining on the filter. The filtrate contains the dissolved phosphorus, most of which is immediately or ultimately bioavailable. The residual contains the particulate phosphorus, none of which is immediately bioavailable, but a portion of it may ultimately become bioavailable. For samples collected from streams and lakes this would include phosphorus contained in the algae collected in the original sample. The residual is placed in the dark chamber. Following decay and/or desorption, phosphorus may be released and pass through the filter separating the two chambers. Once in the lighted chamber it is available for uptake by the phosphorus-starved test algae.

However, some fine colloidal materials less than 0.45 µm may pass through the filter and be hydrolyzed or dissolved by the strong acid medium of the colorimetric procedure of Murphy and Riley (1962). Thus, bioavailable phosphorus in the filtrate may be overestimated, particularly at low orthophosphate concentrations (Rigler, 1966; Tarapchak and Rubitschun, 1981). Although Walton and Lee (1972) found that orthophosphate was essentially entirely bioavailable using standard bioassay procedures, several investigators have reported that only 50 to 95% of orthophosphate was actually bioavailable (Nurnberg and Peters, 1984; Rigler 1968) in surface runoff.

Chemical Extraction

Chemical extraction is a methodology used to estimate the bioavailability of particulate phosphorus in a water sample. This methodology was developed originally for agricultural crops and soils. Chemically defined bioavailability is a sequence of extractions of phosphorus from particulate matter in an increasing order of extractions rigor that yields phosphorus fractions in a sequence of decreasing bioavailability. This method has been applied to suspended sediments in Great lakes tributaries (Logan, 1978; Logan *et al*., 1979; Martin, 1983), urban runoff (Cowan and Lee, 1976), and a variety of lake sediments (Williams *et al*., 1971).

Chemical extractions that have been used to measure the bioavailable particulate phosphorus content of eroded soil material are NaOH (Logan *et al*., 1979; Sagher *et al*. 1975), NH_4F (Dorich *et al.*, 1980; Porcella *et al.*, 1970), ion exchange resins (Hanna, 1989; Huettl *et al.*, 1979), and citrate-dithionite-bicarbonate (CDB) (Logan *et al.*, 1979). The weaker extractants and short-term resin extractions may represent phosphorus available to algae in the photic zone of lakes under aerobic conditions. Once sediment settles to the bottom of the lake, sediment phosphorus bioavailability will be increased by development of reducing conditions at the sediment-water interface (Li *et al.*, 1972; Nurnberg *et al.*, 1986). Under these conditions, NaOH-extractable phosphorus may underestimate phosphorus bioavailability and CDB (Logan *et al.*, 1979) may be more appropriate as it removes a greater proportion of Fe- and Al-bound P. Thus, CDB should more accurately reflect long-term bioavailability (>30 d) of sediment phosphorus under reducing conditions found in the anoxic hypolimnion of stratified lakes (Sharpley *et al*., 1995). For example, in a study of the phosphorus dynamics of two shallow hypereutrophic lakes in Indiana, Theis and McCabe (1978) found that the dissolved phosphorus concentration of lake water was reduced by sorption during oxic periods and increased by release of sediment phosphorus during anoxic periods. This release of phosphorus from sediment can supply bioavailable phosphorus for several years after deposition (Jacoby *et al.*, 1982; Larsen *et al.*, 1981). Consequently, bioavailable phosphorus estimates should be used in conjunction with information on the physicochemical properties of source sediment (e.g., degree of aggregation, texture, settling velocity, clay mineralogy) and receiving lake (e.g., depth of photic zone, degree of surface mixing, development of reducing conditions, water residence time).

Often, the chemical extraction methods have been applied in parallel with bioassay methods to chemically characterize bioavailable phosphorus. As a result, some chemically-determined fractions of particulate phosphorus have been shown to be directly related with bioassay results on bioavailable phosphorus (Golterman, 1977; Dorich *et al*., 1980; Williams *et al*., 1980; Martin, 1983).

Chemical extraction methods for measurement of particulate phosphorus bioavailability are relatively rapid and inexpensive; however, a bioassay can represent a more realistic measure of the amount of particulate phosphorus that is available for algal uptake (Young *et al*., 1995). Bioassays, on the other hand, are time-consuming, tedious, relatively expensive, and imprecise.

Soil Test Methods

Soil test methods that estimate plant availability of soil phosphorus are generally used for relating phosphorus in runoff to soil phosphorus content. Alternative approaches that reflect soil phosphorus release to surface and subsurface runoff include water extractable phosphorus, Fe-oxide phosphorus, and phosphorus sorption saturation of the surface 5 cm of soil (Breeuwsma and Silva, 1992; Sharpley *et al*., 1998). Hedley *et al*. (1995) presented various tests that have been developed in different countries to suit the forms of phosphorus present in their agricultural soils. Those include Mehlich, Olsen, Bray 1, and Bray 2 tests. The form of soil phosphorus extracted by each test is determined by its solution pH and the reaction of the ions present in the extractant with sorbed or mineral phosphorus. For instance, the HCO3- and OH- in the bicarbonate extract promote desorption of phosphorus from CaCO3 and Fe and Al hydrous oxide surfaces. Bray 1 extractable phosphorus are highly correlated to Al- and Fe-P in such soils (Hedley *et al*., 1995). Where data on soil phosphorus depletion by plants are not available, Sharpley *et al*. (1984) have used resin extraction results from calcareous, weakly weathered and strongly weathered soils to rank the suitability of different soil phosphorus tests. Kamprath (1991) summarizes their results as: The Olsen extraction is suitable for calcareous and weakly weathered acid soils and less suitable on strongly weathered soils where Bray 1 and Mehlich tests are more appropriate.

Attachment B

Bioavailable Phosphorus in Suspended and Deposited Sediments

Previous studies have indicated three major factors determining a stream's total and bioavailable phosphorus loads: basin geochemistry (Logan, 1978); land use activities (Omerink, 1976) and agricultural practices (Logan, 1977). DePinto, *et al*. (1981) chemically analyzed suspended sediments collected from five tributaries (Maumee, Sandusky, and Cuyahoga in Ohio and Cattaraugus and Genesee Rivers in New York) for several forms of phosphorus and bioassayed these sediments under aerobic conditions to measure the release of algal-available phosphorus. The bioassay data for all samples, interpreted through a first order model of available phosphorus release, showed an average of 21.8 percent of the total particulate phosphorus available to *Selenastrum capricornutum* and available phosphorus was released at an average rate of 0.154 grams per gram of total phosphorus in the sample per day (0.154/day). Amounts of available phosphorus varied considerably between tributaries of Ohio and New York. Table 1 presents the extractable phosphorus fractions in tributary suspended sediment samples (NaOH-P = sodium hydroxide extractable P, CDB-P= citrate-dithionite-biocarbonate extractable P, HCL-P = hydrochloric acid extractable P, Residual-P = total Particulate P not extracted with above sequence).

Acid-extractable (apatite) fractions are suggested to be low availability (Logan *et al*., 1979a). Apatite is a family of phosphates containing calcium, iron, chlorine, and several other elements in varying quantities. The only common mineral of phosphorus is apatite, $Ca_5F(PO_4)_3$. Non-apatite fractions of inorganic phosphorus (base- and reductant-extractable) correlated well with levels of bioassayed algal-available phosphorus in the suspended sediment samples; however, the first-order release coefficients showed little dependency on the particulate phosphorus characteristics. Among the tributaries in Ohio, the non-apatite fractions of inorganic phosphorus (reactive NaOH- and CDB-extractable) are considered to be of high biological availability (Logan *et al*., 1979a).

In summary, the tributaries may be classified into two distinct groups with respect to the distribution of phosphorus fractions: the Ohio rivers, which had suspended sediments which were relatively rich in non-apatite forms of phosphorus; and the New York rivers, wherein the sediments were impoverished of non-apatite forms, especially those which were base-extractable, but were enriched in apatite forms of phosphorus. The Ohio tributary sediments originated from generally low relief, cropland-pasture watersheds, on the other hand the NY tributary sediments arose from steep slope, forest pasture watersheds and so had relatively low levels of available phosphorus.

Table 1: The extractable phosphorus fractions in tributary suspended sediment samples (NaOH-P = sodium hydroxide extractable P, CDB-P= citrate-dithionite-biocarbonate extractable P, HCL-P = hydrochloric acid extractable P, Residual-P = total Particulate P not extracted with above sequence).

		Extractable Fractions (as % of total Sediment P)				
		NaOH-P				
River	**Total Sediment P (µgP/mg dry wt)**	**Total**	**Reactive**	**CDB-P**	**HCl-P**	**Residual P**
Maumee River, Ohio	1.16	30.1	20.3	20.6	8.8	10.6
Sandusky River, Ohio	1.06	34.2	22.4	22.6	5.4	10.2
Cuyahoga River, Ohio	1.25	43.4	32.1	23.6	15.3	5.1
Cattaraugus River (South Branch), NY	0.60	12.7	7.7	13.7	50.8	8.0
Genesee River, NY	0.99	24.2	17.2	18.9	27.6	7.8

Other studies describe the bioavailable phosphorus fractions from different systems. Fluvial sediments from two streams in Ontario were estimated to contain bioavailable phosphorus in amounts equal to 24 and 37% of the total particulate phosphorus (Williams *et al*., 1980). Urban runoff, mainly from residential areas of Madison, Wisconsin, contained bioavailable particulate phosphorus that averaged 30% of the total particulate phosphorus for 13 samples (Cowan and Lee, 1976). The authors also determined that up to 23% of the particulate phosphorus in snow samples, from the Madison area, was bioavailable. These results and the studies conducted by Sonzogni *et al*. 1980 suggest that generally less than 40% of the particulate phosphorus in diffuse tributary sources to the Great Lakes is biologically available.

The bioavailability of particulate phosphorus in deposited sediments is generally greater than that of suspended sediments, possibly due to the incorporation of phosphorus rich detrital material in the deposits. Release of bioavailable phosphorus from suspended sediment occurs mostly by chemical desorption, whereas bioavailable phosphorus associated with deposited sediments is released more slowly because the dominant process is microbial mineralization. A summary of bioavailable phosphorus study results for suspended and bedded sediments is presented in Table 2.

Table 2: Percent bioavailability of Particulate Phosphorus transported in several lake tributaries draining agricultural watersheds and in deposited lake sediments (Sharpley *et al*. 1995).

Location	Procedure	Bioavailable %	Total P g kg-1	Reference
Suspended Sediment in Tributaries				
Indiana	Bioassay	21	0.2-0.7	Dorich *et al.* (1985)
	NaOH	8		
Great Lakes	Bioassay	0-47	0.5-1.4	DePinto *et al.* (1981)
	NaOH	4-38		
Lake Erie	NaOH	14-42	0.6-1.5	Logan *et al.* (1979)
Amazon R.	NaOH	21-38	0.4-1.1	Engle & Sarnelle (1990)
Deposited Sediments				
Quebec	Resin	8-25	0.8-1.2	Carignan & Kalff (1980)
Netherlands	Bioassay	0-41	0.4-4.8	Klapwijk *et al.* (1982)
Wisconsin	NaOH	60-95	0.6-3.9	Sagher *et al.* (1975)
Lake Ontario	NaOH	2-60		Bannerman et al. 1975
Great Lakes	NaOH	27	0.4-1.4	Williams *et al.* (1980)

Young and DePinto (1982) developed a relationship between the reactive NaOH-extractable phosphorus and ultimate bioavailable phosphorus for tributary suspended solids as:

$$UAAP = 1.08\ NaOH\ extractableP - 0.008$$

where: *UAAP* is the ultimate bioavailable phosphorus.

Solids in natural waters have two primary origins. The solids produced by the photosynthesis process are termed as autochthonous and the solids originating in the drainage basin are termed as allochthonous. DePinto *et al*. (1986) have explored the difference between the bioavailability of allochthonous and autochthonous particulate phosphorus to estimate the form and reactivity of phosphorus loadings to the Lower Laurentian Great Lakes. The comparison and analysis of parallel bioassay and chemical fraction results on suspended sediments collected from 6 different lower Great Lakes tributaries revealed that the most reasonable surrogate measure of biologically available particulate phosphorus is the reactive NaOH-extractable phosphorus (R-NaOH-P) fraction (DePinto *et al*., 1986). They found a very good correlation (r =0.7790, p<0.001) between R-NaOH-P and the bioassay-determined values of bioavailable phosphorus. The CDB-P and the sum of R-NaOH-P and

CDB-P (considered to be measure of non-apatite inorganic phosphorus in sediments) also correlated well with the ultimately bioavailable phosphorus. However, the decision to rely on the R-NaOH-P alone for estimation of bioavailable phosphorus was based on data from 17 of the 40 samples for which the distribution of phosphorus among the chemically defined fractions was determined before and after the bioassays. The authors also found an excellent correlation between the decrease in R-NaOH-P and algal uptake of phosphorus during bioassays on individual samples. This provided very strong evidence in favor of using the R-NaOH-P/ultimately-bioavailable phosphorus correlation to extrapolate their results to basin-wide data sets.

Attachment C

Basin Discharge Summary Sheets

Minnesota River

Basin Specific Total Phosphorus and Bioavailable Phosphorus Summary

Approximate basin area (sq. mi.): **14,939** *(in Minnesota)*

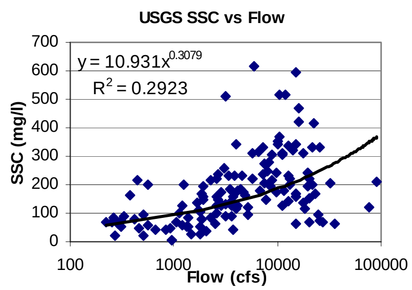
Representative USGS Gauge:	#05330000	Minnesota River near Jordan, MN
Representative MPCA EDA Site:	MWCC040	Minn River near Jordan at Co 9 bridge

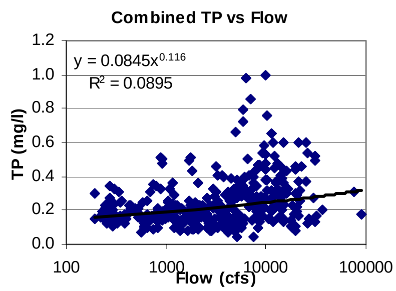
Approximate drainage area at gauge (sq. mi.): **16,200**
Total basin to gauged area multiplier: **0.922** *(<1 because only interested in area within Minnesota)*

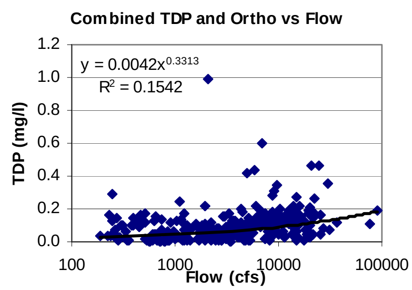
Compiled Water Quality Data

USGS (Water Years 1979-1998)	Count (n)
Suspended sediment concentration (SSC) mg/l:	**134**
Phosphorus, water, unfiltered (TP) (mg/l):	**171**
Phosphorus, water, filtered (TDP) (mg/l):	**166**
MPCA EDA Data Extraction (1985-1992)	
Phosphorus, total (TP) (mg/l as P):	**214**
Phosphorus, dissolved orthophosphate (mg/l P):	**135**

Rating Curves







Estimated Annual Basin Load (metric tons/year)

Representative Years		Suspended Sediment	Total Phosphorus	Total Dissolved Phosphorus	Total Particulate Phosphorus	Total Bioavailable Phosphorus	Fraction Bioavailable
Low Flow Year	1981	277,391	429	130	299	184	43%
	1990	329,196	472	156	316	213	45%
	2000	357,016	525	168	356	232	44%
	Average	*321,201*	*475*	*151*	*324*	*210*	*44%*
Average Flow Year	1985	935,399	1,230	447	783	588	48%
	1998	890,220	1,161	426	735	558	48%
	1999	1,049,252	1,370	501	869	658	48%
	Average	*958,291*	*1,254*	*458*	*796*	*601*	*48%*
High Flow Year	1986	1,915,830	2,280	926	1,354	1,170	51%
	1997	2,016,096	2,275	982	1,294	1,215	53%
	2001	2,398,943	2,433	1,183	1,250	1,408	58%
	Average	*2,110,290*	*2,330*	*1,030*	*1,299*	*1,264*	*54%*

Estimated Annual Basin Yield (lbs/acre/yr)

Flow Condition	Suspended Sediment	Total Phosphorus	Total Dissolved Phosphorus	Total Particulate Phosphorus	Total Bioavailable Phosphorus
Low Flow Year	74	0.11	0.03	0.07	0.05
Average Flow Year	221	0.29	0.11	0.18	0.14
High Flow Year	486	0.54	0.24	0.30	0.29

Estimated Annual Flow Weighted Mean Concentration (mg/l)

Flow Condition	Suspended Sediment	Total Phosphorus	Total Dissolved Phosphorus	Total Particulate Phosphorus	Total Bioavailable Phosphorus
Low Flow Year	152.7	0.226	0.072	0.154	0.100
Average Flow Year	186.9	0.245	0.089	0.155	0.117
High Flow Year	244.4	0.270	0.119	0.150	0.146

Upper Mississippi River

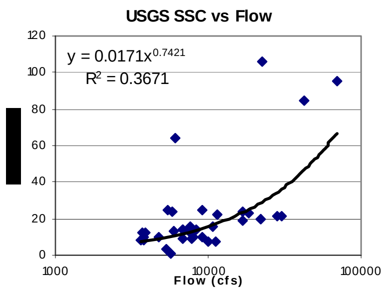
Basin Specific Total Phosphorus and Bioavailable Phosphorus Summary

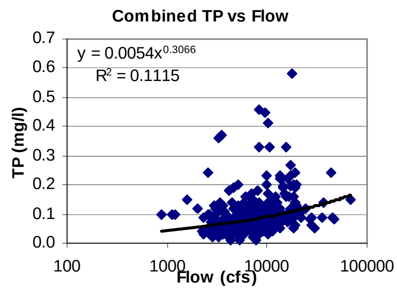
Approximate basin area (sq. mi.):	**20,100**	
Representative USGS Gauge:	#05288500	Mississippi River Near Anoka, MN
Representative MPCA EDA Site:	MWCC006	MISSISSIPPI R UPST L&D 1, 0.2MI DS FORD PKWY
Representative MPCA STORET Site:	S000-024	MISSISSIPPI R MPLS WATERWORKS INTAKE AT FRIDLEY
Approximate drainage area at gauge (sq. mi.):	**19,100**	
Total watershed to gauged area multiplier:	**1.052**	

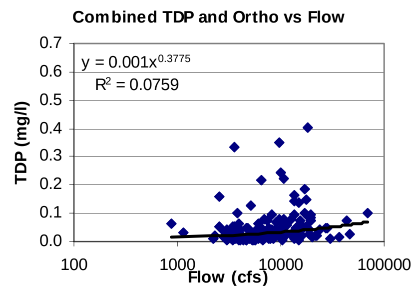
Compiled Water Quality Data

USGS (Water Years 1984-1998)	Count (n)
Suspended sediment concentration (SSC) mg/l:	**35**
Phosphorus, water, unfiltered (TP) (mg/l):	**25**
Phosphorus, water, filtered (TDP) (mg/l):	**25**
MPCA EDA Data Extraction (1985-1992)	
Phosphorus, total (TP) (mg/l as P):	**220**
Phosphorus, orthophosphate as P (mg/l P):	**133**
MPCA New STORET Data (1999-2002)	
Phosphorus as P (mg/l):	**15**

Rating Curves







Estimated Annual Basin Load (metric tons/year)

Representative Years		Suspended Sediment	Total Phosphorus	Total Dissolved Phosphorus	Total Particulate Phosphorus	Total Bioavailable Phosphorus	Fraction Bioavailable
Low Flow Year	1989	81,369	471	166	305	221	47%
	1990	90,080	520	184	336	244	47%
	2000	83,881	534	186	347	249	47%
	Average	*85,110*	*508*	*179*	*329*	*238*	*47%*
Average Flow Year	1982	241,673	1,045	387	658	505	48%
	1995	198,574	984	357	627	470	48%
	2002	197,596	961	350	611	460	48%
	Average	*212,614*	*997*	*365*	*632*	*478*	*48%*
High Flow Year	1986	511,754	1,946	737	1,209	954	49%
	1997	319,259	1,273	476	797	620	49%
	2001	397,499	1,418	540	877	698	49%
	Average	*409,504*	*1,545*	*584*	*961*	*757*	*49%*

Estimated Annual Basin Yield (lbs/acre/yr)

Flow Condition	Suspended Sediment	Total Phosphorus	Total Dissolved Phosphorus	Total Particulate Phosphorus	Total Bioavailable Phosphorus
Low Flow Year	15	0.087	0.031	0.056	0.041
Average Flow Year	36	0.170	0.062	0.108	0.082
High Flow Year	70	0.264	0.100	0.164	0.130

Estimated Annual Flow Weighted Mean Concentration (mg/l)

Flow Condition	Suspended Sediment	Total Phosphorus	Total Dissolved Phosphorus	Total Particulate Phosphorus	Total Bioavailable Phosphorus
Low Flow Year	14.3	0.085	0.030	0.055	0.040
Average Flow Year	21.4	0.100	0.037	0.064	0.048
High Flow Year	30.3	0.114	0.043	0.071	0.056

Lower Mississippi River

Basin Specific Total Phosphorus and Bioavailable Phosphorus Summary

Approximate basin area (sq. mi.): **6,317** *(in Minnesota)*

Representative USGS Gauge: #05355200 Cannon River at Welch, MN
Representative MPCA STORET Site: S001-784 CANNON R, BRG AT 9TH ST N IN CITY OF CANNON FALLS
Approximate drainage area at gauge (sq. mi.): **1,340**

Representative USGS Gauge: #05385000 Root River Near Houston, MN
Representative LTRMP Site: RO00.1M Root River near confluence with Mississippi River
Approximate drainage area at LTRMP site (sq.mi.) **1,660**
Total basin to gauged area multiplier: **2.998** *(assume Root River represents the remainder of the Lower Mississippi Basin in Minnesota)*

Compiled Water Quality Data

See Summary information on separate sheets for the Cannon and Root Rivers

Rating Curves

See Summary information on separate sheets for the Cannon and Root Rivers

Estimated Annual Basin Load (metric tons/year)

Flow Condition	Suspended Sediment	Total Phosphorus	Total Dissolved Phosphorus	Total Particulate Phosphorus	Total Bioavailable Phosphorus	Fraction Bioavailable
Low Flow Year	48,612	238	102	135	127	53%
Average Flow Year	342,383	789	237	552	336	43%
High Flow Year	971,031	1,940	573	1,368	819	42%

Estimated Annual Basin Yield (lbs/acre/yr)

Flow Condition	Suspended Sediment	Total Phosphorus	Total Dissolved Phosphorus	Total Particulate Phosphorus	Total Bioavailable Phosphorus
Low Flow Year	26.5	0.129	0.056	0.074	0.069
Average Flow Year	186	0.430	0.129	0.301	0.183
High Flow Year	528	1.056	0.312	0.744	0.446

Estimated Annual Flow Weighted Mean Concentration (mg/l)

Flow Condition	Suspended Sediment	Total Phosphorus	Total Dissolved Phosphorus	Total Particulate Phosphorus	Total Bioavailable Phosphorus
Low Flow Year	25	0.100	0.038	0.063	0.049
Average Flow Year	81	0.186	0.055	0.131	0.079
High Flow Year	150	0.286	0.079	0.207	0.116

Lower Mississippi River - Cannon River

Watershed Specific Total Phosphorus and Bioavailable Phosphorus Summary

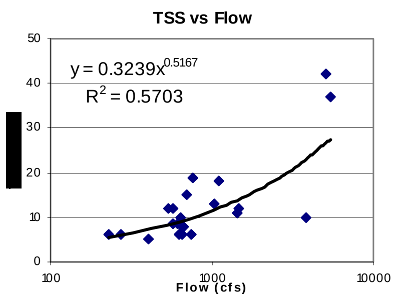
Approximate waterhsed area (sq. mi.): **1,340**

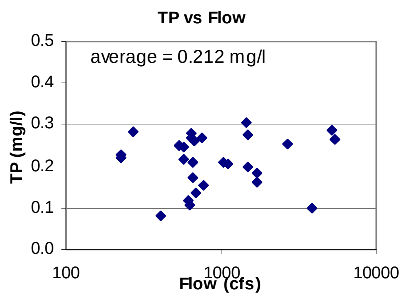
Representative USGS Gauge:	#05355200	Cannon River at Welch, MN
Representative MPCA STORET Site:	S001-784	CANNON R, BRG AT 9TH ST N IN CITY OF CANNON FALLS
Approximate drainage area at gauge (sq. mi.):	**1,340**	
Total watershed to gauged area multiplier:	**1.000**	

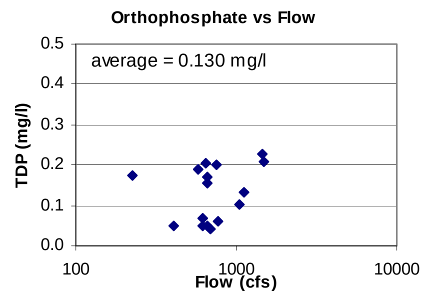
Compiled Water Quality Data

	Count (n)
No useful USGS water quality data available	
No useful MPCA EDA Data available	
MPCA New STORET Data (2001-2002)	
Total Suspended Sediment (TSS) (mg/l):	**22**
Phosphorus as P (mg/l):	**28**
Phosphorus, orthophosphate as P (mg/l):	**16**

Rating Curves







Estimated Annual Watershed Load (metric tons/year)

Representative Years		Suspended Sediment	Total Phosphorus	Total Dissolved Phosphorus	Total Particulate Phosphorus	Total Bioavailable Phosphorus	Fraction Bioavailable
Low Flow Year	1996	8,092	145	89	56	99	68%
	2002	6,775	127	78	49	86	68%
	Average	*7,433*	*136*	*83*	*53*	*93*	*68%*
Average Flow Year	1994	9,711	171	105	66	117	68%
	1998	19,624	229	140	89	156	68%
	Average	*14,668*	*200*	*123*	*77*	*137*	*68%*
High Flow Year	1973	*No flow data*	*No flow data*	*No flow data*	*No flow data*	*No flow data*	*No flow data*
	1974	*No flow data*	*No flow data*	*No flow data*	*No flow data*	*No flow data*	*No flow data*
	1993	41,890	404	247	156	276	68%
	Average	*41,890*	*404*	*247*	*156*	*276*	*68%*

Estimated Annual Watershed Yield (lbs/acre/yr)

Flow Condition	Suspended Sediment	Total Phosphorus	Total Dissolved Phosphorus	Total Particulate Phosphorus	Total Bioavailable Phosphorus
Low Flow Year	19	0.35	0.21	0.13	0.24
Average Flow Year	38	0.51	0.31	0.20	0.35
High Flow Year	107	1.04	0.63	0.40	0.71

Estimated Annual Flow Weighted Mean Concentration (mg/l)

Flow Condition	Suspended Sediment	Total Phosphorus	Total Dissolved Phosphorus	Total Particulate Phosphorus	Total Bioavailable Phosphorus
Low Flow Year	11.6	0.212	0.130	0.082	0.145
Average Flow Year	15.1	0.212	0.130	0.082	0.145
High Flow Year	22.0	0.212	0.130	0.082	0.145

Lower Mississippi River - Root River

Watershed Specific Total Phosphorus and Bioavailable Phosphorus Summary

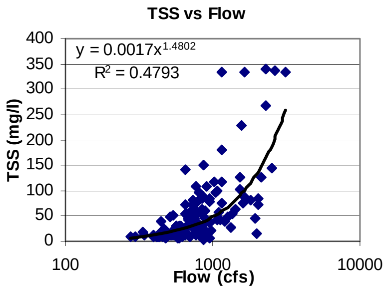
Approximate watershed area (sq. mi.): **1,660**

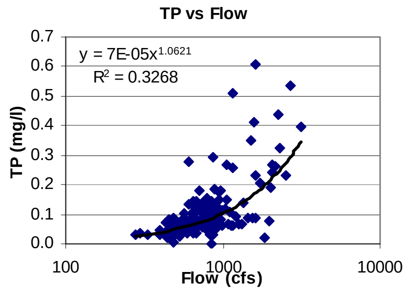
Representative USGS Gauge:	#05385000	Root River Near Houston, MN
Representative LTRMP Site:	RO00.1M	Root River near confluence with Mississippi River
Approximate drainage area at gauge (sq. mi.):	**1,270**	
Approximate drainage area at LTRMP site (sq.mi.):	**1,660**	
Total watershed to gauged area multiplier:	**1.307**	

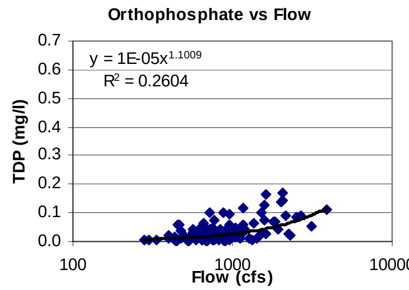
Compiled Water Quality Data

	Count (n)
LTRMP Data (1991-1998)	
Total Suspended Sediment (TSS) (mg/l):	**149**
Phosphorus as P (mg/l):	**140**
Phosphorus, orthophosphate as P (mg/l):	**151**

Rating Curves







Estimated Annual Watershed Load (metric tons/year)

Representative Years		Suspended Sediment	Total Phosphorus	Total Dissolved Phosphorus	Total Particulate Phosphorus	Total Bioavailable Phosphorus	Fraction Bioavailable
Low Flow Year	1977	13,734	34	6	28	11	33%
	2002	*No flow data*	*No flow data*	*No flow data*	*No flow data*	*No flow data*	*No flow data*
	Average	*13,734*	*34*	*6*	*28*	*11*	*33%*
Average Flow Year	1994	89,145	170	33	137	57	34%
	1998	129,464	224	44	180	76	34%
	Average	*109,304*	*197*	*38*	*158*	*67*	*34%*
High Flow Year	1973	282,818	476	101	375	168	35%
	1974	251,219	425	90	336	150	35%
	1993	395,664	636	135	501	225	35%
	Average	*309,900*	*513*	*108*	*404*	*181*	*35%*

Estimated Annual Watershed Yield (lbs/acre/yr)

Flow Condition	Suspended Sediment	Total Phosphorus	Total Dissolved Phosphorus	Total Particulate Phosphorus	Total Bioavailable Phosphorus
Low Flow Year	28	0.07	0.01	0.06	0.02
Average Flow Year	226	0.41	0.08	0.33	0.14
High Flow Year	642	1.06	0.22	0.84	0.38

Estimated Annual Flow Weighted Mean Concentration (mg/l)

Flow Condition	Suspended Sediment	Total Phosphorus	Total Dissolved Phosphorus	Total Particulate Phosphorus	Total Bioavailable Phosphorus
Low Flow Year	28.5	0.070	0.013	0.057	0.023
Average Flow Year	99.4	0.179	0.035	0.144	0.061
High Flow Year	184.4	0.306	0.065	0.241	0.108

Des Moines River

Basin Specific Total Phosphorus and Bioavailable Phosphorus Summary

Approximate basin area (sq. mi.): **1,535** *(in Minnesota)*

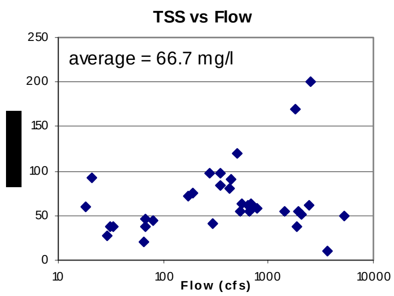
Representative USGS Gauge: #05476000 Des Moines River at Jackson, MN
Representative MPCA STORET Site: S000-027 DES MOINES R.-W FORK AT JACKSON

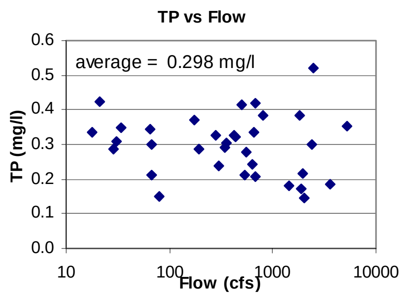
Approximate drainage area at gauge (sq. mi.): **1,250**
Total basin to gauged area multiplier: **1.228**

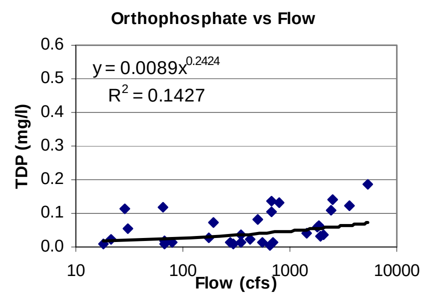
Compiled Water Quality Data

	Count (n)
No useful USGS water quality data available	
No useful MPCA EDA Data available	
MPCA New STORET Data (2001-2002)	
Total Suspended Sediment (TSS) (mg/l):	**34**
Phosphorus as P (mg/l):	**34**
Phosphorus, orthophosphate as P (mg/l):	**31**

Rating Curves







Estimated Annual Basin Load (metric tons/year)

Representative Years		Suspended Sediment	Total Phosphorus	Total Dissolved Phosphorus	Total Particulate Phosphorus	Total Bioavailable Phosphorus	Fraction Bioavailable
Low Flow Year	1989	3,609	16	1.6	14	4.2	26%
	1990	4,192	19	1.9	17	4.9	26%
	2000	5,896	26	2.9	23	7.1	27%
	Average	*4,566*	*20*	*2.2*	*18*	*5.4*	*27%*
Average Flow Year	1987	36,628	163	26	138	50	31%
	1991	31,848	142	25	117	46	32%
	1999	39,678	177	27	150	54	31%
	Average	*36,052*	*161*	*26*	*135*	*50*	*31%*
High Flow Year	1983	87,662	391	74	317	131	33%
	1984	81,950	366	76	290	128	35%
	1994	63,917	285	48	237	91	32%
	Average	*77,843*	*347*	*66*	*281*	*116*	*34%*

Estimated Annual Basin Yield (lbs/acre/yr)

Flow Condition	Suspended Sediment	Total Phosphorus	Total Dissolved Phosphorus	Total Particulate Phosphorus	Total Bioavailable Phosphorus
Low Flow Year	10	0.046	0.005	0.041	0.012
Average Flow Year	81	0.360	0.058	0.302	0.112
High Flow Year	174	0.778	0.147	0.630	0.261

Estimated Annual Flow Weighted Mean Concentration (mg/l)

Flow Condition	Suspended Sediment	Total Phosphorus	Total Dissolved Phosphorus	Total Particulate Phosphorus	Total Bioavailable Phosphorus
Low Flow Year	66.7	0.298	0.031	0.266	0.079
Average Flow Year	66.7	0.298	0.048	0.249	0.093
High Flow Year	66.7	0.298	0.056	0.242	0.099

Cedar River

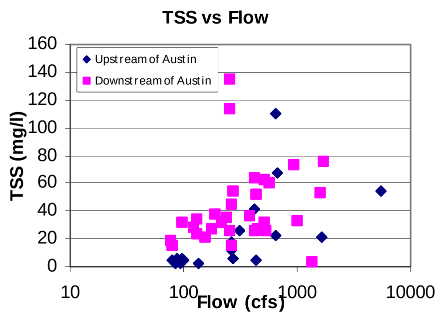
Basin Specific Total Phosphorus and Bioavailable Phosphorus Summary

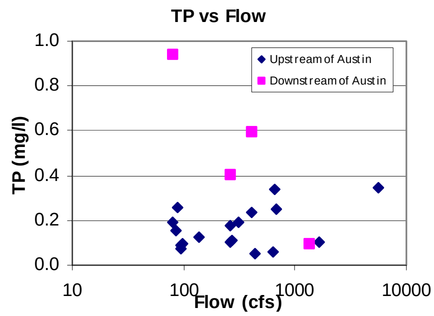
Approximate basin area (sq. mi.):	**1,028**	*(in Minnesota)*
Representative USGS Gauge:	#05457000	Cedar River near Austin, MN
Representative MPCA STORET Site:	S000-136	CEDAR RIVER AT CSAH-4, 3 MILES SOUTH OF AUSTIN
Representative MPCA STORET Site:	S000-137	CEDAR RIVER AT CSAH-2, 0.5 MILES EAST OF LANSING
Approximate drainage area at gauge (sq. mi.):	**399**	
Total basin to gauged area multiplier:	**2.576**	

Compiled Water Quality Data

	Count (n)
No useful USGS water quality data available	
No MPCA EDA Data Available	
MPCA New STORET Data (1999-2002)	
Total suspended solids (TSS) (mg/l):	**50**
Phosphorus as P (mg/l):	**22**

Rating Curves





The apparent impact of the Austin WWTP at the USGS gauge and insufficient data restrict the use of rating curves for developing annual load estimations and bioavailable fractions for the Cedar River basin.

Estimated Annual Basin Load (metric tons/year)

Using annual loads for the Des Moines River Basin based on similar land use characteristics, adjusted for drainage area

Flow Condition	Suspended Sediment	Total Phosphorus	Total Dissolved Phosphorus	Total Particulate Phosphorus	Total Bioavailable Phosphorus	Fraction Bioavailable
Low Flow Year	3,058	14	1.4	12	3.6	27%
Average Flow Year	24,144	108	17	90	34	31%
High Flow Year	52,132	233	44	188	78	34%

Estimated Annual Basin Yield (lb/acre/yr)

Using annual yields for the Des Moines River Basin based on similar land use characteristics

Flow Condition	Suspended Sediment	Total Phosphorus	Total Dissolved Phosphorus	Total Particulate Phosphorus	Total Bioavailable Phosphorus
Low Flow Year	10	0.046	0.005	0.041	0.012
Average Flow Year	81	0.360	0.058	0.302	0.112
High Flow Year	174	0.778	0.147	0.630	0.261

Estimated Annual Flow Weighted Mean Concentration (mg/l)

Using flow weighted mean concenctrations for the Des Moines River Basin based on similar land use characteristics

Flow Condition	Suspended Sediment	Total Phosphorus	Total Dissolved Phosphorus	Total Particulate Phosphorus	Total Bioavailable Phosphorus
Low Flow Year	66.7	0.298	0.031	0.266	0.079
Average Flow Year	66.7	0.298	0.048	0.249	0.093
High Flow Year	66.7	0.298	0.056	0.242	0.099

Missouri River

Basin Specific Total Phosphorus and Bioavailable Phosphorus Summary

Approximate basin area (sq. mi.): **1,782** *(in Minnesota)*

Representative USGS Gauge:	#06483270	Rock River at Rock Rapids, IA
Approximate drainage area at gauge (sq. mi.):	**788**	
Total basin to gauged area multiplier:	**2.261**	

Compiled Water Quality Data

Count (n)

No useful USGS water quality data available
No MPCA EDA Data available
No MPCA New STORET Data available

Rating Curves

Insufficient data restrict the use of rating curves for developing annual load estimations and bioavailable fractions for the Rock River watershed, and therefore, the Missouri Basin in Minnesota.

Estimated Annual Basin Load (metric tons/year)

Using annual loads for the Des Moines River Basin based on similar land use characteristics, adjusted for drainage area

Flow Condition	Suspended Sediment	Total Phosphorus	Total Dissolved Phosphorus	Total Particulate Phosphorus	Total Bioavailable Phosphorus	Fraction Bioavailable
Low Flow Year	5,300	24	2.5	21	6.3	27%
Average Flow Year	41,853	187	30	157	58	31%
High Flow Year	90,369	403	76	327	135	34%

Estimated Annual Basin Yield (lbs/acre/yr)

Using annual yields for the Des Moines River Basin based on similar land use characteristics

Flow Condition	Suspended Sediment	Total Phosphorus	Total Dissolved Phosphorus	Total Particulate Phosphorus	Total Bioavailable Phosphorus
Low Flow Year	10	0.046	0.005	0.041	0.012
Average Flow Year	81	0.360	0.058	0.302	0.112
High Flow Year	174	0.778	0.147	0.630	0.261

Estimated Annual Flow Weighted Mean Concentration (mg/l)

Using flow weighted mean concencntrations for the Des Moines River Basin based on similar land use characteristics

Flow Condition	Suspended Sediment	Total Phosphorus	Total Dissolved Phosphorus	Total Particulate Phosphorus	Total Bioavailable Phosphorus
Low Flow Year	66.7	0.298	0.031	0.266	0.079
Average Flow Year	66.7	0.298	0.048	0.249	0.093
High Flow Year	66.7	0.298	0.056	0.242	0.099

St. Croix River

Basin Specific Total Phosphorus and Bioavailable Phosphorus Summary

Approximate basin area (sq. mi.):	**3,528**	*(in Minnesota)*
Representative USGS Gauge:	#05338500	Snake River near Pine City, MN
Representative MPCA STORET Site:	S000-198	SNAKE R BRIDGE AT CSAH-9, 2 MI NE OF PINE CITY
Approximate drainage area at gauge (sq. mi.):	**958**	
Representative USGS Gauge:	#05336700	Kettle River below Sandstone, MN
Representative MPCA STORET Site:	S000-121	KETTLE R BRIDGE ON MN-48, 4.5 MI E OF HINCKLEY
Approximate drainage area at gauge (sq. mi.):	**868**	
Total basin to gauged area multiplier:	**1.932**	*(assume Snake and Kettle Rivers equally represent the remainder of the St. Croix Basin in Minnesota)*

Compiled Water Quality Data

See Summary information on separate sheets for the Snake and Kettle Rivers

Rating Curves

See Summary information on separate sheets for the Snake and Kettle Rivers

Estimated Annual Basin Load (metric tons/year)

Representative Years		Suspended Sediment	Total Phosphorus	Total Dissolved Phosphorus	Total Particulate Phosphorus	Total Bioavailable Phosphorus	Fraction Bioavailable
Low Flow Year	1987	*No flow data*	*No flow data*	*No flow data*	*No flow data*	*No flow data*	*No flow data*
	1988	*No flow data*	*No flow data*	*No flow data*	*No flow data*	*No flow data*	*No flow data*
	1998	6,355	85	29	56	39	46%
	Average	*6,355*	*85*	*29*	*56*	*39*	*46%*
Average Flow Year	1994	12,068	145	48	97	66	45%
	1995	14,100	181	60	120	82	45%
	1999	11,108	139	46	92	63	46%
	Average	*12,426*	*155*	*52*	*103*	*70*	*45%*
High Flow Year	1986	*No flow data*	*No flow data*	*No flow data*	*No flow data*	*No flow data*	*No flow data*
	2001	28,605	254	78	176	110	43%
	Average	*28,605*	*254*	*78*	*176*	*110*	*43%*

Estimated Annual Basin Yield (lbs/acre/yr)

Flow Condition	Suspended Sediment	Total Phosphorus	Total Dissolved Phosphorus	Total Particulate Phosphorus	Total Bioavailable Phosphorus
Low Flow Year	6.2	0.083	0.029	0.054	0.038
Average Flow Year	12	0.151	0.050	0.100	0.068
High Flow Year	28	0.247	0.076	0.171	0.107

Estimated Annual Flow Weighted Mean Concentration (mg/l)

Flow Condition	Suspended Sediment	Total Phosphorus	Total Dissolved Phosphorus	Total Particulate Phosphorus	Total Bioavailable Phosphorus
Low Flow Year	4	0.068	0.024	0.045	0.032
Average Flow Year	5	0.071	0.024	0.047	0.032
High Flow Year	8	0.075	0.024	0.052	0.033

St. Croix River - Snake River

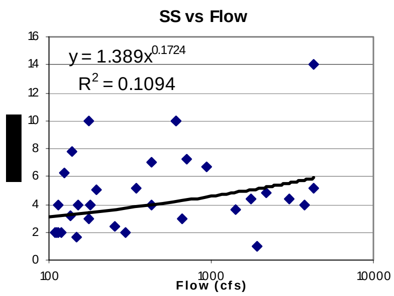
Watershed Specific Total Phosphorus and Bioavailable Phosphorus Summary

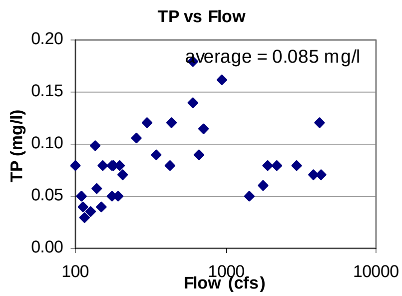
Approximate watershed area (sq. mi.):	**958**	
Representative USGS Gauge:	#05338500	Snake River near Pine City, MN
Representative MPCA STORET Site:	S000-198	SNAKE R BRIDGE AT CSAH-9, 2 MI NE OF PINE CITY
Approximate drainage area at gauge (sq. mi.):	**958**	
Total watershed to gauged area multiplier:	**1.000**	

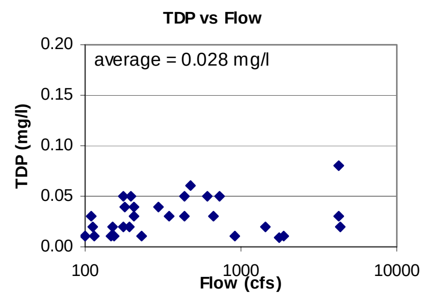
Compiled Water Quality Data

USGS (Water Years 1979-1998)	Count (n)	
Suspended sediment concentration (SSC) mg/l:	**13**	
Phosphorus, water, unfiltered (TP) (mg/l):	**15**	
Phosphorus, water, filtered (TDP) (mg/l):	**12**	*(excluded one outlier)*
Orthophosphate, water, filtered, as P (mg/l):	**10**	
No MPCA EDA data available		
MPCA New STORET Data (1999-2002)		
Total suspended solids (TSS) (mg/l):	**20**	*(excluded one outlier)*
Phosphorus as P (mg/l):	**21**	
Phosphorus, orthophosphate as P (mg/l):	**10**	

Rating Curves







Estimated Annual Watershed Load (metric tons/year)

Representative Years		Suspended Sediment	Total Phosphorus	Total Dissolved Phosphorus	Total Particulate Phosphorus	Total Bioavailable Phosphorus	Fraction Bioavailable
Low Flow Year	1987	*No flow data*	*No flow data*	*No flow data*	*No flow data*	*No flow data*	*No flow data*
	1988	*No flow data*	*No flow data*	*No flow data*	*No flow data*	*No flow data*	*No flow data*
	1998	1,117	23	8	15	11	45%
	Average	*1,117*	*23*	*8*	*15*	*11*	*45%*
Average Flow Year	1994	2,325	43	14	28	19	45%
	1995	3,335	59	20	39	27	45%
	1999	2,017	38	13	25	17	45%
	Average	*2,559*	*47*	*16*	*31*	*21*	*45%*
High Flow Year	1986	*No flow data*	*No flow data*	*No flow data*	*No flow data*	*No flow data*	*No flow data*
	2001	4,968	74	25	50	34	45%
	Average	*4,968*	*74*	*25*	*50*	*34*	*45%*

Estimated Annual Watershed Yield (lbs/acre/yr)

Flow Condition	Suspended Sediment	Total Phosphorus	Total Dissolved Phosphorus	Total Particulate Phosphorus	Total Bioavailable Phosphorus
Low Flow Year	4.0	0.083	0.028	0.055	0.038
Average Flow Year	9	0.168	0.056	0.112	0.076
High Flow Year	18	0.267	0.089	0.178	0.121

Estimated Annual Flow Weighted Mean Concentration (mg/l)

Flow Condition	Suspended Sediment	Total Phosphorus	Total Dissolved Phosphorus	Total Particulate Phosphorus	Total Bioavailable Phosphorus
Low Flow Year	4.1	0.085	0.028	0.057	0.039
Average Flow Year	4.6	0.085	0.028	0.057	0.039
High Flow Year	5.7	0.085	0.028	0.057	0.039

St. Croix River - Kettle River

Watershed Specific Total Phosphorus and Bioavailable Phosphorus Summary

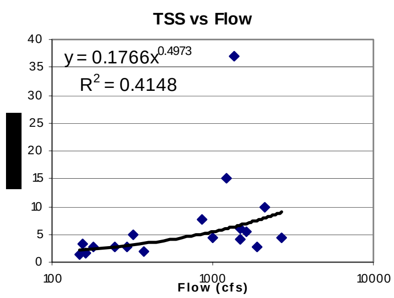
Approximate watershed area (sq. mi.): **868**

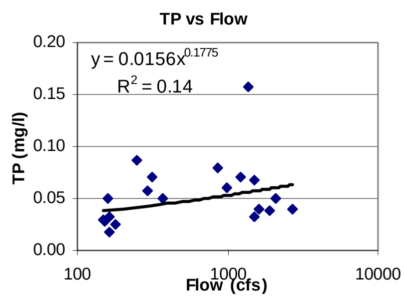
Representative USGS Gauge:	#05336700	Kettle River below Sandstone, MN
Representative MPCA STORET Site:	S000-121	KETTLE R BRIDGE ON MN-48, 4.5 MI E OF HINCKLEY
Approximate drainage area at gauge (sq. mi.):	**868**	
Total watershed to gauged area multiplier:	**1.000**	

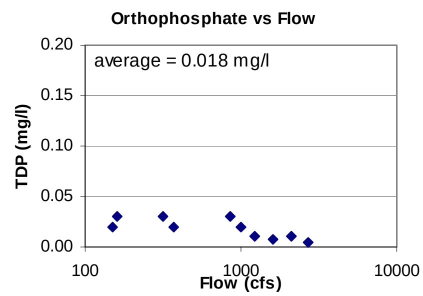
Compiled Water Quality Data

	Count (n)
No useful USGS water quality data available	
No MPCA EDA data available	
MPCA New STORET Data (1999-2002)	
Total suspended solids (TSS) (mg/l):	**19**
Phosphorus as P (mg/l):	**20**
Phosphorus, orthophosphate as P (mg/l):	**10**

Rating Curves







Estimated Annual Watershed Load (metric tons/year)

Representative Years		Suspended Sediment	Total Phosphorus	Total Dissolved Phosphorus	Total Particulate Phosphorus	Total Bioavailable Phosphorus	Fraction Bioavailable
Low Flow Year	1987	1,443	17	6.4	10.2	8.2	50%
	1988	1,408	14	5.2	8.9	6.8	48%
	1998	2,172	21	7.4	13.5	9.8	47%
	Average	*1,674*	*17*	*6.3*	*10.9*	*8.3*	*48%*
Average Flow Year	1994	3,921	33	11	22	15	45%
	1995	3,963	34	11	23	15	45%
	1999	3,732	34	11	22	15	46%
	Average	*3,872*	*33*	*11*	*22*	*15*	*45%*
High Flow Year	1986	11,476	76	22	54	32	42%
	2001	9,837	57	16	41	23	40%
	Average	*10,657*	*67*	*19*	*48*	*27*	*41%*

Estimated Annual Watershed Yield (lbs/acre/yr)

Flow Condition	Suspended Sediment	Total Phosphorus	Total Dissolved Phosphorus	Total Particulate Phosphorus	Total Bioavailable Phosphorus
Low Flow Year	6.6	0.068	0.025	0.043	0.033
Average Flow Year	15	0.132	0.044	0.088	0.060
High Flow Year	42	0.264	0.074	0.189	0.108

Estimated Annual Flow Weighted Mean Concentration (mg/l)

Flow Condition	Suspended Sediment	Total Phosphorus	Total Dissolved Phosphorus	Total Particulate Phosphorus	Total Bioavailable Phosphorus
Low Flow Year	4.8	0.049	0.018	0.031	0.024
Average Flow Year	6.3	0.055	0.018	0.036	0.025
High Flow Year	10.5	0.065	0.018	0.047	0.027

Lake Superior

Basin Specific Total Phosphorus and Bioavailable Phosphorus Summary

Approximate basin area (sq. mi.):	**6,149**	*(in Minnesota)*
Representative USGS Gauge:	#04024000	St. Louis River at Scanlon, MN
Representative MPCA EDA Site:	SL 297	ST. LOUIS RIVER AT USH-61 BRIDGE
Representative MPCA STORET Site:	S000-046	ST LOUIS R. OLD USH-61 AT SCANLON
Approximate drainage area at gauge (sq. mi.):	**3,430**	
Total St. Louis River watershed area (sq. mi.):	**3,634**	*(includes a small portion in Wisconsin)*
Total watershed to gauged area multiplier:	**1.059**	
Representative USGS Gauge:	#04014500	Baptism River near Beaver Bay, MN
Representative MPCA EDA Site:	110	BAPTISM RIVER
Approximate drainage area at gauge (sq. mi.):	**140**	

Lake Superior drainage area outside of St. Louis River (sq. mi.): **2,515**
Assume Baptism represents this area, gauged area multiplier: **17.964**

Compiled Water Quality Data

See Summary information on separate sheets for the St. Louis and Baptism Rivers

Rating Curves

See Summary information on separate sheets for the St. Louis and Baptism Rivers

Estimated Annual Basin Load (metric tons/year)

Representative Years		Suspended Sediment	Total Phosphorus	Total Dissolved Phosphorus	Total Particulate Phosphorus	Total Bioavailable Phosphorus	Fraction Bioavailable
Low Flow Year	1980	12,231	40	8	33	13	33%
	1988	12,461	40	7	32	13	33%
	1990	15,918	45	10	35	17	37%
	Average	*13,537*	*42*	*8*	*33*	*14*	*35%*
Average Flow Year	1981	24,474	70	13	58	23	33%
	1992	27,885	80	16	63	28	35%
	1993	30,945	83	17	66	29	35%
	Average	*27,768*	*78*	*15*	*62*	*26*	*34%*
High Flow Year	1983	39,490	104	20	84	35	34%
	1984	34,813	95	18	77	32	34%
	Average	*37,152*	*100*	*19*	*81*	*34*	*34%*

Estimated Annual Basin Yield (lbs/acre/year)

Flow Condition	Suspended Sediment	Total Phosphorus	Total Dissolved Phosphorus	Total Particulate Phosphorus	Total Bioavailable Phosphorus
Low Flow Year	7.6	0.023	0.005	0.019	0.008
Average Flow Year	15.5	0.043	0.008	0.035	0.015
High Flow Year	20.8	0.056	0.011	0.045	0.019

Estimated Annual Flow Weighted Mean Concentration (mg/l)

Flow Condition	Suspended Sediment	Total Phosphorus	Total Dissolved Phosphorus	Total Particulate Phosphorus	Total Bioavailable Phosphorus
Low Flow Year	11	0.030	0.011	0.019	0.014
Average Flow Year	14	0.033	0.011	0.022	0.015
High Flow Year	15	0.035	0.011	0.023	0.015

Lake Superior - St. Louis River

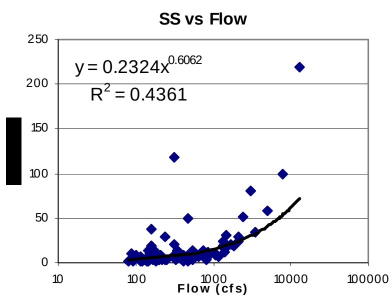
Watershed Specific Total Phosphorus and Bioavailable Phosphorus Summary

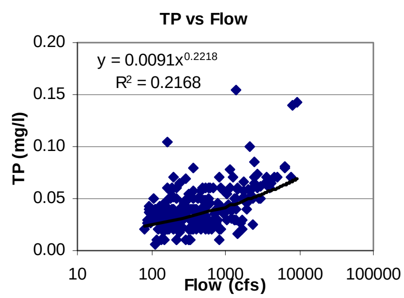
Approximate watershed area (sq. mi.):	**3,430**	
Representative USGS Gauge:	#04024000	St. Louis River at Scanlon, MN
Representative MPCA EDA Site:	SL 297	ST. LOUIS RIVER AT USH-61 BRIDGE
Representative MPCA STORET Site:	S000-046	ST LOUIS R. OLD USH-61 AT SCANLON
Approximate drainage area at gauge (sq. mi.):	**3,430**	
Total watershed to gauged area multiplier:	**1.000**	

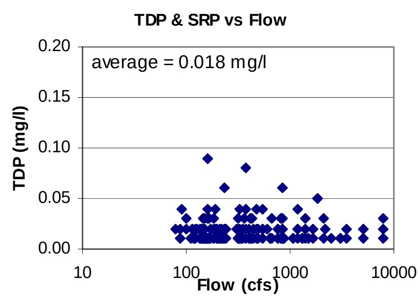
Compiled Water Quality Data

USGS (Water Years 1979-1994)	Count (n)	
Suspended sediment concentration (SSC) mg/l:	**98**	
Phosphorus, water, unfiltered (TP) (mg/l):	**99**	*(excluded one outlier)*
Phosphorus, water, filtered (TDP) (mg/l):	**99**	*(excluded one outlier)*
Orthophosphate, water, filtered, as P (SRP) (mg/l):	**80**	
MPCA EDA (Water Year 1979-1996)		
Phosphorus, Total (mg/l as P):	**158**	
MPCA New STORET Data (2001)		
Phosphorus as P (mg/l):	**8**	

Rating Curves







Estimated Annual Watershed Load (metric tons/year)

Representative Years		Suspended Sediment	Total Phosphorus	Total Dissolved Phosphorus	Total Particulate Phosphorus	Total Bioavailable Phosphorus	Fraction Bioavailable
Low Flow Year	1980	3,796	11.3	5.4	5.9	6.5	57%
	1988	3,993	11.0	5.1	5.9	6.2	56%
	1990	8,203	19.9	8.4	11.4	10.5	53%
	Average	*5,331*	*14.1*	*6.3*	*7.7*	*7.7*	*55%*
Average Flow Year	1981	9,847	22.4	9.2	13.3	11.6	52%
	1992	13,091	30.9	12.6	18.3	15.9	52%
	1993	15,885	33.7	13.1	20.6	16.8	50%
	Average	*12,941*	*29.0*	*11.6*	*17.4*	*14.8*	*51%*
High Flow Year	1983	19,877	41.6	15.9	25.7	20.5	49%
	1984	16,025	35.1	13.9	21.3	17.7	50%
	Average	*17,951*	*38.3*	*14.9*	*23.5*	*19.1*	*50%*

Estimated Annual Watershed Yield (lbs/acre/year)

Flow Condition	Suspended Sediment	Total Phosphorus	Total Dissolved Phosphorus	Total Particulate Phosphorus	Total Bioavailable Phosphorus
Low Flow Year	5.3	0.014	0.006	0.008	0.008
Average Flow Year	13.0	0.029	0.012	0.017	0.015
High Flow Year	18.0	0.038	0.015	0.024	0.019

Estimated Annual Flow Weighted Mean Concentration (mg/l)

Flow Condition	Suspended Sediment	Total Phosphorus	Total Dissolved Phosphorus	Total Particulate Phosphorus	Total Bioavailable Phosphorus
Low Flow Year	14.7	0.040	0.018	0.022	0.022
Average Flow Year	19.9	0.045	0.018	0.027	0.023
High Flow Year	21.7	0.046	0.018	0.028	0.023

Lake Superior - Baptism River

Watershed Specific Total Phosphorus and Bioavailable Phosphorus Summary

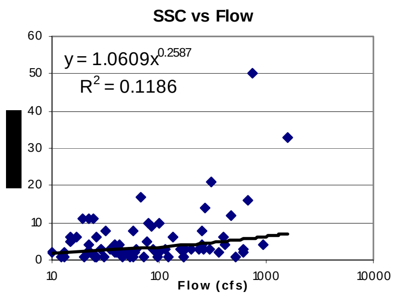
Approximate watershed area (sq. mi.): **140**

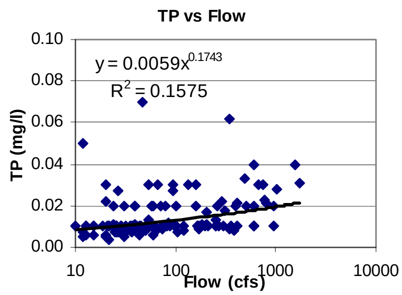
Representative USGS Gauge:	#04014500	Baptism River near Beaver Bay, MN
Representative MPCA EDA Site:	110	BAPTISM RIVER
Approximate drainage area at gauge (sq. mi.):	**140**	
Total watershed to gauged area multiplier:	**1.000**	

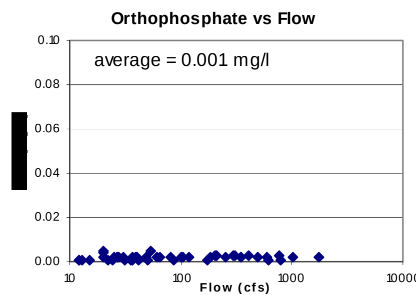
Compiled Water Quality Data

USGS (Water Years 1979-1993)	Count (n)	
Suspended sediment concentration (SSC) mg/l:	**75**	
Phosphorus, water, unfiltered (TP) (mg/l):	**71**	*(excluded three outliers)*
MPCA EDA (Water Year 1979-1983)		
Phosphorus as P (mg/l):	**59**	*(excluded one outlier)*
Phosphorus, orthophosphate as P (mg/l):	**48**	*(adjusted non-detects to 1/2 the detection limit)*
No MPCA New STORET data available		

Rating Curves







Estimated Annual Watershed Load (metric tons/year)

Representative Years		Suspended Sediment	Total Phosphorus	Total Dissolved Phosphorus	Total Particulate Phosphorus	Total Bioavailable Phosphorus	Fraction Bioavailable
Low Flow Year	1980	457	1.56	0.10	1.46	0.36	23%
	1988	458	1.56	0.10	1.46	0.36	23%
	1990	402	1.34	0.08	1.26	0.31	23%
	Average	*439*	*1.49*	*0.09*	*1.39*	*0.34*	*23%*
Average Flow Year	1981	782	2.60	0.16	2.44	0.60	23%
	1992	780	2.61	0.16	2.45	0.60	23%
	1993	786	2.61	0.16	2.45	0.60	23%
	Average	*783*	*2.61*	*0.16*	*2.45*	*0.60*	*23%*
High Flow Year	1983	1,026	3.35	0.19	3.16	0.76	23%
	1984	993	3.23	0.19	3.05	0.73	23%
	Average	*1,009*	*3.29*	*0.19*	*3.10*	*0.75*	*23%*

Estimated Annual Watershed Yield (lb/acre/year)

Flow Condition	Suspended Sediment	Total Phosphorus	Total Dissolved Phosphorus	Total Particulate Phosphorus	Total Bioavailable Phosphorus
Low Flow Year	11	0.037	0.002	0.034	0.008
Average Flow Year	19	0.064	0.004	0.060	0.015
High Flow Year	25	0.081	0.005	0.076	0.018

Estimated Annual Flow Weighted Mean Concentration (mg/l)

Flow Condition	Suspended Sediment	Total Phosphorus	Total Dissolved Phosphorus	Total Particulate Phosphorus	Total Bioavailable Phosphorus
Low Flow Year	4.7	0.016	0.001	0.015	0.004
Average Flow Year	5.0	0.017	0.001	0.016	0.004
High Flow Year	5.3	0.017	0.001	0.016	0.004

Rainy River

Basin Specific Total Phosphorus and Bioavailable Phosphorus Summary

Approximate basin area (sq. mi.): **11,236** *(in Minnesota)*

Representative USGS Gauge: #05133500 Rainy River at Manitou Rapids, MN

Approximate drainage area at gauge (sq. mi.):	**19,400**	*(includes drainage from Canada)*
Weighting factor for Rainy River	**0.290**	*(assume drainage area at this gauge is representative of half of the Rainy River basin in Minnesota)*

Representative USGS Gauge: #05131500 Little Fork River at Littlefork, MN

Approximate drainage area at gauge (sq. mi.):	**1,680**	
Weighting factor for Rainy River basin:	**3.344**	*(assume Little Fork is representative of half of the Rainy River basin in Minnesota)*

Compiled Water Quality Data

See Summary information on separate sheets for the Rainy and Little Fork Rivers

Rating Curves

See Summary information on separate sheets for the Rainy and Little Fork Rivers

Estimated Annual Basin Load (metric tons/year)

Representative Years		Suspended Sediment	Total Phosphorus	Total Dissolved Phosphorus	Total Particulate Phosphorus	Total Bioavailable Phosphorus	Fraction Bioavailable
Low Flow Year	1977	134,285	183	64	118	86	47%
	1980	89,597	176	70	106	89	50%
	2002	173,386	309	121	188	155	50%
	Average	*132,422*	*223*	*85*	*137*	*110*	*49%*
Average Flow Year	1992	145,574	286	114	172	145	51%
	1993	204,907	341	128	213	167	49%
	1997	301,469	411	146	266	193	47%
	Average	*217,316*	*346*	*129*	*217*	*168*	*49%*
High Flow Year	1975	437,618	470	154	316	210	45%
	1996	421,768	514	176	338	237	46%
	2001	541,876	600	198	402	270	45%
	Average	*467,087*	*528*	*176*	*352*	*239*	*45%*

Estimated Annual Basin Yield (lbs/acre/yr)

Flow Condition	Suspended Sediment	Total Phosphorus	Total Dissolved Phosphorus	Total Particulate Phosphorus	Total Bioavailable Phosphorus
Low Flow Year	41	0.068	0.026	0.042	0.034
Average Flow Year	66	0.106	0.040	0.066	0.051
High Flow Year	143	0.162	0.054	0.108	0.073

Estimated Annual Flow Weighted Mean Concentration (mg/l)

Flow Condition	Suspended Sediment	Total Phosphorus	Total Dissolved Phosphorus	Total Particulate Phosphorus	Total Bioavailable Phosphorus
Low Flow Year	28	0.047	0.018	0.029	0.023
Average Flow Year	30	0.048	0.018	0.030	0.023
High Flow Year	47	0.054	0.018	0.036	0.024

Rainy River - Rainy River

Watershed Specific Total Phosphorus and Bioavailable Phosphorus Summary

Approximate watershed area (sq. mi.):	**11,236**	*(in Minnesota)*
Representative USGS Gauge:	#05133500	Rainy River at Manitou Rapids, MN
Approximate drainage area at gauge (sq. mi.):	**19,400**	
Total watershed to gauged area multiplier:	**1.000**	

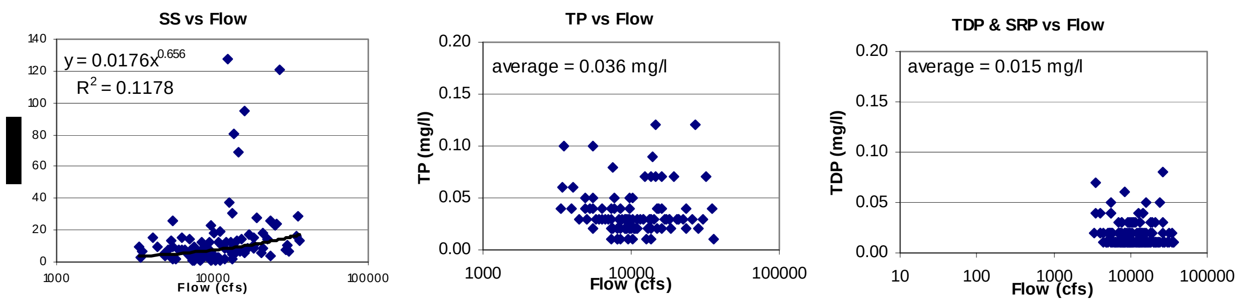
Compiled Water Quality Data

USGS (Water Years 1979-1994)	Count (n)	
Suspended sediment concentration (SSC) mg/l:	**104**	
Phosphorus, water, unfiltered (TP) (mg/l):	**102**	*(excluded 2 outliers)*
Phosphorus, water, filtered (TDP) (mg/l):	**104**	*(non-detects set to 1/2 the D.L.)*
Orthophosphate, water, filtered, as P (SRP) (mg/l):	**79**	

No MPCA EDA data available

MPCA New STORET data available

Rating Curves



Estimated Annual Watershed Load (metric tons/year)

Representative Years		Suspended Sediment	Total Phosphorus	Total Dissolved Phosphorus	Total Particulate Phosphorus	Total Bioavailable Phosphorus	Fraction Bioavailable
Low Flow Year	1977	43,177	186	78	108	98	53%
	1980	43,513	232	98	134	122	53%
	2002	175,498	488	206	283	257	53%
	Average	*87,396*	*302*	*127*	*175*	*159*	*53%*
Average Flow Year	1992	134,443	452	190	262	238	53%
	1993	136,157	462	195	267	243	53%
	1997	149,444	475	200	275	250	53%
	Average	*140,015*	*463*	*195*	*268*	*243*	*53%*
High Flow Year	1975	150,691	476	200	275	250	53%
	1996	237,705	629	265	364	330	53%
	2001	270,482	653	275	378	343	53%
	Average	*219,626*	*586*	*247*	*339*	*308*	*53%*

Estimated Annual Watershed Yield (lbs/acre/yr)

Flow Condition	Suspended Sediment	Total Phosphorus	Total Dissolved Phosphorus	Total Particulate Phosphorus	Total Bioavailable Phosphorus
Low Flow Year	27	0.092	0.039	0.054	0.049
Average Flow Year	43	0.142	0.060	0.082	0.074
High Flow Year	67	0.179	0.076	0.104	0.094

Estimated Annual Flow Weighted Mean Concentration (mg/l)

Flow Condition	Suspended Sediment	Total Phosphorus	Total Dissolved Phosphorus	Total Particulate Phosphorus	Total Bioavailable Phosphorus
Low Flow Year	9.2	0.036	0.015	0.021	0.019
Average Flow Year	10.8	0.036	0.015	0.021	0.019
High Flow Year	13.2	0.036	0.015	0.021	0.019

Rainy River - Little Fork River

Watershed Specific Total Phosphorus and Bioavailable Phosphorus Summary

Approximate watershed area (sq. mi.): **1,680**

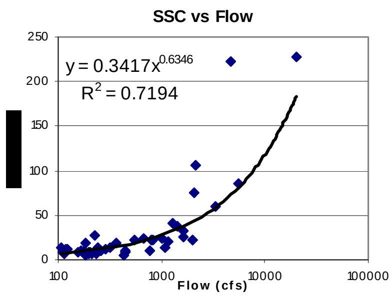
Representative USGS Gauge:	#05131500	Little Fork River at Littlefork, MN
Approximate drainage area at gauge (sq. mi.):	**1,680**	
Total watershed to gauged area multiplier:	**1.000**	

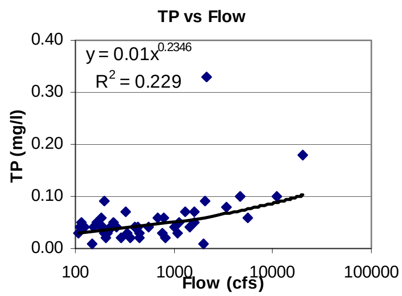
Compiled Water Quality Data

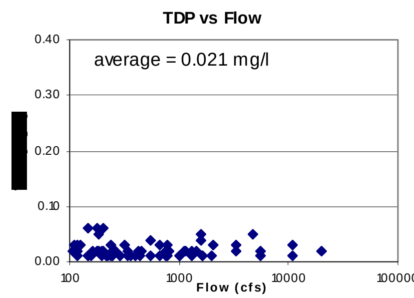
USGS (Water Years 1979-1986)	Count (n)	
Suspended sediment concentration (SSC) mg/l:	**44**	
Phosphorus, water, unfiltered (TP) (mg/l):	**48**	
Phosphorus, water, filtered (TDP) (mg/l):	**47**	*(excluded one outlier)*
Orthophosphate, water, filtered, as P (SRP) (mg/l):	**22**	*(excluded one outlier)*

No MPCA EDA data available
No MPCA New STORET data available

Rating Curves







Estimated Annual Watershed Load (metric tons/year)

Representative Years		Suspended Sediment	Total Phosphorus	Total Dissolved Phosphorus	Total Particulate Phosphorus	Total Bioavailable Phosphorus	Fraction Bioavailable
Low Flow Year	1977	36,417	39	12	26	17	45%
	1980	23,025	33	12	20	16	49%
	2002	36,651	50	18	32	24	48%
	Average	*32,031*	*40*	*14*	*26*	*19*	*47%*
Average Flow Year	1992	31,890	46	17	29	23	49%
	1993	49,484	62	22	40	29	46%
	1997	77,209	82	26	56	36	44%
	Average	*52,861*	*63*	*22*	*42*	*29*	*46%*
High Flow Year	1975	117,815	99	29	71	41	42%
	1996	105,540	99	30	70	42	43%
	2001	138,619	123	35	87	51	42%
	Average	*120,658*	*107*	*31*	*76*	*45*	*42%*

Estimated Annual Watershed Yield (lbs/acre/yr)

Flow Condition	Suspended Sediment	Total Phosphorus	Total Dissolved Phosphorus	Total Particulate Phosphorus	Total Bioavailable Phosphorus
Low Flow Year	66	0.083	0.030	0.053	0.039
Average Flow Year	108	0.130	0.044	0.085	0.060
High Flow Year	247	0.219	0.064	0.155	0.092

Estimated Annual Flow Weighted Mean Concentration (mg/l)

Flow Condition	Suspended Sediment	Total Phosphorus	Total Dissolved Phosphorus	Total Particulate Phosphorus	Total Bioavailable Phosphorus
Low Flow Year	47.4	0.059	0.021	0.038	0.028
Average Flow Year	49.5	0.061	0.021	0.040	0.028
High Flow Year	81.1	0.072	0.021	0.051	0.030

Red River

Basin Specific Total Phosphorus and Bioavailable Phosphorus Summary

Approximate basin area (sq. mi.): **17,741** *(in Minnesota)*

Representative USGS Gauge: #05046000 Otter Tail River Below Orwell Dam near Fergus Falls, MN
Representative MPCA STORET Site: S002-003 OTTERTAIL R BLW ORWELL DAM, CSAH-15, 8 MI SW OF FERGUS FALLS
Approximate drainage area at gauge (sq. mi.): **1,740**
Weighting factor for Red River Basin: **1.00** *(assume Otter Tail watershed is not representative of other portions of the Red River Basin)*

Representative USGS Gauge: #05064000 Wild Rice River at Hendrum, MN
Representative MPCA STORET Site: S000-216 WILD RICE R. USH-75 N OF HENDRUM
Approximate drainage area at gauge (sq. mi.): **1,560**
Weighting factor for Red River Basin: **6.88** *(assume Wild Rice watershed is representative of the Red River Basin outside of the Otter Tail and Red Lake watersheds)*

Representative USGS Gauge: #05079000 Red Lake River at Crookston, MN
Representative MPCA STORET Site: S000-031 RED LAKE RIVER AT BRIDGE ON CSAH-15 AT FISHER
Approximate drainage area at gauge (sq. mi.): **5,270**
Weighting factor for Red River Basin: **1.00** *(assume Red Lake River watershed is not representative of other portions of the Red River Basin)*

Compiled Water Quality Data
See Summary information on separate sheets for the Otter Tail, Wild Rice, and Red Lake Rivers

Rating Curves
See Summary information on separate sheets for the Otter Tail, Wild Rice, and Red Lake Rivers

Estimated Annual Basin Load (metric tons/year)

Representative Years		Suspended Sediment	Total Phosphorus	Total Dissolved Phosphorus	Total Particulate Phosphorus	Total Bioavailable Phosphorus	Fraction Bioavailable
Low Flow Year	1989	308,644	388	127	261	174	45%
	1990	73,542	87	35	52	45	51%
	1991	71,252	89	36	53	45	51%
	Average	*151,146*	*188*	*66*	*122*	*88*	*47%*
Average Flow Year	1994	365,516	461	164	298	217	47%
	1995	495,399	615	213	401	286	46%
	2002	1,189,614	1,576	485	1,091	681	43%
	Average	*683,510*	*884*	*287*	*597*	*395*	*45%*
High Flow Year	1997	1,122,144	1,499	446	1,053	636	42%
	1998	941,478	1,206	387	819	534	44%
	2001	1,051,717	1,371	428	943	598	44%
	Average	*1,038,447*	*1,359*	*420*	*938*	*589*	*43%*

Estimated Annual Basin Yield (lbs/acre/yr)

Flow Condition	Suspended Sediment	Total Phosphorus	Total Dissolved Phosphorus	Total Particulate Phosphorus	Total Bioavailable Phosphorus
Low Flow Year	29	0.036	0.013	0.024	0.017
Average Flow Year	132	0.171	0.056	0.116	0.076
High Flow Year	201	0.263	0.081	0.182	0.114

Estimated Annual Flow Weighted Mean Concentration (mg/l)

Flow Condition	Suspended Sediment	Total Phosphorus	Total Dissolved Phosphorus	Total Particulate Phosphorus	Total Bioavailable Phosphorus
Low Flow Year	77	0.095	0.036	0.058	0.047
Average Flow Year	104	0.133	0.044	0.089	0.060
High Flow Year	124	0.164	0.051	0.113	0.071

Red River - Otter Tail River

Watershed Specific Total Phosphorus and Bioavailable Phosphorus Summary

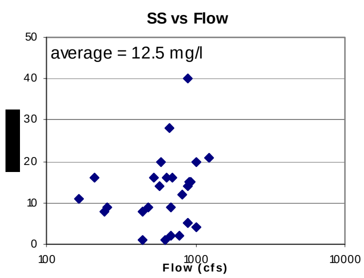
Approximate watershed area (sq. mi.): **1,740**

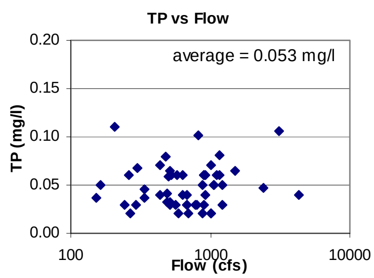
Representative USGS Gauge:	#05046000	Otter Tail River Below Orwell Dam near Fergus Falls, MN
Representative MPCA STORET Site:	S002-003	OTTERTAIL R BLW ORWELL DAM, CSAH-15, 8 MI SW OF FERGUS FALLS
Approximate drainage area at gauge (sq. mi.):	**1,740**	
Total watershed to gauged area multiplier:	**1.000**	

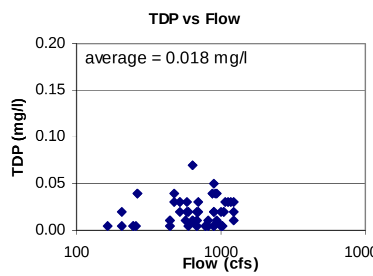
Compiled Water Quality Data

USGS (Water Years 1985-1995)	Count (n)	
Suspended sediment concentration (SSC) mg/l:	**27**	
Phosphorus, water, unfiltered (TP) (mg/l):	**38**	
Phosphorus, water, filtered (TDP) (mg/l):	**34**	
Orthophosphate, water, filtered, as P (mg/l):	**29**	*(non-detects adjusted to 1/2 the D.L.)*
No MPCA EDA data available		
MPCA New STORET Data (2001-2002)		
Phosphorus as P (mg/l):	**16**	

Rating Curves







Estimated Annual Watershed Load (metric tons/year)

Representative Years		Suspended Sediment	Total Phosphorus	Total Dissolved Phosphorus	Total Particulate Phosphorus	Total Bioavailable Phosphorus	Fraction Bioavailable
Low Flow Year	1989	3,019	13	4	8	6	46%
	1990	2,989	13	4	8	6	46%
	1991	3,800	16	5	11	7	46%
	Average	*3,269*	*14*	*5*	*9*	*6*	*46%*
Average Flow Year	1994	7,544	32	11	21	15	46%
	1995	5,549	24	8	16	11	46%
	2002	12,925	55	19	36	25	46%
	Average	*8,673*	*37*	*12*	*24*	*17*	*46%*
High Flow Year	1997	7,747	33	11	22	15	46%
	1998	7,713	33	11	22	15	46%
	2001	8,874	38	13	25	17	46%
	Average	*8,111*	*34*	*12*	*23*	*16*	*46%*

Estimated Annual Watershed Yield (lbs/acre/yr)

Flow Condition	Suspended Sediment	Total Phosphorus	Total Dissolved Phosphorus	Total Particulate Phosphorus	Total Bioavailable Phosphorus
Low Flow Year	6.5	0.027	0.009	0.018	0.013
Average Flow Year	17	0.073	0.025	0.048	0.033
High Flow Year	16	0.068	0.023	0.045	0.031

Estimated Annual Flow Weighted Mean Concentration (mg/l)

Flow Condition	Suspended Sediment	Total Phosphorus	Total Dissolved Phosphorus	Total Particulate Phosphorus	Total Bioavailable Phosphorus
Low Flow Year	12.5	0.053	0.018	0.035	0.024
Average Flow Year	12.5	0.053	0.018	0.035	0.024
High Flow Year	12.5	0.053	0.018	0.035	0.024

Red River - Wild Rice

Watershed Specific Total Phosphorus and Bioavailable Phosphorus Summary

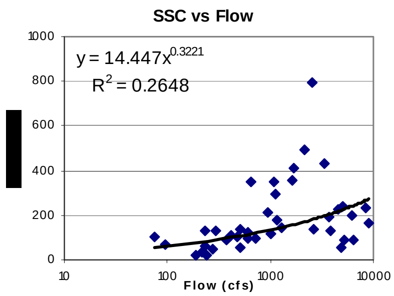
Approximate watershed area (sq. mi.): **1,560**

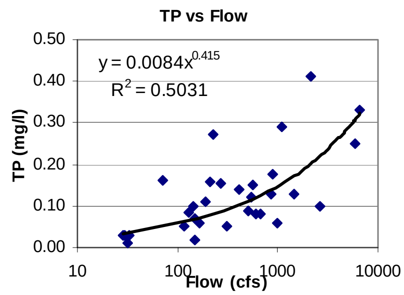
Representative USGS Gauge:	#05064000	Wild Rice River at Hendrum, MN
Representative MPCA STORET Site:	S000-216	WILD RICE R. USH-75 N OF HENDRUM
Approximate drainage area at gauge (sq. mi.):	**1,560**	
Total watershed to gauged area multiplier:	**1.000**	

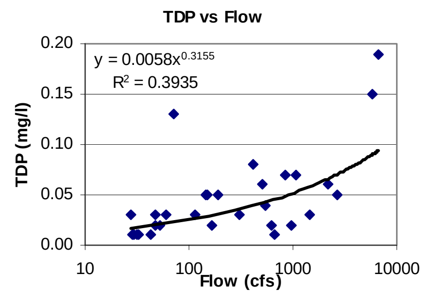
Compiled Water Quality Data

USGS (Water Years 1979-2001)	Count (n)
Suspended sediment concentration (SSC) mg/l:	**40**
Phosphorus, water, unfiltered (TP) (mg/l):	**24**
Phosphorus, water, filtered (TDP) (mg/l):	**30**
No MPCA EDA data available	
MPCA New STORET Data (1999-2002)	
Phosphorus as P (mg/l):	**7**

Rating Curves







Estimated Annual Watershed Load (metric tons/year)

Representative Years		Suspended Sediment	Total Phosphorus	Total Dissolved Phosphorus	Total Particulate Phosphorus	Total Bioavailable Phosphorus	Fraction Bioavailable
Low Flow Year	1989	41,501	49	16	33	22	44%
	1990	9,831	10	4	6	5	50%
	1991	9,174	9	4	6	5	50%
	Average	*20,169*	*23*	*8*	*15*	*10*	*46%*
Average Flow Year	1994	44,486	49	17	31	23	47%
	1995	61,659	68	24	45	32	46%
	2002	156,355	195	59	135	84	43%
	Average	*87,500*	*104*	*33*	*71*	*46*	*44%*
High Flow Year	1997	137,353	172	52	119	74	43%
	1998	123,828	149	47	102	66	44%
	2001	134,530	164	51	113	72	44%
	Average	*131,904*	*161*	*50*	*111*	*70*	*44%*

Estimated Annual Watershed Yield (lbs/acre/yr)

Flow Condition	Suspended Sediment	Total Phosphorus	Total Dissolved Phosphorus	Total Particulate Phosphorus	Total Bioavailable Phosphorus
Low Flow Year	44	0.050	0.017	0.033	0.023
Average Flow Year	193	0.229	0.074	0.156	0.102
High Flow Year	291	0.356	0.111	0.245	0.155

Estimated Annual Flow Weighted Mean Concentration (mg/l)

Flow Condition	Suspended Sediment	Total Phosphorus	Total Dissolved Phosphorus	Total Particulate Phosphorus	Total Bioavailable Phosphorus
Low Flow Year	112.1	0.122	0.043	0.079	0.057
Average Flow Year	146.5	0.170	0.056	0.114	0.077
High Flow Year	176.2	0.216	0.067	0.149	0.094

Red River - Red Lake River

Watershed Specific Total Phosphorus and Bioavailable Phosphorus Summary

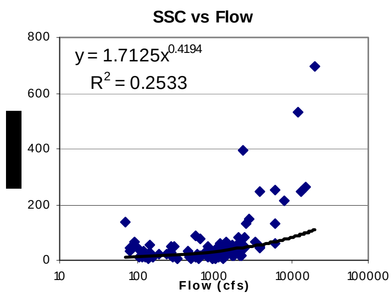
Approximate watershed area (sq. mi.): **5,270**

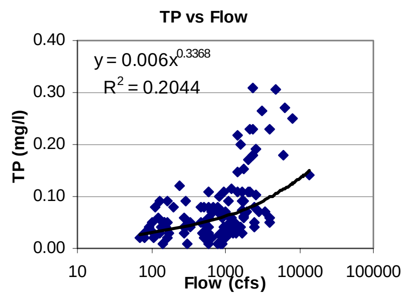
Representative USGS Gauge:	#05079000	Red Lake River at Crookston, MN
Representative MPCA STORET Site:	S000-031	RED LAKE RIVER AT BRIDGE ON CSAH-15 AT FISHER
Approximate drainage area at gauge (sq. mi.):	**5,270**	
Total watershed to gauged area multiplier:	**1.000**	

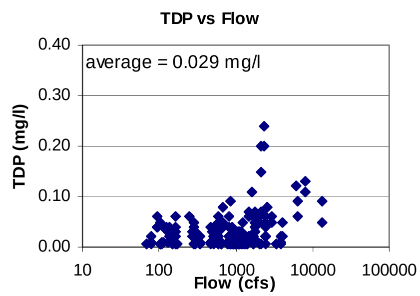
Compiled Water Quality Data

USGS (Water Years 1979-2001)	Count (n)	
Suspended sediment concentration (SSC) mg/l:	**120**	
Phosphorus, water, unfiltered (TP) (mg/l):	**119**	
Phosphorus, water, filtered (TDP) (mg/l):	**118**	*(excluded 2 outliers) (non-detects set to 1/2 the D.L.)*
Orthophosphate, water, filtered, (mg/l):	**102**	*(non-detects set to 1/2 the D.L.)*
No MPCA EDA data available		
MPCA New STORET Data (2000-2002)		
Phosphorus as P (mg/l):	**16**	

Rating Curves







Estimated Annual Watershed Load (metric tons/year)

Representative Years		Suspended Sediment	Total Phosphorus	Total Dissolved Phosphorus	Total Particulate Phosphorus	Total Bioavailable Phosphorus	Fraction Bioavailable
Low Flow Year	1989	20,143	37	14	23	18	49%
	1990	2,924	6	5	2	5	79%
	1991	4,345	9	6	3	7	72%
	Average	*9,138*	*17*	*8*	*9*	*10*	*57%*
Average Flow Year	1994	51,961	96	35	60	46	48%
	1995	65,704	120	43	77	57	47%
	2002	101,143	180	57	123	79	44%
	Average	*72,936*	*132*	*45*	*87*	*61*	*46%*
High Flow Year	1997	169,565	286	76	210	113	40%
	1998	81,973	149	51	98	69	46%
	2001	117,430	206	63	144	89	43%
	Average	*122,989*	*214*	*63*	*151*	*90*	*42%*

Estimated Annual Watershed Yield (lbs/acre/yr)

Flow Condition	Suspended Sediment	Total Phosphorus	Total Dissolved Phosphorus	Total Particulate Phosphorus	Total Bioavailable Phosphorus
Low Flow Year	6.0	0.011	0.005	0.006	0.006
Average Flow Year	47.6	0.086	0.029	0.057	0.040
High Flow Year	80.2	0.139	0.041	0.098	0.059

Estimated Annual Flow Weighted Mean Concentration (mg/l)

Flow Condition	Suspended Sediment	Total Phosphorus	Total Dissolved Phosphorus	Total Particulate Phosphorus	Total Bioavailable Phosphorus
Low Flow Year	26.7	0.053	0.029	0.024	0.033
Average Flow Year	46.2	0.084	0.029	0.055	0.039
High Flow Year	55.3	0.097	0.029	0.068	0.041

BARR

Technical Memorandum

To: Marvin Hora, Minnesota Pollution Control Agency
Doug Hall, Minnesota Pollution Control Agency
Mark Tomasek, Minnesota Pollution Control Agency

From: Jamie Bankston and Patrick Hirl

Subject: Effluent Total Phosphorus Reduction Efforts by Wastewater Treatment Plants

Date: November 24, 2003

Project: 23/62-853 CMPL 001

c: Greg Wilson
Henry Runke

The purpose of this memorandum is to provide the Minnesota Pollution Control Agency (MPCA) with information on current practices of cities to reduce the phosphorus concentration in their wastewater treatment plant (WWTP) effluent through such approaches as reduction in the influent phosphorus loading, chemical phosphorus precipitation, and enhanced biological phosphorus removal (EBPR). Information was collected from six Minnesota cities and two Oregon cities on their programs to reduce their effluent phosphorus loading. A small sampling of Minnesota cities was used due to the limited number of cities that had data available on phosphorus reduction and its costs. The two Oregon cities were included because of their ability to meet a very stringent effluent phosphorus limit of 0.07 mg/L.

This memorandum provides a review of the efforts of each of the cities to reduce the phosphorus in their effluent. Where available, costs for the specific phosphorus reduction efforts are provided. Finally, conclusions are drawn on the effectiveness of effluent phosphorus reduction efforts based on the data provided.

Effluent Phosphorus Reduction Approaches

As mentioned above, three approaches were used either separately or in combination by the communities surveyed to reduce their effluent phosphorus concentrations: source reduction, chemical precipitation, and EBPR. Source reduction efforts varied significantly between cities in the survey.

The simplest approach was a public education campaign to promote reductions in the use of household products with high concentrations of phosphorus. The more aggressive cities implemented fees based on the phosphorus content of the sewered discharge for their significant industrial users (SIU). Pretreatment was also required in one city if a SIU exceeded a pre-defined phosphorus loading threshold. The specifics of each effort are described below.

Chemical phosphorus precipitation is the use of metal salts to promote the precipitation of metal phosphates. Iron or aluminum are the most commonly used metals. The metal salt can be added at many different points in the WWTP treatment train. The most common point of application is immediately prior to secondary clarification. The chemical used and point of application are identified for each plant surveyed. The equipment required for chemical precipitation is minimal with systems adding metal salts prior to secondary clarification needing only a bulk storage tank and a chemical dosing pump. The largest cost for chemical precipitation phosphorus treatment is operations, which includes chemical cost and the cost of additional sludge disposal. The chemical costs are provided for all WWTPs surveyed using chemical precipitation.

EBPR is achieved in the activated sludge system by promoting the growth of bacteria that can hyper-accumulate phosphorus. This is achieved by creating an initial anaerobic zone in the activated sludge system followed by the traditional aerobic zone. In addition, low molecular weight organic acids must be present in the anaerobic zone to achieve EBPR. These acids can be produced in the sewer system, in the primary clarifier, or in a separate sludge fermenter. EBPR can be implemented using a wide range of approaches. The simplest approach can be to adjust air flow within the activated sludge basins to create the anaerobic zone. The more sophisticated approaches can require separate anaerobic basins and separate sludge digestion tanks. Phosphorus is ultimately removed from the EBPR system when the bacteria, which have hyper-accumulated phosphorus, are wasted from the activated sludge system.

It should be noted that reductions in the influent phosphorus concentrations to a WWTP may or may not reduce the effluent phosphorus concentration. The effect of influent phosphorus concentration reduction on effluent phosphorus concentration is dependent on the operation of the WWTP. WWTPs that have not implemented phosphorus treatment (i.e., either chemical phosphorus precipitation or EBPR) will likely see a reduction in the effluent phosphorus concentration proportional to the reduction in influent phosphorus concentration. WWTPs using chemical precipitation to meet effluent phosphorus limits will not likely experience a reduction in effluent phosphorus concentration if the influent phosphorus concentration is reduced because chemical precipitation will continue to be required to meet the effluent phosphorus limit. A reduction in influent phosphorus (soluble) concentration will reduce the amount of chemical required to achieve the effluent phosphorus limit, which will ultimately result in a reduction in chemical cost for phosphorus treatment. However, if the influent phosphorus was not soluble, which is precipitated chemically, but was particulate phosphorus, which is precipitated by flocculation, there may not be a direct reduction in chemical costs. Finally, WWTPs using EBPR will not likely experience a reduction in effluent phosphorus concentration if the influent phosphorus concentration is reduced because of the limits of this technology. The cost for operating EBPR will not be affected by the reductions in the influent phosphorus concentration.

Survey of Wastewater Treatment Plants for Phosphorus Removal

Several WWTPs were contacted by Barr Engineering regarding phosphorus treatment methods at their plant. The WWTPs were asked to identify the total flow into the plant, unit operations at the plant, phosphorus treatment method, influent and effluent phosphorus concentrations, estimated costs for phosphorus treatment, and methods used for limiting phosphorus input to the WWTPs. The WWTPs ranged in size (0.7 to 24 million gallons per day), treatment methods (chemical and/or biological), and phosphorus discharge requirements (0.07 mg/L to 2.41 mg/L). All of the WWTPs surveyed were activated sludge plants. This section summarizes the findings of the WWTP surveys, for a more detailed description of each WWTP see Attachment A. Phosphorus removal performance data for each of the WWTPs surveyed are presented in Table 1. Average wet weather design flow (AWWDF) and additional information concerning significant industrial users (SIUs) are included in Table 1 and Attachment A, respectively.

Wastewater Treatment Plants that Chemically Treat for Phosphorus

Four of the eight WWTPs that responded to our survey used chemical treatment only for phosphorus removal. The chemicals used were either alum or ferric chloride. Listed below is a brief description of the WWTPs that used chemical phosphorus removal. The WWTPs are described below in order from the lowest total phosphorus discharge requirement (0.3 mg/L, Bemidji, MN) to the highest (2.41 mg/L, Mankato, MN). Pond systems were not evaluated for this study, but it should be noted that pond systems are capable of removing phosphorus by batch chemical treatment prior to their controlled discharges.

Bemidji, Minnesota

This WWTP is the first WWTP discharge into the Mississippi River, just upstream of Lake Bemidji. A phosphorus discharge requirement of 0.3 mg/L total phosphorus or less is required as part of the NPDES permit. To meet the NPDES requirements, the WWTP uses alum for phosphorus precipitation and polymer for suspended solids precipitation. The alum and polymer are added after the activated sludge aeration basin but before the secondary clarifier. The average total phosphorus concentration entering the plant is 7 mg/L and the average total phosphorus concentration discharging from the plant is 0.15 mg/L. Bemidji does not have any significant industrial users, so the phosphorus entering the plant is primarily from domestic sources. This system has an average flow of 1.15 MGD. Costs for chemical treatment were based solely on alum costs. A treatment cost of $3.25 per pound of total phosphorus removed was calculated using the average influent and effluent total phosphorus concentrations, the average flow, and alum costs for a year.

St. Croix Valley, Minnesota

This WWTP discharges into the St. Croix River/Lake St. Croix at Oak Park Heights, Minnesota and is one of the WWTPs operated by the Metropolitan Council. A phosphorus discharge requirement of 0.8 mg/L total phosphorus or less is required as part of the NPDES permit. To reach the NPDES requirements, the WWTP uses alum for phosphorus precipitation. The alum is added at the inlet to the primary clarifier. The average total phosphorus concentration entering the plant is 4.8 mg/L and the average total phosphorus concentration discharging from the plant is 0.45 mg/L. This system has an average flow of 3.4 MGD. Costs for chemical treatment were based solely on alum costs. A treatment cost of $0.96 per pound of total phosphorus removed was calculated using the average influent and effluent total phosphorus concentrations, the average flow, and alum costs for a year.

Rochester, Minnesota

This WWTP discharges into the Zumbro River upstream of Lake Zumbro. A phosphorus discharge requirement of 1 mg/L total phosphorus or less is required as part of the NPDES permit. To reach the NPDES requirements, the WWTP uses ferric chloride and alum for phosphorus precipitation and polymer for suspended solids precipitation. The ferric chloride is added to the primary clarifier and alum and polymer are added to the secondary clarifier. The average total phosphorus concentration entering the plant is 7.5 mg/L and the average total phosphorus concentration discharging from the plant is 0.7 mg/L. Rochester has several significant industrial users that discharge to the WWTP. Daily maximum and monthly average total phosphorus limits are set for significant industrial users to limit the phosphorus discharged to the WWTP by industry. This system has an average flow of 14 MGD. A treatment cost of $1.76 per pound of phosphorus removed was given by the Rochester Environmental Coordinator. It should be noted that no further description of the treatment costs was given, so it was assumed that treatment costs were based solely on chemical costs.

Mankato, Minnesota

This WWTP discharges into the Minnesota River. A phosphorus discharge cap of 20,000 kg/yr (2.41 mg/L at 6 MGD) of total phosphorus is required as part of the NPDES permit, with a phosphorus discharge goal of 15,700 kg/yr (1.89 mg/L at 6 MGD). To reach the NPDES requirements, the WWTP uses ferric chloride for phosphorus precipitation and polymer for suspended solids precipitation. The ferric chloride is added at the influent of the WWTP and is settled out in the primary clarifier. Polymer is added to the secondary clarifier for solids precipitation. The average total phosphorus concentration entering the plant is 8.0 mg/L and the average total phosphorus concentration discharging from the plant is 1.88 mg/L. This system has an average flow of 6 MGD.

Mankato has several significant industrial users (SIUs) that discharge to the WWTP. SIUs are allowed to discharge 1 kg/day of total phosphorus, which is averaged on an annual basis. Any discharge above this loading is charged a fee. The fee is based on the treatment costs and phosphorus treatment efficiency for the year and includes chemical costs, biosolids disposal, maintenance, utilities, and lab analysis. The all inclusive treatment cost, which does not include capital costs, is approximately $1.70 per pound of phosphorus removed ($3.75 per kg). In comparison, the cost for phosphorus removal using chemical costs alone was $0.70 per pound of phosphorus removed. The all-inclusive costs are 2.3 times greater than the chemical only costs. This was the only facility in the survey that provided all-inclusive costs for chemical phosphorus removal.

Wastewater Treatment Plants that use Enhanced Biological Phosphorus Removal

Four of the eight WWTPs that responded to our survey used enhanced biological phosphorus removal (EBPR). In addition to EBPR, three of the four plants surveyed also use chemical treatment to meet total phosphorus discharge requirements below 1 mg/L. Listed below is a brief description of the WWTPs that used EBPR. The WWTPs are described in order from the lowest total phosphorus discharge requirement (0.07 mg/L, Durham and Rock Creek WWTPs, Oregon) to the greatest (monitoring only, St. Cloud).

Rock Creek and Durham WWTPs – Portland, Oregon

The Rock Creek and Durham WWTPs are located just west of Portland, Oregon in the Tualatin Watershed and have one of the lowest phosphorus discharge requirements in the United States of approximately 0.07 mg/L total phosphorus. These WWTPs are two of four WWTPs operated by Clean Water Services in urban Washington County, who serves approximately 455,000 customers with an average daily flow rate of 72 million gallons. The average flow for the Durham WWTP is approximately 20 MGD and the Rock Creek WWTP is 24 MGD. The average total phosphorus influent concentration is 7 mg/L for both plants. The WWTPs discharge to the Tualatin River and their combined flow comprises approximately one-third of the flow in the Tualatin River. These WWTPs are located in the Tualatin Watershed Sub-basin of the Willamette Watershed Basin. Each WWTP has a mass-based monthly median total phosphorus discharge of 9 lb/day (0.07 mg/L total phosphorus based on the average flow rate for each plant) during the summer (May – October). The total phosphorus discharge concentration is based on a TMDL for the Tualatin Watershed Sub-basin. The total phosphorus discharge requirements are subject to change when the TMDLs are re-evaluated for this watershed (effluent levels may be increased).

The Rock Creek and Durham WWTPs use EBPR and two-point alum addition to meet the stringent 0.07 mg/L total phosphorus discharge requirement. Pilot testing and full scale system modifications were required to reach the high level of phosphorus removal achieved by these plants. Alum is added to the primary clarifier prior to EBPR, total phosphorus concentrations after alum treatment in the primary clarifier and EBPR are approximately 0.5 mg/L. After the first alum treatment and EBPR, alum is added to the secondary clarifier; the effluent from the secondary clarifier is then filtered for an average total phosphorus effluent concentration of 0.05 mg/L. Prior to implementing EBPR, the Durham facility only used chemical treatment (alum) for phosphorus removal. Significant cost savings were observed once enhanced biological phosphorus removal was implemented at the Durham facility (i.e., the chemical costs for alum were cut by one third). Chemical costs for the facility are now approximately $0.47 per pound of total phosphorus removed. The pilot test and plant modifications to achieve EBPR at the Durham facility cost approximately $900,000.

The city of Portland implemented a phosphorus ban for non-industrial dischargers, which was soon followed by a state-wide ban. A 22% reduction in total phosphorus was observed in the influent to the WWTPs after the ban (9 mg/L pre-ban to 7 mg/L post-ban). Industrial users are not required to limit phosphorus discharge. Because of the public awareness of phosphorus discharge into this sensitive watershed, industries have voluntarily reduced phosphorus discharges.

Ely, Minnesota

The Ely WWTP discharges into Shagawa Lake. The NPDES discharge requirement is 0.3 mg/L total phosphorus. EBPR and chemical addition of alum are used to meet the NPDES discharge requirements. The average annual flow into the WWTP is approximately 0.7 MGD. Lime had originally been used at the Ely plant for chemical precipitation, but because of the high cost associated with lime treatment, the plant switched to alum.

When EBPR does not meet the discharge requirement alum is added to the mixing zone of the secondary clarifier. The secondary clarifier effluent is then passed through sand filters; the final total phosphorus average effluent discharge concentration is 0.2 mg/L. For short periods of time, the WWTP has been able to achieve 0.05 mg/L total phosphorus discharge concentrations. It was estimated by the WWTP superintendent that the costs associated with phosphorus removal are approximately 25% of the annual operating budget. Therefore, the estimated cost for phosphorus treatment is approximately $20 per pound of phosphorus removed. It should be noted that raw cost data was not immediately available for this WWTP and that the phosphorus treatment costs were based on verbal estimates given by the WWTP superintendent, therefore, the estimated costs presented here may be greater than the actual treatment costs.

This WWTP does not have any significant industrial users discharging to the WWTP; therefore, the phosphorus source is primarily from domestic dischargers. Phosphorus influent to the plant was significantly reduced in the early 1980's by educating the public on limiting the use of phosphorus in detergents. As estimated by the WWTP superintendent, the total phosphorus influent to the WWTP was reduced from 12 to 15 mg/L prior to public education to approximately 5 mg/L after public education.

St. Cloud, Minnesota

The St. Cloud WWTP uses EBPR for phosphorus removal. The discharge from this WWTP is into the Upper Mississippi River. This WWTP was not initially designed for EBPR. In 1996 the City of St. Cloud modified the existing wastewater treatment plant to improve energy efficiency by replacing the coarse air diffusers in the aeration basin with fine air diffusers. In addition to the energy efficiency improvements, the WWTP was modified for EBPR by installing an anaerobic zone in the first pass of each aeration tank. The average flow into the WWTP in 2002 was 10.6 MGD and the average total phosphorus influent in 2002 was 5.03 mg/L; after EBPR the average effluent total phosphorus is 0.93 mg/L. The St. Cloud WWTP NPDES discharge permit requires monitoring of effluent total phosphorus and development and implementation of a phosphorus management plan.

The City of St. Cloud has a Phosphorus Management Plan (PMP) that was implemented in 2001, the major goal of this PMP is to limit the amount of phosphorus coming into the facility by means of pretreatment and public outreach. The goal of the pretreatment program is to assist non-domestic nutrient contributors (NDNC) in developing phosphorus reduction strategies that will reduce the amount of phosphorus that enters the wastewater collection system and eliminate phosphorus slug loads. The city works with industrial users to keep phosphorus discharges to the WWTP below 6 mg/L. This method is effective at reducing spike loads and the average influent phosphorus concentrations. Comparing the 95% confidence limits of the average influent phosphorus concentrations prior to implementation of the PMP (7.72 mg/L ± 1.22 mg/L, 2000) to the 95% confidence limits of the average influent phosphorus concentrations after implementation of the PMP (5.03 mg/L ± 0.14 mg/L, 2002), there has been a significant reduction and less variability in the average phosphorus influent concentration. The lowering and stabilization of the influent total phosphorus concentration has also resulted in a decreased average total phosphorus effluent concentration from 2.01 mg/L± 0.64 mg/L in 2000 to 0.93 mg/L ± 0.11 mg/L in 2002.

Conclusions

Phosphorus Reduction Methods

- The cities implementing source reduction programs all achieved significant reduction in phosphorus loading on their WWTPs using a variety of methods: public outreach, phosphorus bans, surcharges for phosphorus treatment, and maximum limits on SIU phosphorus discharges.
- The St. Cloud WWTP showed that a reduction in influent phosphorus loading and phosphorus slug loads lead to a reduction in effluent phosphorus concentration.

Chemical Treatment of Phosphorus

- Chemical treatment is capable of reaching the lowest phosphorus effluent concentrations.

- The cost per unit of total phosphorus removed varied from $0.96 to $20.00 per pound of total phosphorus removed. The cost of treating phosphorus chemically appeared to show an economy of scale.
- The cost for chemical treatment was lower for those WWTPs that used a combination of EBPR and chemical treatment.

Biological Treatment of Phosphorus

- EBPR alone is generally effective at achieving 0.5 mg/L to 1 mg/L effluent phosphorus concentrations. Chemical addition is necessary to achieve effluent phosphorus concentrations less than 0.5 mg/L. One of the best available bio/chemical treatment facilities (Durham WWTP, OR) was able to achieve an average effluent phosphorus concentration of 0.05 mg/L. To reach this low effluent concentration, significant pilot testing was required and phosphorus removal efficiency was dependent upon wastewater characteristics.
- Once the initial capital improvements are made there are no additional costs associated with phosphorus removal using EBPR.
- EBPR can be implemented with simple process modifications (e.g., St Cloud aeration modifications) that achieve reductions in effluent phosphorus concentrations. St Cloud was able to achieve an effluent phosphorus concentration of 2 mg/L with this approach.

Table 1
MPCA Phosphorus Study
Wastewater Treatment Plant Summary
Phosphorus Removal

Treatment Plant	Treatment Method	Average WWDF (MGD)	Average Flow (MGD)	TP Influent (mg/L)	Average TP Effluent (mg/L)	Treatment Cost	Total Phosphorus NPDES Requirement
Ely	EBPR and alum after activated sludge and before secondary clarifier when necessary and sand filtration	3	0.7	5	0.2	$20/lb All inclusive	0.3 mg/L
Bemidji	Alum & polymer after activated sludge and before secondary clarifier	2.5	1.15	7	0.15	$3.25/lb TP Chemical only	0.3 mg/L
St. Croix Valley	Alum in primary clarifier inlet	5.8	3.4	4.8	0.45	$0.96/lb TP Chemical only	0.8 mg/L
Mankato	Ferric chloride at influent and polymer at belt filter for sludge dewatering	11.25	6	8	1.88	$1.70/lb TP all inclusive $0.74/lb Chemical only	20,000 kg/yr (cap) = 2.41 mg/L TP at 6 MGD and 15,700 kg/yr (goal) = 1.89 mg/L at 6 MGD
St. Cloud	EBPR	26	10.6	5.03	0.93	NA	ND
Rochester	Ferric chloride in primary; alum & polymer in secondary	19.1	14	7.5	0.7	$1.76/lb TP Chemical only	1 mg/L
Durham WWTP (Tigard, OR)	Alum in primary, EBPR, alum in tertiary, and filtration	NA	20	7	0.05	$0.47/lb TP Chemical only	9 lb/day monthly median = approx. 0.07 mg/L at current flow
Rock Creek (Hillsboro, OR)	Alum in primary, EBPR, alum in tertiary, and filtration	NA	24	7	0.05	$0.47/lb TP Chemical only	9 lb/day monthly median = approx. 0.07 mg/L at current flow

Key:
EBPR = Enhanced Biological Phosphorus Removal
NA = Not Available
MGD = Million Gallons per Day
TP = Total Phosphorus
ND = Not Determined

Bemidji WWTP

Contacts: Brian Freeberg (218) 759-3590 and Tim Whiting (WWTP Superintendent – (218) 751-2894)

Unit Operations: Bar racks → Screens → Primary Clarification → Activated Sludge → Alum/Polymer Addition → Secondary Clarification → Gravity Sand Filter → UV disinfection and an anaerobic digester for sludge. Note that the system was originally designed for dissolved air flotation thickening (DAF) but did not work well. Sends sludge from clarifiers directly to digester.

Phosphorus Treatment: Chemical treatment: Alum and polymer added after activated sludge and before secondary clarifier.

SIUs: None

Phosphorus Input: Because there are no significant industrial users and the phosphorus input is primarily from domestic sources, there is no phosphorus reduction plan or phosphorus bans in the city of Bemidji.

Additional Notes: Annual phosphorus treatment budget is $78,000. Annual laboratory and O&M costs are approximately $10,000. The plant was constructed in 1985, the capital costs for chemical holding tanks and pumps was $80,000 in 1985. Alum is wasted with sludge. The actual alum concentrations added to the system were derived from alum dosing/alum costs given by Tim Whiting and ranged from 220 mg/L to 400 mg/L.

Treatment Summary:

Qin (MGD)	AWWDF (MGD)	Treatment Method	TPin (mg/L)	TPout (mg/L)	Chemical Conc.	Treatment Cost (chem.)	NPDES TP Effluent Limit
1.15	2.5	Alum & Polymer	7	0.15	400 mg/L Alum (estimated by cost)	$3.25/lb TP	0.3 mg/L

Ely WWTP

Contacts: Micky Schusta (WWTP Operator (218) 365-3247) and Terry Jackson (WWTP Superintendent (218) 365-2695)

Unit Operations: Screens → Degritter → Activated Sludge (for both BOD and P by tweaking aeration zones)→ Alum/Polymer Addition → Secondary Clarification → Overflow Basin → Continuous Flow Sand Filter → Chlorine disinfection with sulfur dioxide for chlorine residual removal. Dissolved air flotation (DAF) for sludge thickening.

Phosphorus Treatment: Biological phosphorus removal with chemical addition when necessary; Alum and polymer added after activated sludge and before secondary clarifier. Acetic acid is added to the activated sludge for volatile fatty acids (VFAs).

SIUs: None

Phosphorus Input: There was a public education outreach (early 1980s) on using non-phosphate/low-phosphate containing detergents. Prior to public education total phosphorus influent was estimated by Terry Jackson to be 12-15 mg/L, after education total phosphorus influent was 5 mg/L.

Additional Notes: Because there was not any itemized cost data available, Terry Jackson estimated that approximately 25% of annual operating budget goes toward phosphorus treatment, which includes: sampling, maintenance, labor, etc. The estimated annual costs are $200,000. TPout average is approximately 0.2 mg/L, but the plant has achieved effluent concentrations of 0.05 mg/L TP.

Treatment Summary:

Qin (MGD)	AWWDF (MGD)	Treatment Method	TPin (mg/L)	TPout (mg/L)	Chemical Conc.	Treatment Cost (Total)	NPDES TP Effluent Limit
0.7	3	Bio P w/ Alum & Polymer	5	0.2	Not Available	$20/lb TP	0.3 mg/L

Rochester WWTP

Contacts: David Lane (Environmental Coordinator (507) 281-6190 ext 3006)

Unit Operations: Bar Screens → Aerated Grit Tanks → Primary Clarification → Two-Stage High Purity Oxygen Activated Sludge → Intermediate/Secondary Clarification → Chlorine Disinfection → Sodium Bisulfite De-Chlorination.

Phosphorus Treatment: Chemical treatment with ferric chloride in the primary clarifiers and alum and polymer in the secondary clarifiers.

SIUs: Yes. AMPI, Marigold S., Marigold N., Pace, Quest, and Seneca are sampled 5 days a week. Crenlo has a significant phosphorus load, but is only sampled 3 times per year. Their phosphorus load was calculated from the concentration times the total flow for the month divided by 30. Their flow is also only measured monthly as opposed to daily for the other industries.

Phosphorus Input: Methods in place for limiting phosphorous input to WWTP include daily maximum and monthly average total phosphorus limits for large industrial users.

Additional Notes: None

Treatment Summary:

Qin (MGD)	**AWWDF (MGD)**	**Treatment Method**	**TPin (mg/L)**	**TPout (mg/L)**	**Chemical Conc.**	**Treatment Cost (Chem.)**	**NPDES TP Effluent Limit**
14	19.1	Ferric Chloride in Primary and Alum/polymer in Secondary	7.5	0.7	Not Available	$1.76/lb TP	1 mg/L TP

St. Croix Valley WWTP (Metropolitan Council Plant)

Contacts: Kathy Larson (651) 602-1275 (Met Council point of contact for MPCA study) and Dennis Lindeke (Hastings WWTP (651) 437-4212)

Unit Operations: Bar screen → Grit Removal → Primary Clarification (Alum added to primary inlet) → Plug Flow Activated Sludge → Final Clarification → Effluent Ultraviolet Disinfection. Solids are co-thickened in a gravity thickener and hauled off site for disposal.

Phosphorus Treatment: Chemical treatment with alum addition to the primary clarifier inlet.

SIUs: Not Available.

Phosphorus Input: Not Available.

Additional Notes: Annual phosphorus treatment budget is $43,000. The actual alum concentrations added to the system were derived from alum dosing/alum costs.

Treatment Summary:

Qin (MGD)	AWWDF (MGD)	Treatment Method	TPin (mg/L)	TPout (mg/L)	Chemical Conc.	Treatment Cost (Chem)	NPDES TP Effluent limit
3.4	5.8	Alum in primary	4.8	0.45	76 mg/l Alum (est. by cost)	$0.96/lb TP	0.8 mg/L

St. Cloud WWTP

Contacts: Tracy Hodel (Water Quality Coordinator (320) 255-7226)

Unit Operations: Bar Screen → 2 Grit Tanks → Aerated Influent Channel to Primaries → 4 Primary Settling Tanks → 3 Aeration Tanks → 3 Final Clarifiers → 2 Chlorine Contact Tanks

2 Primary and 1 Secondary Anaerobic Digester and 5 MG Biosolids Holding Tanks

Phosphorus Treatment: Biological, modified the preexisting WWTP. The City of St. Cloud did an energy improvement project in 1996 where the diffusers were changed from coarse air to fine air and an anoxic zone was placed in the first pass of each aeration tank for phosphorus removal. The city has also changed the way decant from the biosolids storage cells returns to the plant to prevent foaming in the aeration tanks.

SIUs: Electrolux Home Products, Northern Wire Products, Precision Optics, AmeriPride Linen & Apparel Services, G&K Services, Grede Foundaries Landfill, International Paper Landfill, Dezurik Landfill, X-Cel Optical Company, Rapid Plating, DBL Labs, Essilor Coating Center, and New Flyer. SIUs do not get charged for phosphorus treatment, SIUs need to follow Phosphorus Management Plan (PMP).

Phosphorus Input: The City of St. Cloud has an extensive Phosphorus Management Plan (PMP), the major goal of this PMP is to limit the amount of phosphorus coming into the facility by means of pretreatment and education outreach. The Phosphorus Management Plan sets operational guidelines for the following: slug loads, laboratory testing, phosphorus reporting, chlorine practices, and plant improvements, etc. The goal of the pretreatment program is to assist non-domestic nutrient contributors (NDNC) in developing phosphorus reduction strategies that will reduce the amount of phosphorus that enters the wastewater collection system and eliminate phosphorus slug loads.

1. Permitted Industries:

All permitted industries are required to test for phosphorus in their discharge. Industrial discharges that exceed 6.0 mg/L require daily testing for three months or a specified time period as determined by the Director. If any sample exceeds 6.0 mg/L a phosphorus reduction strategy (PRS) is required.

- Commercial Laundry:

PRS: Requires daily testing for phosphorus to develop loading information. Any test result greater than 6.0 mg/L will require elimination of phosphorus-based chemicals, pretreatment, and/or other phosphorus reduction measures.

- Metal Finishers:

PRS: Requires daily testing for phosphorus to develop loading information. Any test result greater than 6.0 mg/L will require pretreatment, elimination of phosphorous-based chemicals, and/or other phosphorus reduction measures.

2. NDNC's Categories

- Car Washes:

PRS: The use of phosphorus-based chemicals is prohibited. All car washes must annually submit MSDS information to the POTW.

- Other Large Laundry Services:

PRS: The use of phosphorus-based chemicals is prohibited without written consent from the Director and adequate pretreatment and/or other phosphorus reduction methods to achieve phosphorus levels below the domestic level of 6.0 mg/L.

Additional Notes: The PMP went into effect in 2001. The PMP was effective at reducing spike loads and the average influent phosphorus concentrations. Comparing the 95% confidence limits of the average influent phosphorus concentrations prior to implementation of the PMP (7.72 mg/L ± 1.22 mg/L, 2000) to the 95% confidence limits of the average influent phosphorus concentrations after implementation of the PMP (5.03 mg/L ± 0.14 mg/L, 2002), there has been a significant reduction and less variability in the average phosphorus influent concentration. The lowering and stabilization of the influent total phosphorus concentration has also resulted in a decreased average total phosphorus effluent concentration from 2.01 mg/L± 0.64 mg/L in 2000 to 0.93 mg/L ± 0.11 mg/L in 2002.

Treatment Summary:

Qin (MGD)	**AWWDF (MGD)**	**Treatment Method**	**TPin 2002 Avg (mg/L)**	**TPout 2002 Avg (mg/L)**	**Chemical Conc.**	**Treatment Cost (Bio)**	**NPDES TP Effluent Limit**
10.6	26	Biological	5.03 mg/L	0.93 mg/L	NA	NA	ND

Mankato WWTP

Contacts: Mary Fralish (Utility Supervisor Wastewater Treatment Plant (507) 387-8665)

Unit Operations: (Assuming Bar Racks and Screens even though not listed) → Equalization Basins (assuming here location not listed)→ Primary Clarifiers → Aeration Basins → Secondary Clarifiers → Primary Digesters → Secondary Digesters → Disinfection Tank → Dechlorination Tank

Phosphorus Treatment: Ferric chloride is added to the influent and is settled out in the primary clarifier. Polymer is used in the operation of the belt filter press for biosolids dewatering. Polymer is added to the phosphorus removal costs, because phosphorus removal increases biosolids by 20%.

SIUs: Honeymead, ADM, WISPAK, Ameripride, Associated Finishing, Jones Metal, Viessman, Hiniker, and Coloplast. SIUs are allowed 1 kg/day TP discharge limit. TP above this limit are charged a fee which is based on the quantity of TP that exceeds the 1 kg/d of TP allowed for the year. Charges to these users are based on the treatment costs for TP treatment for the year; this includes chemical costs, biosolids, maintenance, utilities, and lab analyses. The final fee is based on the phosphorus removal efficiency for the plant (70%). The PMP went into effect when the plant upgrade was completed. Although several industries decreased their phosphorus output, there is one soybean processor who increased their phosphorus output considerably, overshadowing gains from the others. The amount of phoshorus in their effluent is directly related to the uptake of phosphorus in the bean during the growing season. The city of Mankato has told them that they have to reduce the amount of phosphorus in their effluent and we have entered into a joint study to determine whether it should be done at their facility or at the Mankato WWTP through EBPR.

Phosphorus Input: PMP plan and working with industries to reduce TP loading. Several SIUs have reduced TP loading, however a soybean processor has significantly increased TP loading. The city and industry are currently doing a joint study to determine if phosphorus pretreatment should occur at the facility or at the WWTP using biological phosphorus removal.

Additional Notes: The PMP plan went into effect in 2001 when the WWTP upgrade was completed.

Treatment Summary:

Qin (MGD)	AWWDF (MGD)	Treatment Method	TPin-2002 (mg/L)	TPout-2002 (mg/L)	Chemical Conc.	Treatment Cost (2002)	NPDES TP Effluent Limit
6	11.25	Ferric Chloride and Polymer	8.0	1.88	Not Available	\$1.70/lb TP \$3.75/kg TP (all inclusive) \$0.74/lb TP \$1.62/kg TP (chem. only) 2.3 (all incl/chem.)[a]	20,000 kg/yr (cap) = 2.41 mg/L @ 6 MGD 15,700 kg/yr (goal) = 1.89 mg/L @ 6 MGD

a) all inclusive cost for phosphorus removal ÷ the cost for phosphorus precipitation chemicals only

Durham WWTP (Oregon – 0.07 mg/L TP discharge)

Contacts: Rob Baur (R&D for Cleanwater Services (503) 846-4617) and Mark Pohling (Director of WWTP)

Unit Operations: Not completely specified. Summary or partial description: Bar Screen → Primary Clarifier (30 mg/L alum addition)→ Activated Sludge with Bio P → Secondary Clarifier → Filters (30 mg/L alum addition)→ Tertiary Clarifier → Hypochlorite Disinfection with Persulfite for Dechlorination → Fermenter with VFA addition.

Phosphorus Treatment: Chemical (alum) and Biological. Alum addition to primary and bio P gets TP concentrations to approximately 0.5 mg/L. Alum addition at filter followed by tertiary clarification reduces TP to 0.05 mg/L. NPDES permit is based on a monthly median of 9 lbs TP/day (0.07 mg/L for current flows) for discharges from May to October. The plant was originally designed for lime treatment but was modified for alum treatment. Alum use was cut in 1/3 once EBPR was implemented.

SIUs: There are no TP discharge limits for industries. There have been voluntary reductions, the major reduction was by Intel who spent $200,000 to not discharge from phosphate acid bath to WWTP. Instead waste was used for making fertilizer.

Phosphorus Input: Initially, the phosphorus ban in the city resulted in a 22% TP influent reduction. After city implementation, the phosphorus ban went to the entire state of Oregon. Currently TMDL is being re-evaluated, so TP discharge from WWTP may be increased after further study.

Additional Notes: First TMDL in nation of 0.07 mg/L TP discharge. Discharge is to the Tualatin River. The Durham and Rock Creek WWTP are required to discharge to river in the summer, because they provide approximately 1/3 of the rivers total flow. Rob Baur stated that 90% of the TP discharged from the WWTP is tied up with the alum and that only 10% is bioavailable.

Treatment Summary:

Qin (MGD)	AWWDF (MGD)	Treatment Method	TPin - 2002 (mg/L)	TPout -2002 (mg/L)	Chemical Conc.	Treatment Cost (2002)	NPDES TP Effluent Limit
20	NA	Alum and Bio P	7	0.05	60 mg/L Alum Total (30 mg/L in primary and 30 mg/L at filters)	$0.47/lb TP Alum	9 lb TP per day (0.07 mg/L based on current flow – required May - October)

Rock Creek WWTP (Oregon – 0.07 mg/L TP discharge)

Contacts: Rob Baur (R&D for Cleanwater Services (503) 846-4617) and Mark Pohling (Director of WWTP)

Unit Operations: Not specified. Claricones are used for contact clarification of the wastewater; this is considered an innovative unit operation because it is generally used for drinking water clarification. The claricone process uses tangential flow and gravity precipitation to remove suspended solids.

Phosphorus Treatment: Chemical (alum) and Biological. Alum added to the primary (20 mg/L) and the tertiary clarifier (40 mg/L).

SIUs: See Durham WWTP

Phosphorus Input: Initially phosphorus ban in city resulted in 22% TP influent reduction. Then phosphorus ban went to entire state of Oregon. Currently TMDL is being evaluated, so TP discharge from WWTP may be increased.

Additional Notes: First TMDL in nation of 0.07 mg/L TP discharge. Discharge is to the Tualatin River. The Durham and Rock Creek WWTP are required to discharge to river in the summer, because they provide approximately 1/3 of the rivers total flow. Rob Baur stated that 90% of the TP discharged from the WWTP is tied up with the alum and that only 10% is bioavailable.

Treatment Summary:

Qin (MGD)	AWWDF (MGD)	Treatment Method	TPin -2002 (mg/L)	TPout - 2002 (mg/L)	Chemical Conc.	Treatment Cost (2002)	NPDES TP Effluent Limit
24	NA	Alum and Bio-P	7	0.05	60 mg/L Alum Total (20 mg/L in primary and 40 mg/L at tertiary)	$0.47/lb TP Alum	9 lb TP per day (0.07 mg/L based on current flow – required May - October)