1995 and 1996 Water Year Data Summary

May 1997

Minnesota
Department of
Natural Resources
Division of Waters

1995 and 1996 Water Year Data Summary

October 1, 1994 -
September 30, 1996

by the Division of Waters Staff

St. Paul, MN

May 1997

Minnesota
Department of Natural Resources
Division of Waters

This information is available in an alternative format upon request

Equal opportunity to participate in and benefit from programs of the Minnesota Department of Natural Resources is available to all individuals regardless of race, color, national origin, sex, sexual orientation, marital status, status with regard to public assistance, age or disability. Discrimination inquiries should be sent to: MN/DNR, 500 Lafayette Road, St. Paul, MN 55155-4031; or the Equal Opportunity Office, Department of the Interior, Washington, D.C. 20240.

The DNR Information Center phone numbers:
Twin Cities: (612) 296-6157
MN Toll Free: 1-800-766-6000
Telecommunication Device for the Deaf:
(612) 296-5484
MN Toll Free: 1-800-657-3929

World Wide Web Site Address:
http://www.dnr.state.mn.us

Printed on Recycled Paper

Introduction

This publication provides a review and summary of basic hydologic data gathered through DNR-Division of Waters programs. There are four major areas of data collection including climatology, surface water, ground water and water use. These areas follow the hydrologic cycle (see diagram) and provide important facts concerning the distribution and availability of Minnesota's water resources.

Basic hydrologic data is essential to a variety of water resource programs and related efforts. The extent of our knowledge depends on the quality and quantity of hydrologic data. Analysis and use of data is vital to understanding complex hydrologic relationships. With expanding technologies, there is a greater need for even more data of higher quality.

This report is a continuation of Water Year reports published by the Division of Waters in 1979, 1980, 1991, 1993 and 1995.

Water Year

The climatology, surface water and ground water data presented are for Water Years 1995 and 1996.

WY 1995: October 1, 1994 - September 30, 1995
WY 1996: October 1, 1995 - September 30, 1996

Use of water year as a standard follows the national water supply data publishing system that was started in 1913. This convention was adopted because responses of hydrologic systems after October 1 are practically all a reflection of precipitation (snow and rain) occurring within that water year.

Water use data is reported and presented on a calendar year basis.

Acknowledgements

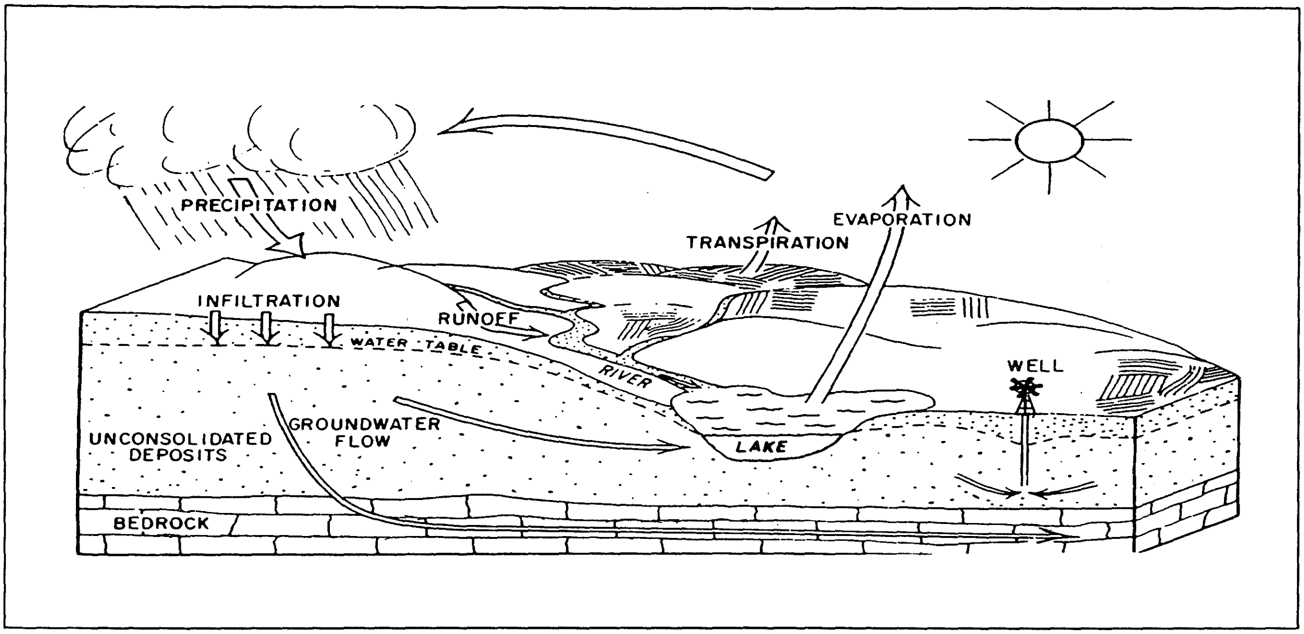
We wish to express our gratitude to the listed authors and others who contributed to this publication. Special thanks to Jerry Johnson and Jim Zicopula for technical mapping and graphic design, respectively, and also for their unending patience.

Glen Yakel, *Editor* Kent Lokkesmoe, *Director*

Table of Contents

Table of Contents

Hydrologic Cycle

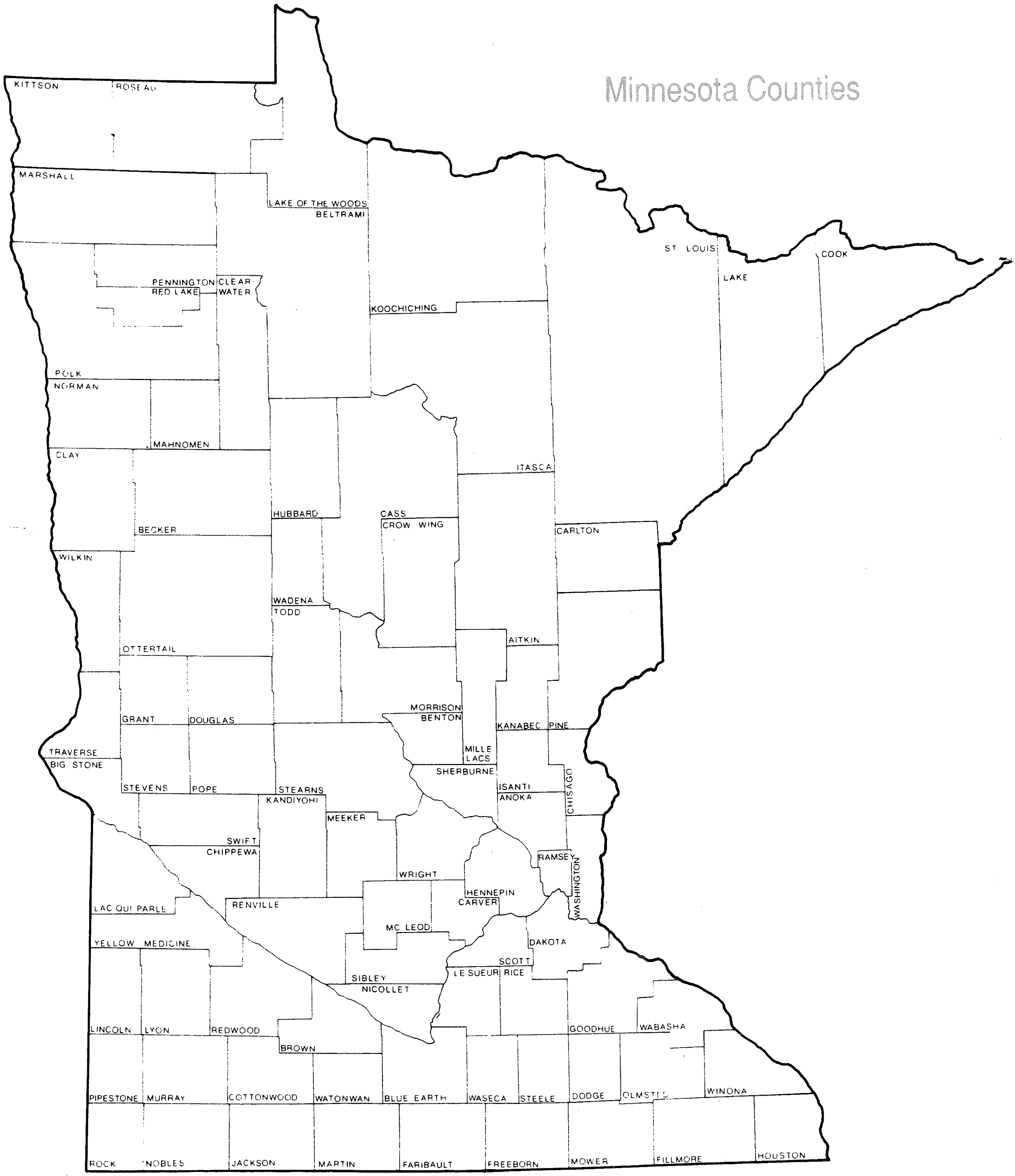


The hydrologic cycle is a concept used to explain the movement of water around the earth. This movement is continuous and has no beginning or end. Change at any point in the cycle will be reflected later in the cycle.

Surface water, which predominately exists in oceans, is evaporated into the atmosphere by the energy of the sun. It returns to the earth as precipitation (rain or snow). As precipitation falls, it may be intercepted by vegetation and evaporate or it may reach the ground surface. Water that reaches the surface may either soak into the soil or move downslope. As it soaks into the soil (infiltration), it may be held in the soil or continue to move downward and become ground water. Ground water may be stored in the ground, returned to the surface as a spring, flow into a concentrated body such as a stream or lake, or be returned to the atmosphere by plant transpiration. Water that does not infiltrate the soil moves downslope, until concentrated areas form a stream. Streams lead to lakes and into other streams, which ultimately return the water to oceans.

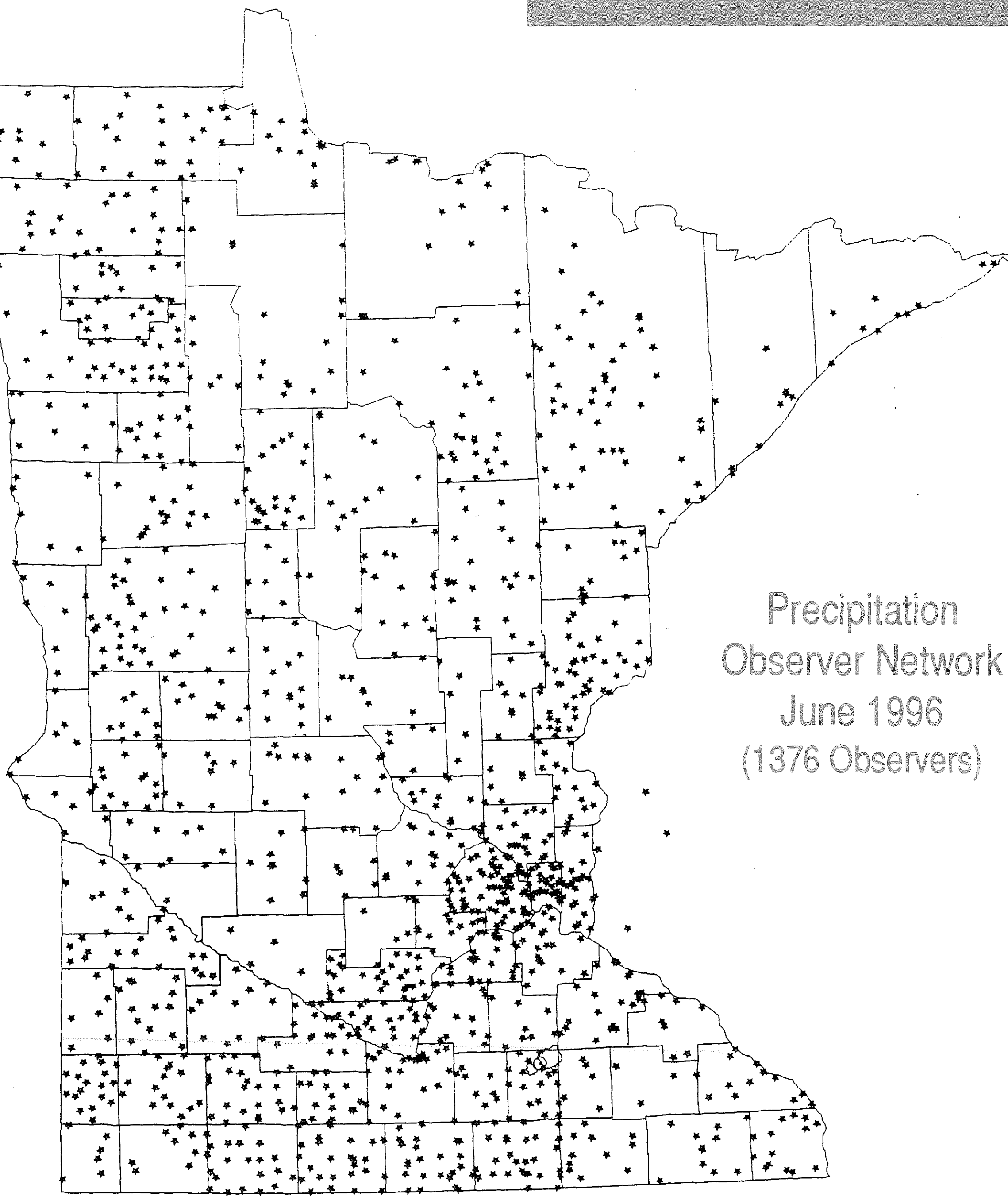
At any point where water is on the ground surface, it is subject to evaporation into the atmosphere or infiltration into the soil.

Minnesota Counties



Chapter 1

CLIMATOLOGY



Precipitation
Observer Network
June 1996
(1376 Observers)

Introduction

The State Climatology Office exists to gather and analyze climate data for the benefit of the State of Minnesota and its citizens. A variety of organizations provide climate data (see side bar). These organizations rely primarily on the efforts of volunteer observers. The data are consolidated into a unified database and climate information is distributed to many users.

A review of climate information can assist in explaining a prior event or condition or in evaluating the likelihood of a future event. Climate information aids long-range planning efforts by characterizing what is typical or extreme, likely or unlikely. Users of climate information include government agencies (local, state, federal); academic institutions; media; private sector professionals and the general public. Specifically, engineers use temperature and precipitation data to design roads and storm sewers. Wildlife managers use temperature and snow depth information to identify emergency feeding needs for deer. Agricultural specialists use temperature and precipitation data to determine the types of crops that will grow in Minnesota. Other disciplines relying upon climate information include hydrologists, foresters, meteorologists, attorneys, insurance adjusters, journalists and recreation managers.

Climate Data Sources:

Soil and Water Conservation Districts
National Weather Service
University of Minnesota
Department of Natural Resources
State Climatology Office Back Yard Network
Metropolitan Mosquito Control District
Minnesota Association of Watershed Districts
Metropolitan Waste Control Commission
Deep Portage Conservation Reserve
Minnesota Power and Light Company
Future Farmers of America
Emergency Management
MN Department of Transportation

The word *'normal'* in this chapter refers to a 30-year mathematical average of measurements made over the period 1961-1990. Thirty-year averages are used as a compromise between shorter sampling periods that may not capture climatic variation, and longer sampling periods that may incorrectly filter out long-term climate change.

WORLD WIDE WEB SITE ADDRESS:
http://www.dnr.state.mn.us
(see Climatology section)

Water Year 1995

October 1, 1994 - September 30, 1995

Highlights

- mild, snow-free winter
- cold spring
- warm and humid summer
- dry early summer in north
- wet summer in south
- wet fall in north

Fall/Winter 1994-1995

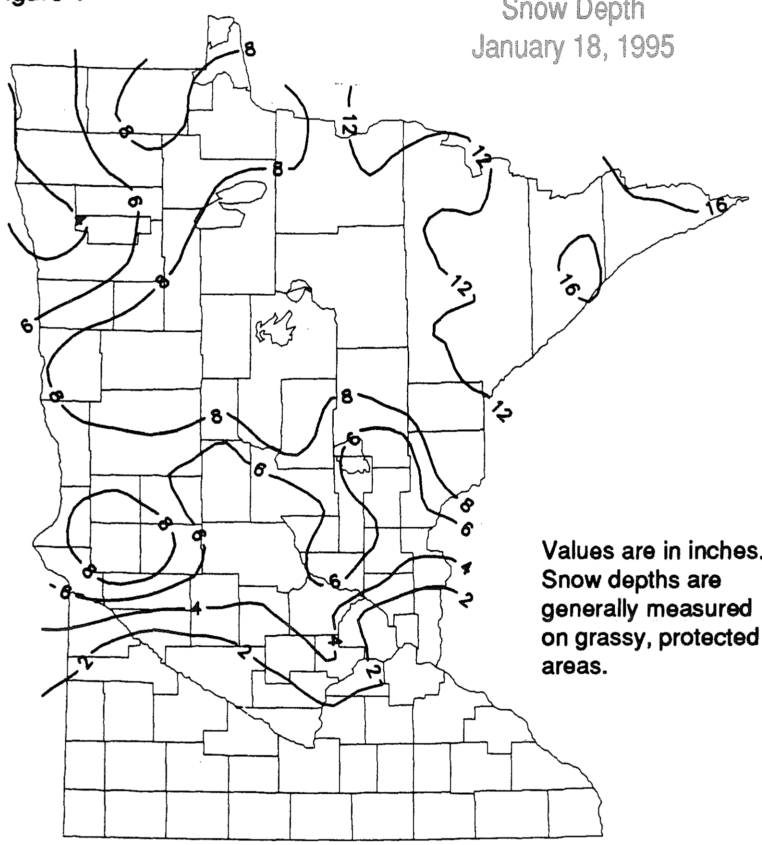
October 1994 weather featured mild and pleasant stretches, interspersed with occasional wet spells. October's most notable weather feature was an absence of a killing frost until late in the month. Many locations went two to four weeks beyond their average frost dates without receiving freezing temperatures.

Minnesota then experienced a mild late fall and early winter. Temperatures for November, December, and January were well above average. Many maximum temperature records were broken in northern Minnesota in mid to late December. Above-normal December temperatures slowed the creation of lake ice, leading to warnings of unsafe ice as far north as International Falls. Heating degree days, a measure of temperature used to estimate residential and commercial heating requirements, fell 15 percent below the average.

The first significant snowfall of the season came on November 18 in northern Minnesota, and November 27 for the remainder of the state. These dates roughly match the historical average occurrence of the first measurable snowfall, and contrast with the late-October and early-November first-snows experienced earlier in the 1990's. Through mid-January, snowfall

Figure 1

Snow Depth
January 18, 1995

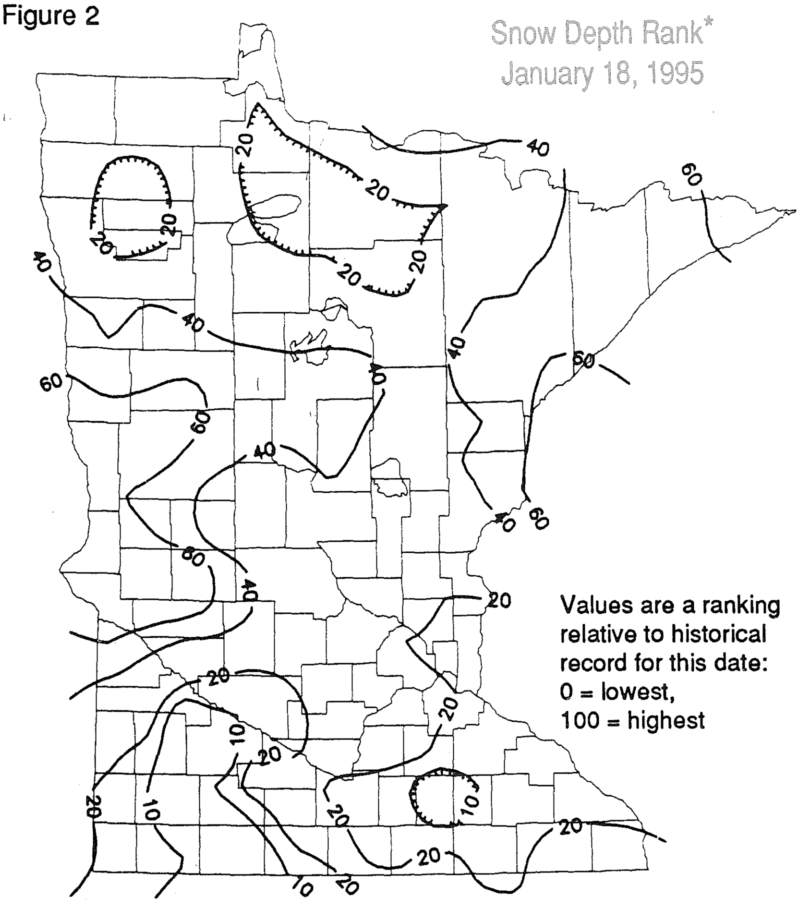


Values are in inches. Snow depths are generally measured on grassy, protected areas.

was generally light. Snow depths on January 18 ranged from less than two inches in southern Minnesota to over 12 inches in the northeast (Figure 1). Generally, snow depths ranked far below the median when compared with historical snow depth data (Figure 2).

After a winter of relatively snow-free conditions, early March brought significant snows. By the end of the first week of March, most of Minnesota ranked above the median for depth of snow on the ground. However, very mild temperatures in mid-March quickly reduced the snow pack to near zero over much of the state. In spite of the rapid melt, flooding was limited to a few west-central locations.

Figure 2



* Snow Depth Rank is a measure of the rarity of the absolute snow depth. The numbers represent an estimate of the number of years out of 100 in which the depth is less than the observed depth on the stated date. Thus a "95" would mean: "in 95 out of 100 years, the snow depth will be less" or "the snow depth is the 95th highest in a 100-year record" for the given day of the year. Actual long term snow depth records are generally less than 100 years in length.

Spring/Summer 1995

In sharp contrast to the mild temperatures of March, April began with a stretch of extremely cold days. The cold weather persisted through the month and into May. While the southern third of the state experienced early lake ice-out due to warm March weather, the cold early-spring temperatures delayed lake ice-out for many days across the remainder of the state. For example, Mille Lacs Lake completely lost its ice on May 5, 10 days past its average ice-out date. The first 70 degree weather was not observed in many Minnesota communities until the second week of May, the third latest occurrence on record.

For the period April through May, precipitation ranged from well above normal in the southwest to near normal elsewhere (Figure 3). Normal-to above-normal precipitation, along with reduced evaporation rates (due to the cool temperatures), produced very wet soil conditions. Wet soils led to significant delays in agricultural field operations.

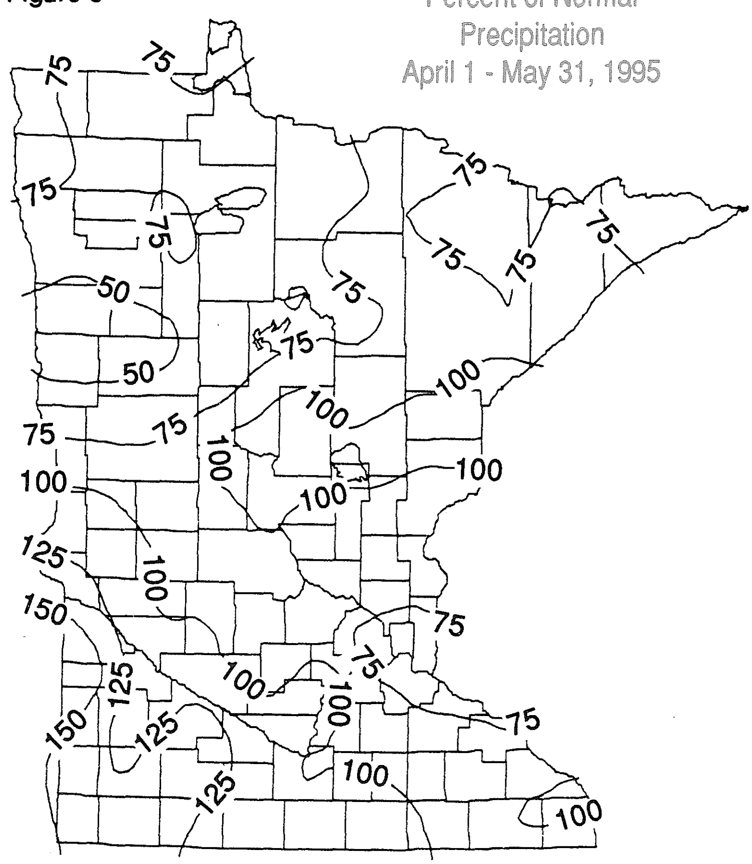
The 1995 growing season provided a sharp contrast in climate conditions across the state. Large sections of southern Minnesota received above-normal precipitation through the late spring and into the summer. Conversely, some areas of northern Minnesota reported very low precipitation totals. Warm temperatures and unusually high relative humidity were common statewide throughout the summer.

Heat and high humidity occurred during each of the summer months. Many areas set high temperature records on June 17 and 18, in the upper 90's and lower 100's. The Twin Cities recorded the longest June spell of 90-degree days in history. The very hot weather combined with sparse May and June precipitation and created agronomic crop stress in the northwest and heightened forest fire potential in the northeast. Large forest fires blazed in the Boundary Waters Canoe Wilderness Area in June and again in August.

In contrast to the problems created in the north, extended periods of high temperatures benefited crops in the south. The hot weather accelerated crop development delayed by a cool spring. However, another heat spell in mid-July killed several thousand turkeys, and boosted energy demands to all-time highs. The very warm summer temperatures, along with an unusually large number of days with dewpoint temperatures in the 70s, may have indirectly contributed to an outbreak of airborne disease in Mankato and Luverne.

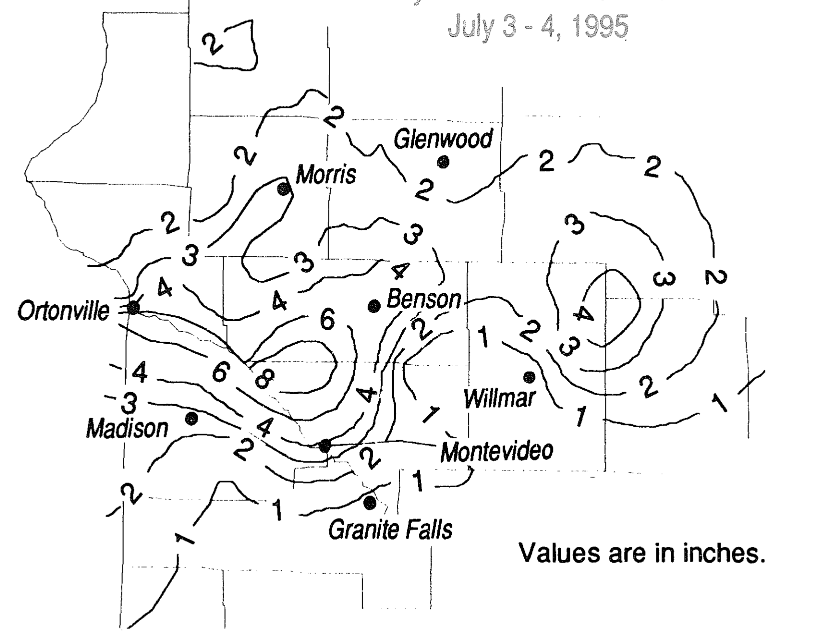
Figure 3

Percent of Normal Precipitation April 1 - May 31, 1995



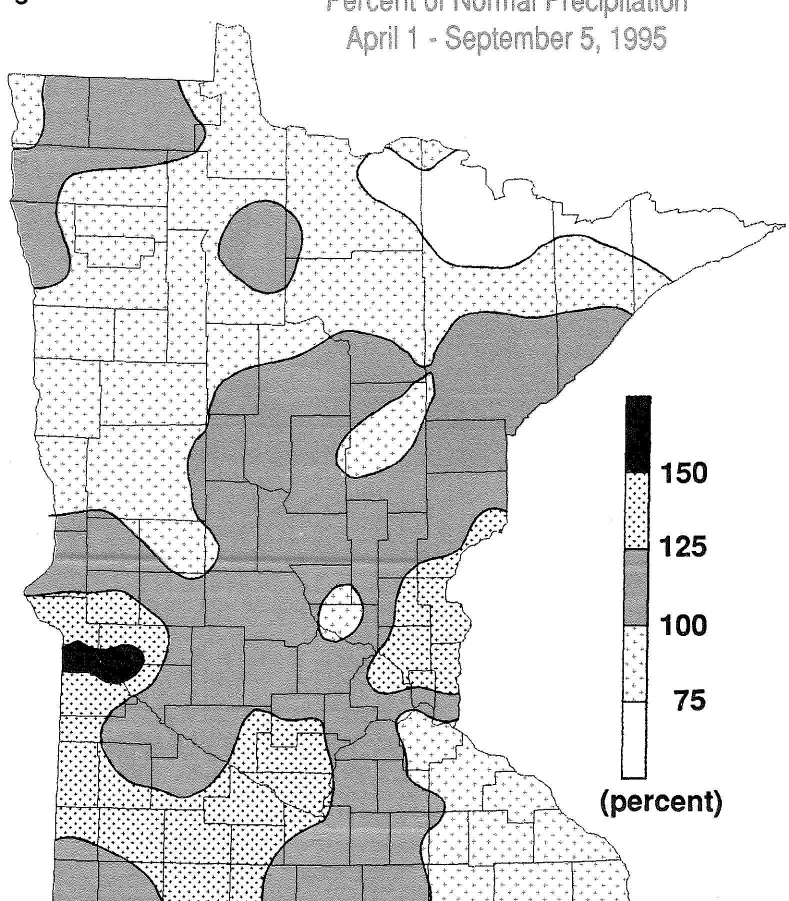
July precipitation was above normal over the entire state, temporarily easing the dryness in the north. However, the precipitation also brought high winds, hail and tornadoes that damaged many Minnesota communities. An extremely heavy rainfall event occurred on July 3 and 4 in west central Minnesota, dropping ten or more inches of rain on northern Chippewa and southern Swift Counties (Figure 4). High water covered roads and washed out fields. On July 13 and 14, intense windstorms downed millions of trees, affecting approximately 200,000 acres of forested land.

Figure 4



Heavy rains continued into August, especially in the south. By the end of August, many areas of southern Minnesota reported 125 to 150 of normal precipitation for the season (Figure 5).

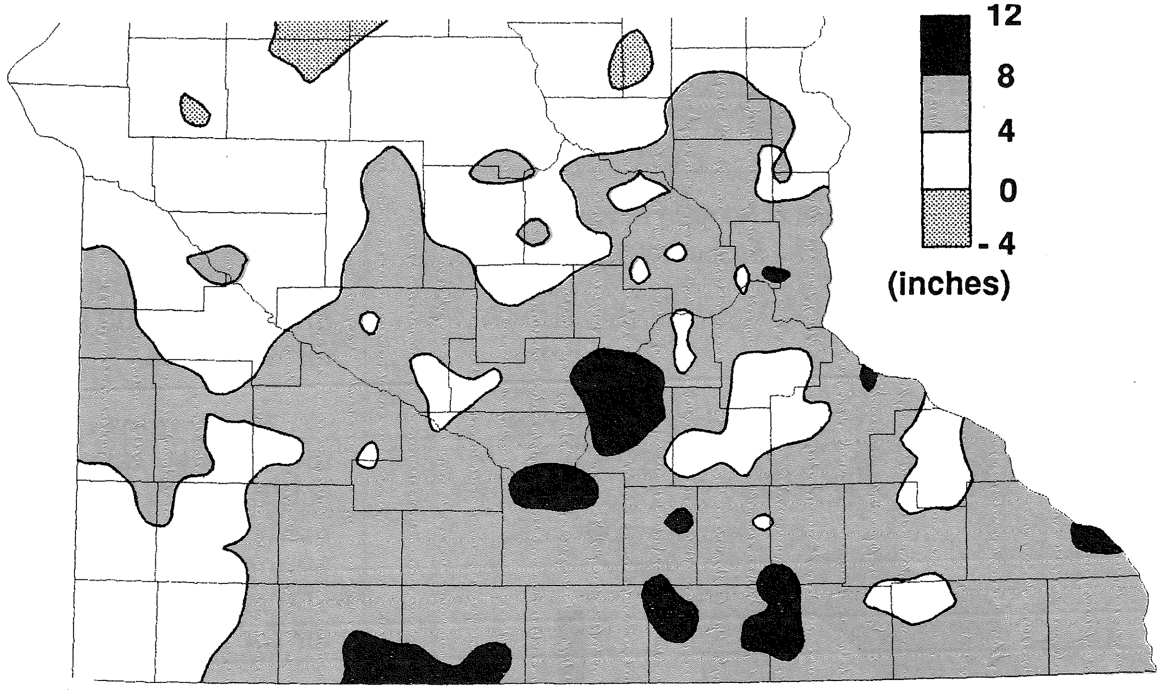
Figure 5



The very wet conditions in the south led to unusually high lake levels and stream flows. The hydrologic imbalances were most apparent in those areas dampened by above-normal precipitation throughout the 1990's (Figure 6). The decade's unusually heavy precipitation in southern Minnesota is comparable in magnitude (but not in areal extent) to the abnormally wet conditions found during the mid-1980's in southern and central Minnesota.

Figure 6

Average Annual Departure from Normal Precipitation (1990 - 1994)

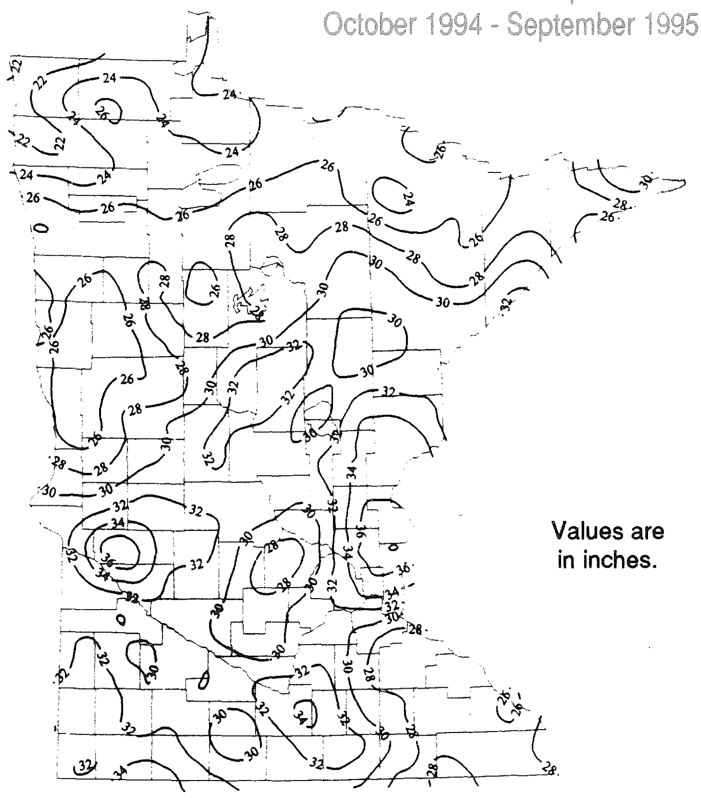


Water Year Summary

The 1995 Water Year precipitation ranged from less than 22 inches in northwestern Minnesota to over 36 inches in portions of central Minnesota (Figure 7). For much of the state, precipitation was near historical averages. However, many western counties received precipitation that exceeded the norm by more than six inches (Figure 8).

Figure 7

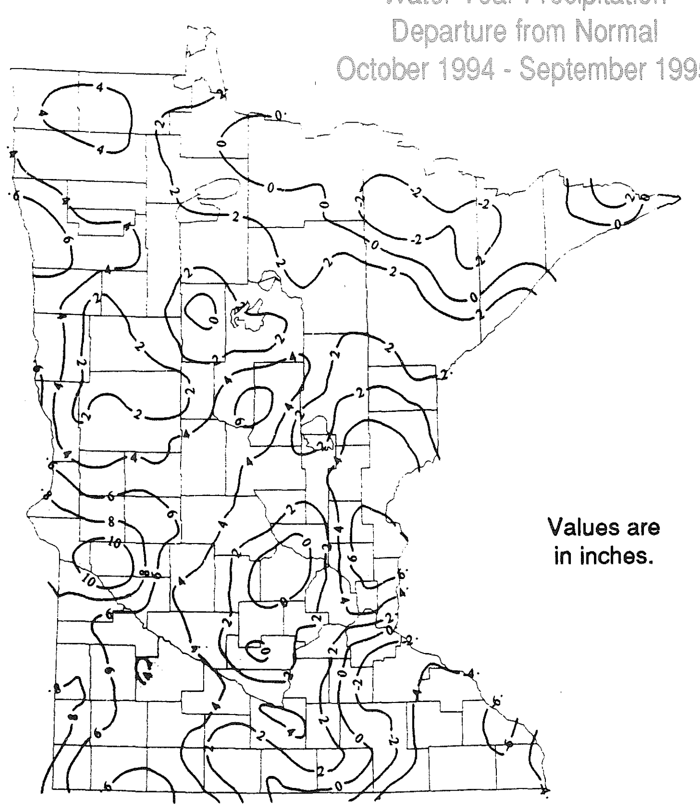
Water Year Precipitation
October 1994 - September 1995



Values are in inches.

Figure 8

Water Year Precipitation
Departure from Normal
October 1994 - September 1995



Values are in inches.

Water Year 1996

October 1, 1995 - September 30, 1996

Highlights

- frigid, snowy winter in north
- all-time record low temperature set (- 60°F) February, 1996*
- cold spring and delayed lake ice-out
- spring flooding in northwest
- extreme dryness in late summer/ early fall in southeast and central

Fall/Winter 1995 - 1996

The fall of 1995 was dry until heavy rains fell in late September and early October. Some locations in north central Minnesota received over five inches of rain during this period. The combined September and October precipitation was above normal for most of Minnesota (Figure 9). The heavy rains dampened soils and led to unusually high stream flows in many areas.

Signs of the winter to come appeared early in western and northern Minnesota when five to nine inches of snow fell on October 23. Very cold November temperatures also foreshadowed the winter. By late November, a blanket of snow covered most of northern Minnesota, a blanket that lasted until spring.

The cold weather of November extended into the first half of December. Heavy snows on December 8 and 13 snarled transportation and closed schools and offices. By mid-December, much of northern Minnesota had at least 18 inches of snow on the ground. The weather turned mild for the second half of December, however, the snowpack remained generally intact.

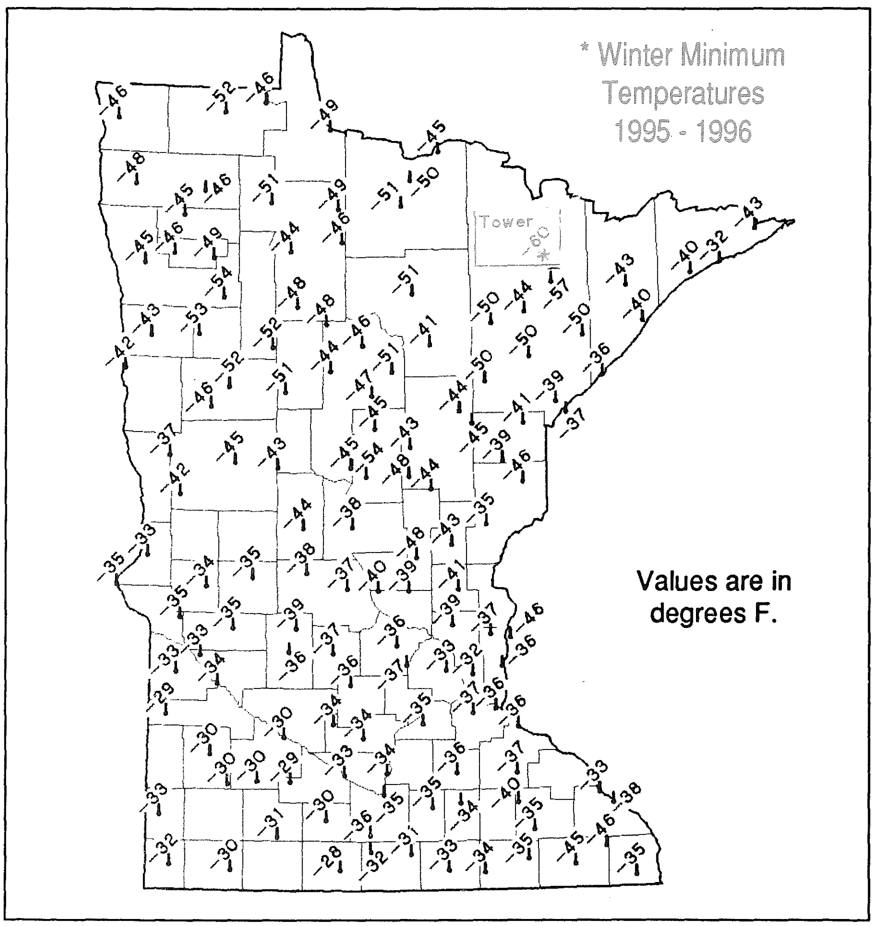
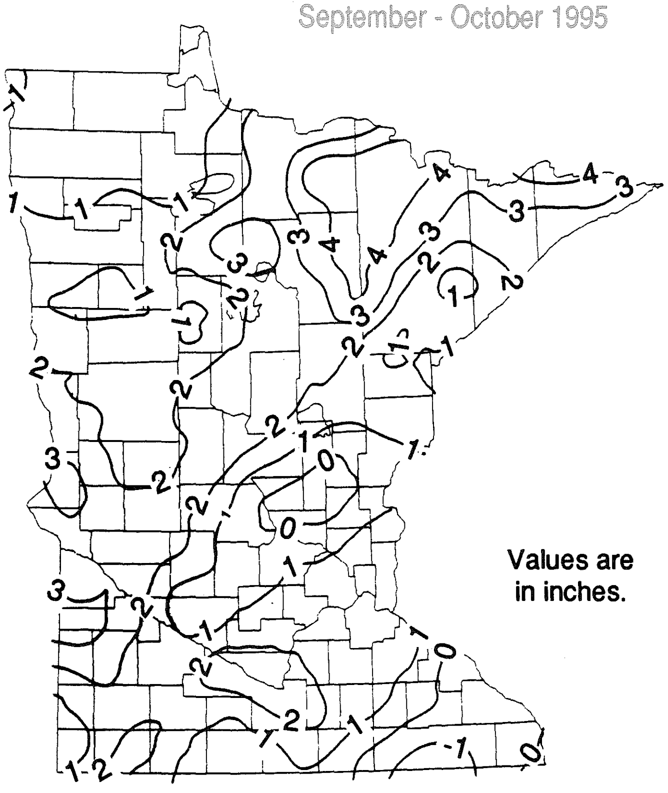


Figure 9



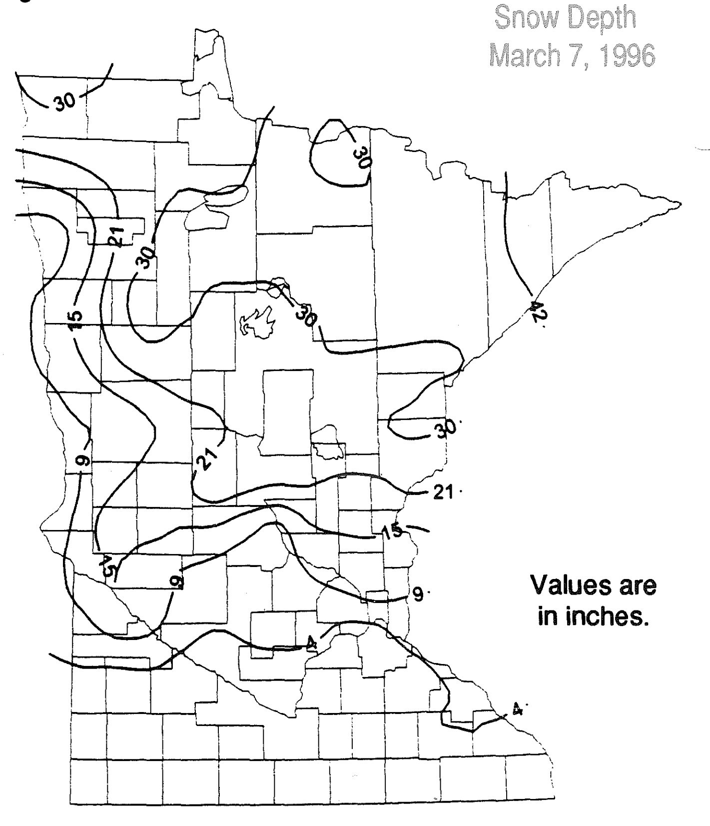
and some all-time low temperature records. A location near Tower broke the all-time Minnesota low temperature record with minus 60 degrees F on February 2.

Temperatures moderated by the second week of February and slowly melted the snow cover from southern Minnesota, easing flooding concerns somewhat in those areas. However, northern Minnesota lost relatively little snow cover. By late March, snow depths were still greater than 18 inches over a large area (Figure 10).

January 1996 brought an assortment of mild and frigid temperatures. A powerful storm on January 17 and 18 produced heavy snow in the north and west, and left southeastern Minnesota covered with ice. Throughout the state, schools and offices closed, travel was very difficult, and power outages occurred.

Late January and early February brought a cold spell of historic proportions to the Upper Midwest. Various locations across Minnesota set daily low temperature records

Figure 10



Spring 1996

After enduring one of the harshest winters of the century, northern Minnesota experienced a very cold spring. Significant snow cover persisted in the north well into mid-April. Spring runoff from the heavy snow cover led to flooding, with northwestern Minnesota experiencing the most serious flooding.

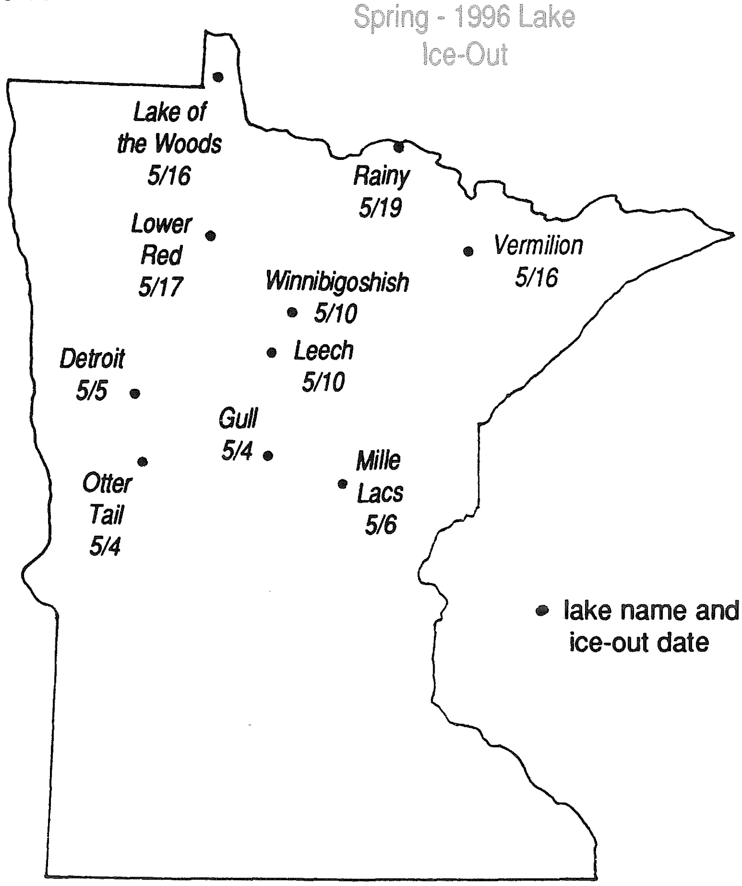
Lake ice-out dates were among the latest ever recorded in the north. A few northern Minnesota lakes failed to lose their ice until mid-May and remained frozen for the opening of the fishing season (Figure 11).

Southern Minnesota also experienced an unusually cold spring. Temperatures averaged three to five degrees below normal for April and May. The Twin Cities reached 67 degrees on April 10, the first time the temperature reached 60 or more for nearly six months. The cold temperatures suppressed soil warming and drying, leading to significant delays in 1996 spring planting.

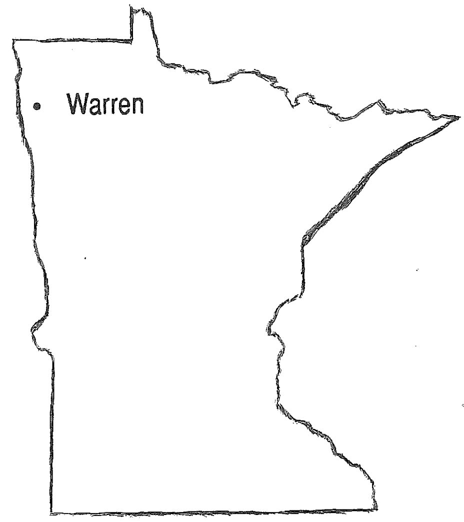
Heavy rains in mid-May dropped two to six inches of water on the already saturated Red River Valley, further delaying agricultural field operations and leading to more flooding (see sidebar on flooding in Warren). May also brought the usual spate of spring severe weather to western and southern Minnesota which led to significant property damage in some areas.

Figure 11

Spring - 1996 Lake Ice-Out



1996 Spring Flooding in Warren, MN



Warm temperatures during the weekend of April 13-14, 1996, sent vast amounts of water from the melting snowpack flowing westerly along the Snake River toward the city of Warren, MN. Area residents hoped that this huge snowmelt would flow through ditches and channels to the Red River without flooding in Warren and other communities.

However, on April 17, the daytime temperature soared to 65°, which is 10°-15° above normal. The resulting snowmelt caused a surge in the Snake River flow. The next day, with little advance warning, the Snake River went over its banks near the fairgrounds on the east side of Warren. Later that day, the temperature again reached 65°, causing a second, more damaging surge in flow.

By 5 AM on April 19, the Snake reached its peak level of 851.7, and an estimated 70 percent of the residences in Warren were impacted by flood waters. Those structures that were affected primarily involved basement flooding, while a few homes had flood water on their main floors. Many other residences were protected by sandbags installed by owners and volunteers.

Warren suffered a second and more severe flood on May 18, 1996. Heavy rains fell on the Snake River watershed on May 16-17, resulting in a peak stage of 853.7. This was a full two feet higher than the peak observed one month earlier and within a half foot of matching the flood of record at Warren.

City officials estimated that 80-90 percent of residences were impacted by this flood event. In most cases, damage included partially or fully flooded basements, with an additional number suffering main floor flooding.

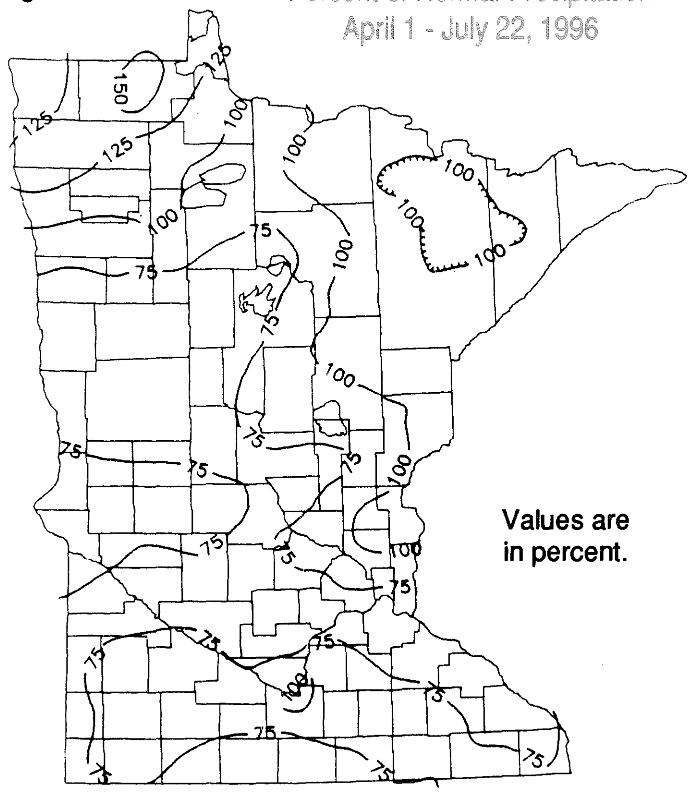
The floods of 1996 have sparked an interest in flood control, flood protection and flood damage reduction measures in the City of Warren.

Photo courtesy of *Warren Sheaf*

Summer 1996

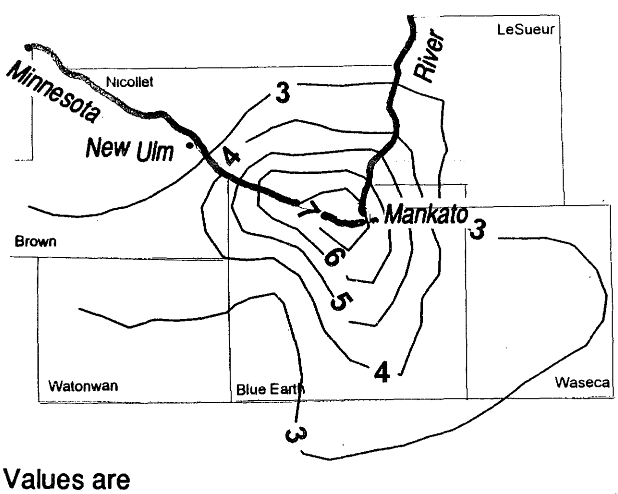
The weather was highly variable across the state in June. Very dry weather for the first three weeks of the month led to forest fires in the north, especially northeastern Minnesota. Fortunately, late June rains quelled the fire potential. In contrast to the dryness of the north, some areas of southern Minnesota received torrential rains in mid-June. A slow-moving low pressure system, plodding through the Upper Midwest, produced a deluge in south-central Minnesota on June 16 and 17. Rainfall totals exceeded six inches in portions of Nicollet and Blue Earth Counties leading to small stream and urban flooding as well as mud slides (Figure 12).

Figure 13 Percent of Normal Precipitation
April 1 - July 22, 1996



Values are in percent.

Figure 12 Heavy Rains - South-Central MN
June 16 - 17, 1996



Values are in inches.

Relatively dry weather was the major climate issue of July 1996. As of late July, many areas of central and western Minnesota had received just 50 to 75 percent of normal precipitation for the season (Figure 13). However, there was a notable exception to this pattern. Extreme north- western Minnesota received substantial rains in July and precipitation totals were well above normal for the season.

Dry and pleasant weather was the rule throughout the late summer and early fall across Minnesota. For some regions of the state, dry weather was a continuation of a very dry growing season. For a few communities, the precipitation deficit was similar to the worst droughts of the century (Figure 14). Fortunately, moderate summer temperatures led to reduced evaporation rates, mitigating the impact of the rainfall shortage. The Palmer Drought Severity Index indicated that southeastern Minnesota was in the "moderate drought" category in the fall of 1996. Northwestern, central, and east-central Minnesota fell in the "moderate drought" category for much of the summer and early fall.

A notable exception to the dry fall weather was in the Mankato area in early September. For the second time in 1996, the area received extremely heavy rains leading to urban flooding, mud slides and sewer backups. Rainfall totals exceeded six inches.

Figure 14

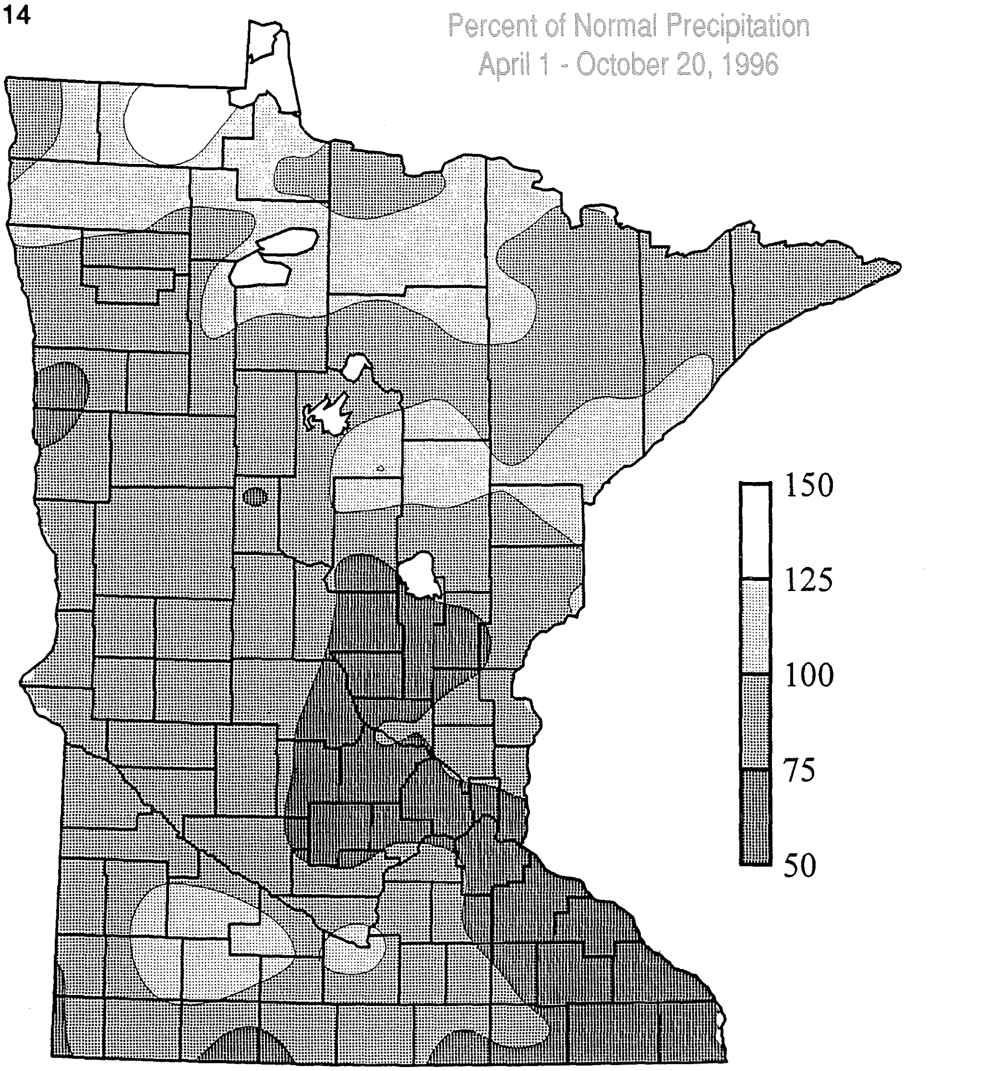
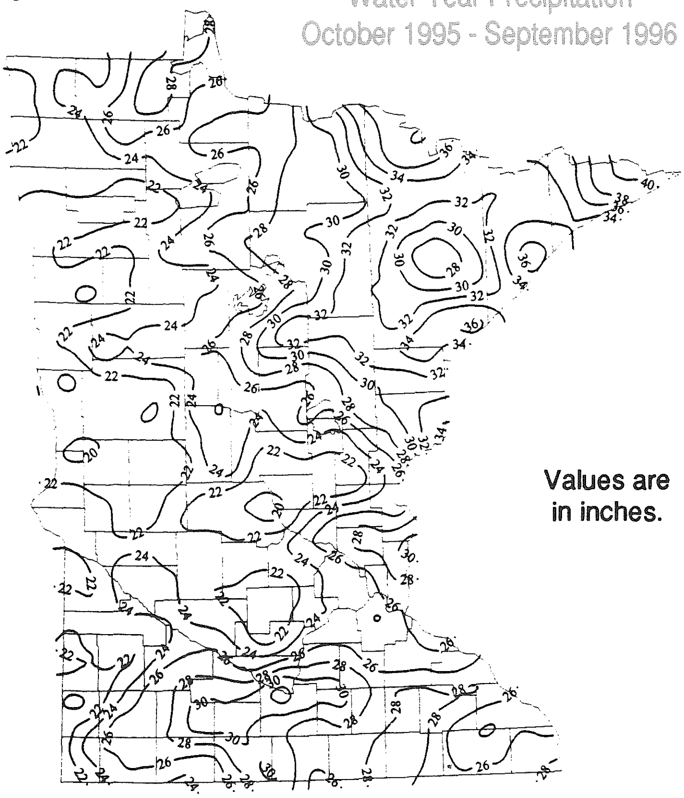


Figure 15

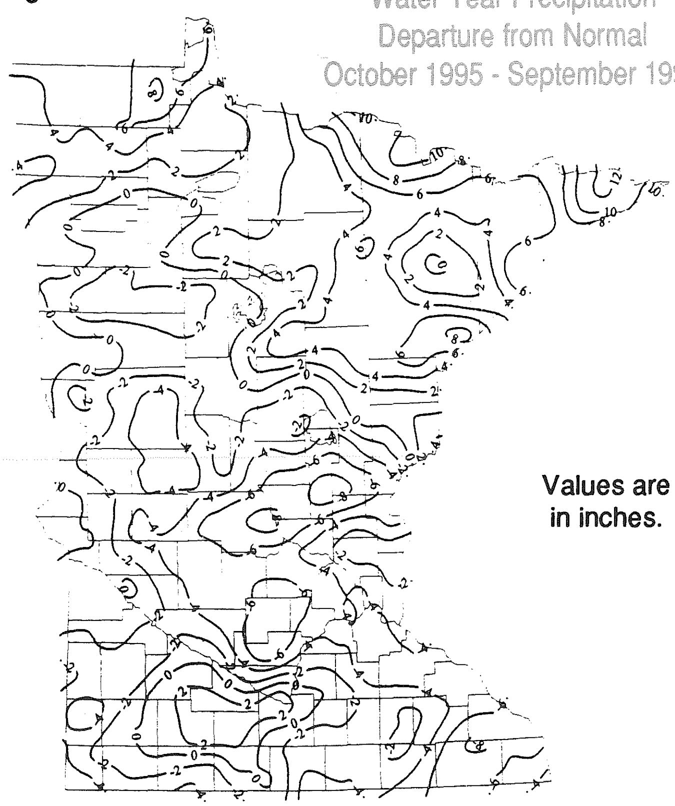
Water Year Precipitation
October 1995 - September 1996



Values are in inches.

Figure 16

Water Year Precipitation
Departure from Normal
October 1995 - September 1996



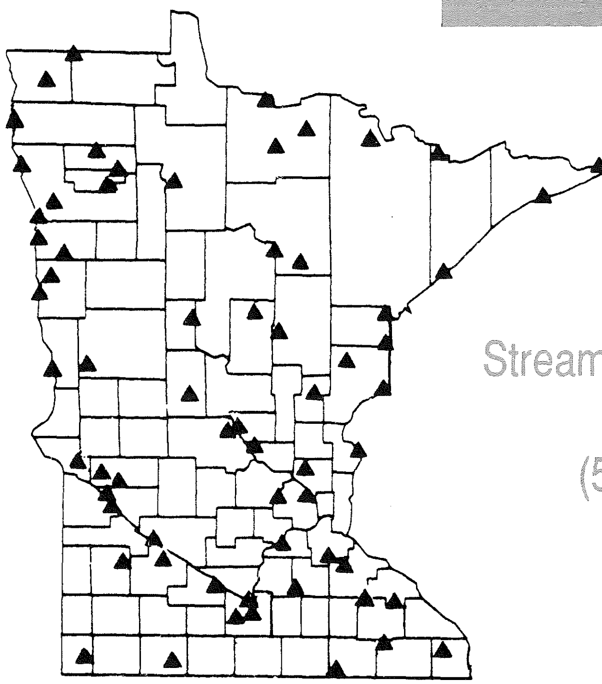
Values are in inches.

Water Year Summary

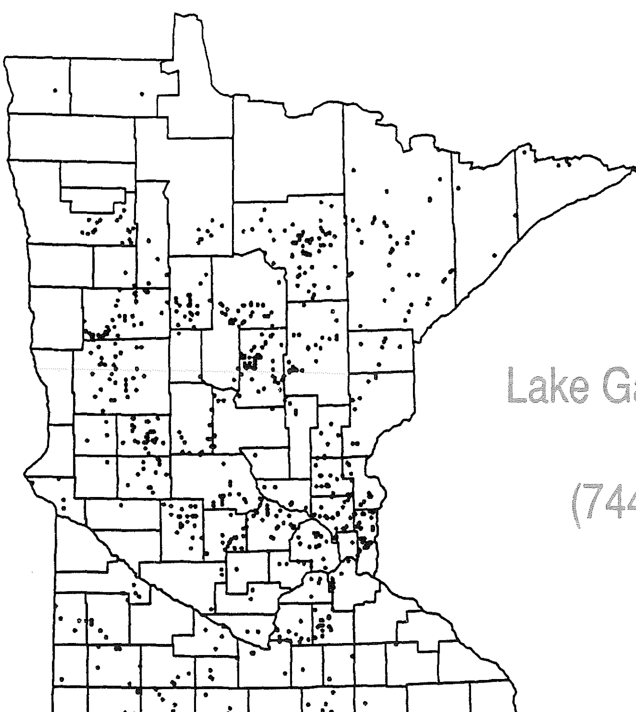
The 1996 Water Year precipitation ranged from less than 22 inches in portions of northwestern and central Minnesota, to over 36 inches in extreme north-eastern Minnesota (Figure 15). For much of the state, precipitation was below historical averages (Figure 16), especially in southeastern and central Minnesota.

Chapter 2

SURFACE WATER



Stream Gage Network
1996
(57 Gages)



Lake Gage Network
1996
(744 Gages)

Stream Flow

Introduction

The Stream Flow Unit is responsible for gathering and analyzing flow data for rivers and streams of Minnesota. Figure 1 shows the 81 major watersheds of the state and the location of the many gages within those watersheds. These gages are used to gather data related to stream flow conditions including historic high and low flow information and basic flow statistics such as exceedence values (see sidebar). Most stream gages in Minnesota are operated by the United States Geological Survey with additional funding from the Department of Natural Resources - Division of Waters, the National Weather Service and the U. S. Army Corps of Engineers.

Using the 81 major watersheds as a base, appropriate gages are chosen to monitor stream flow conditions throughout the state.

Stream Drainage Systems

There are many types of rivers and streams in Minnesota. Along the North Shore of Lake Superior, and along the Mississippi River blufflands in the southeast, are high gradient streams that have scoured channels into bedrock. In the northwest are highly meandered streams that are situated in an ancient lake bed and are prone to flooding. In the southern third of the state, streams are often entrenched with well developed channels and are largely impacted by agricultural practices. North-central streams can be impacted by both agricultural and forest land uses.

Minnesota is unique in that two of the three continental divides in North America pass through it. These two continental divides separate river flows into the Hudson Bay/Arctic Ocean Drainage Basin, the Great Lakes/Atlantic Ocean Drainage Basin, and the Mississippi River/ Gulf of Mexico Drainage Basin (Figure 1). The Mississippi River Drainage Basin is divided by rivers that flow into the Upper and Lower Mississippi River, the Minnesota River and the Missouri River sub-basins.

EXCEEDENCE VALUE

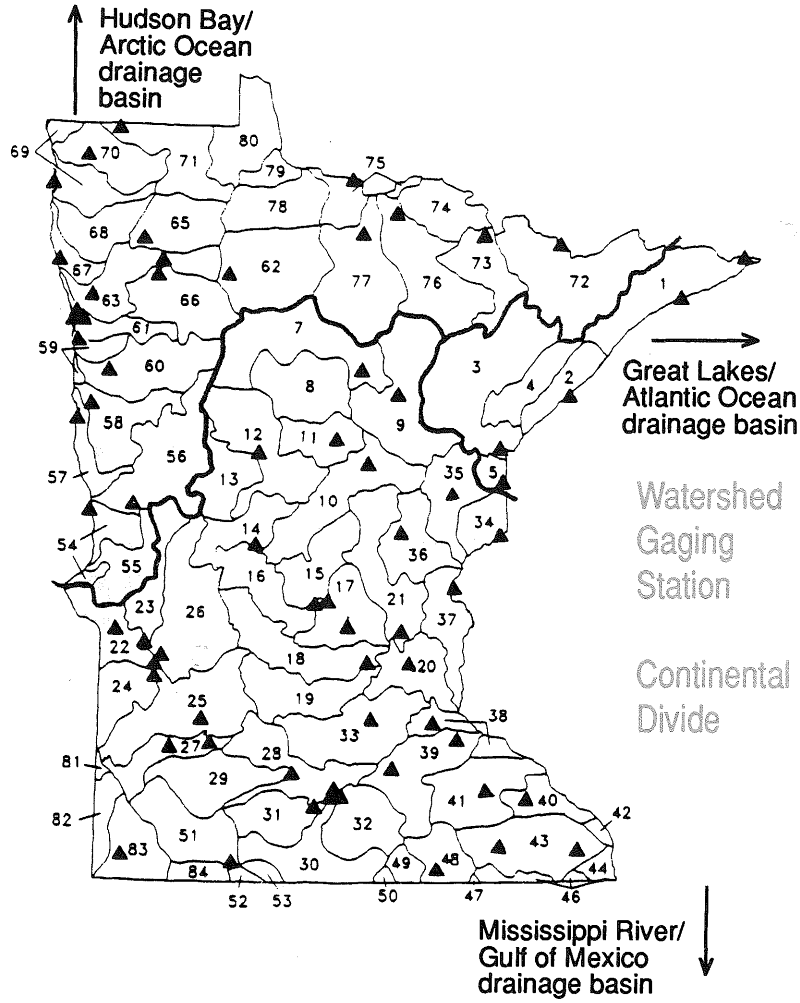
An exceedence value is a statistical parameter, based upon historical discharge records, and is the probability of stream flow *exceeding* a certain value. A 50% exceedence value (Q50) indicates that the discharge at that reporting station has been *equalled* or *exceeded* 50% of the time during the period of record (monthly, yearly, etc).

Stream flow reports are based upon the following exceedence values during the open water season.

Critical Flow = < annual Q90
Low Flow = < monthly Q75
Normal Flow = monthly Q75 to Q25
High Flow = > monthly Q25
Flood Flow = NWS flood stage
(or highest monthly Q10)

Figure 1

81 Major Watersheds



1 Lake Superior (north) ▲
2 Lake Superior (south) ▲
3 St. Louis River ▲
4 Cloquet River
5 Nemadji River ▲
*
7 Mississippi River (Headwaters, Lake Winnibigoshish) ▲
8 Leech Lake River
9 Mississippi River (Grand Rapids) ▲
10 Mississippi River (Brainerd) ▲
11 Pine River ▲
12 Crow Wing River ▲
13 Redeye River (Leaf River)
14 Long Prairie River ▲
15 Mississippi River (St. Cloud)
16 Sauk River ▲
17 Elk River (Elk River) ▲
18 North Fork Crow River ▲
19 South Fork Crow River
20 Mississippi River (Metro) ▲
21 Rum River ▲
22 Minnesota River (Headwaters)
23 Pomme de Terre River ▲
24 Lac qui Parle River ▲
25 Minnesota River (Montevideo) ▲
26 Chippewa River ▲
27 Redwood River ▲
28 Minnesota River (Mankato) ▲
29 Cottonwood River ▲
30 Blue Earth River ▲
31 Watonwan River ▲
32 Le Sueur River ▲
33 Minnesota River (Shakopee) ▲
34 St. Croix River (Upper)
35 Kettle River
36 Snake River
37 St. Croix River (St. Croix Falls) ▲
38 Vermillion River (Empire) ▲
39 Cannon River ▲
40 Mississippi River (Winona) ▲
41 Zumbro River ▲
42 Mississippi River (La Crescent)
43 Root River ▲
44 Mississippi River (Nevo)
*
46 Upper Iowa River
47 Wapsipinican River (Headwaters)
48 Cedar River ▲
49 Shell Rock River
50 Winnebago River (Lime Creek)
51 West Fork Des Moines River (Headwaters) ▲
52 West Fork Des Moines River (Lower)
53 East Fork Des Moines River
54 Bois de Sioux River ▲
55 Mustinka River
56 Otter Tail River ▲
57 Red River of the North (Headwaters) ▲
58 Buffalo River ▲
59 Marsh River ▲
60 Wild Rice River ▲
61 Sandhill River ▲
62 Upper and Lower Red Lake ▲
63 Red Lake River ▲
*
65 Thief River ▲
66 Clearwater River ▲
67 Grand Marais Creek (Red River of the North) ▲
68 Snake River
69 Tamarack River (Red River of the North) ▲
70 Two River ▲
71 Roseau River ▲
72 Rainy River (Headwaters) ▲
73 Vermillion River ▲
74 Rainy River (Rainy Lake)
75 Rainy River (Manitou) ▲
76 Little Fork River ▲
77 Big Fork River ▲
78 Rapid River
79 Rainy River (Baudette)
80 Lake of the Woods
81 Big Sioux River (Medary Creek)
82 Big Sioux River (Pipestone)
83 Rock River
84 Little Sioux River

Stream Flow Reports

A weekly report called the Minnesota Stream Flow Report is produced during the open water season (late March to October) to keep Division of Waters staff and other interested persons appraised of stream flow conditions throughout the state. A map that presents flow conditions in the 81 major watersheds is included with the weekly stream flow report. This map classifies each major watershed as having flow characteristics of critical, low, normal, high or flooding, based on historical flow statistics. Flood flows are based on a stage established by the local community at which flooding begins. When no flood stage has been established, the highest monthly Q10 is used as an interim number until a flood stage can be established for that site. Critical flow is below the annual Q90. At critical flow, fish and other aquatic organisms may experience significant stress. Watersheds that do not have a gage, or lack telemetry or other forms of instantaneous communications, are assigned flow categories based on a gage in an adjacent watershed with similar characteristics.

The weekly stream flow report gives water resource managers current information on a stream or river. However, the weekly nature of the report is such that it can be impacted by a single event. For example, during periods of low flow, a light Sunday rain may make a stream appear to be at normal flow, when in fact the stream may be at normal flow for only a couple of hours.

To filter out these transient effects, monthly and annual stream flow reports are produced. Unlike weekly reports which list flow conditions in critical, low, normal, high or flooding catagories, the monthly and annual reports use statistical exceedence numbers (see sidebar at the beginning of this chapter). These maps are posted on the Internet upon completion, and are used in this report.

1995 Water Year

At the end of WY94, stream flow conditions throughout most of the state remained well above normal. In October, high flow conditions could be found in all watersheds except those in the northeast. Stream flow throughout the winter remained higher than normal with soil moisture conditions above normal.

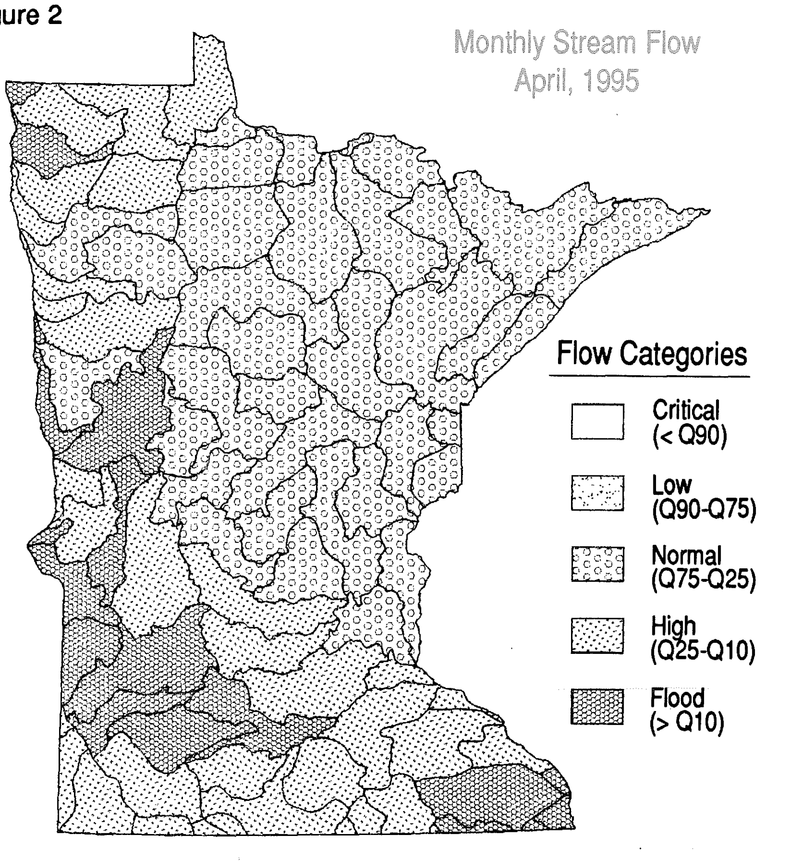
While there was significant potential for major flooding in the spring of 1995, it did not occur due to an early spring breakup. In the Red River headwaters and tributaries (basin), spring runoff started as much as 10 days before average. This early runoff had the effect of releasing storage which would otherwise exacerbate flooding. However, while the overall flooding potential was reduced, there was still major flooding in parts of the Red River basin and the Minnesota River basin. Flooding ended early in the Red River basin, but heavy rains caused flooding in the Minnesota River basin until early May.

WORLD WIDE WEB SITE ADDRESS:
http://www.dnr.state.mn.us
(see Climatology section)

Both precipitation and stream flow remained well above normal for April and May in the southern half of the state, while the Upper Mississippi, Great Lakes and Rainy River basins remained near normal (Figure 2). The map shows that a significant volume of water moved through the Upper Minnesota River basin and some of the Red River watersheds. The volume of water flowing in the Red River watersheds would surely have been greater if not for the early snow melt.

Flows in the Upper Mississippi, Great Lakes and Rainy River basins remained near normal for the balance of the spring. However, a lack of precipitation throughout April and May in the northern half of the state had significant effects on stream flow in these watersheds. This precipitation pattern continued well into summer throughout most of the state.

Figure 2

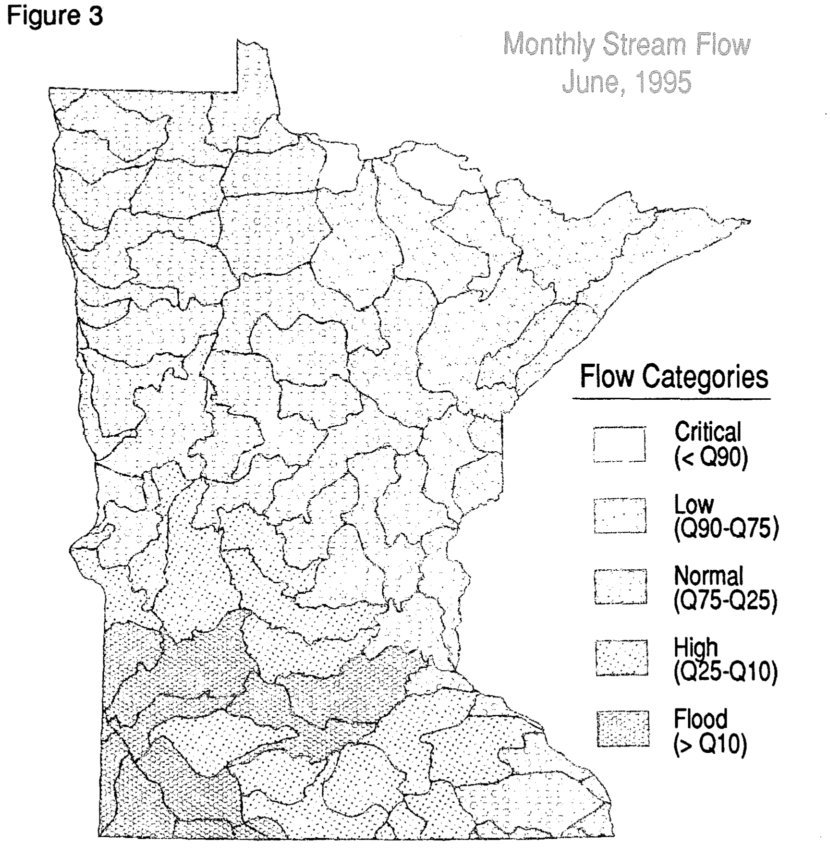


Early summer conditions remained well above normal in the southwest while low flow conditions could be found in much of the northeast (Figure 3). Normal stream flow could be found in the northwest and southeast.

By August, flow in the northeast had fallen to critical levels for parts of the Rainy River and North Lake Superior watersheds. These were the first critical flows in Minnesota since 1992. Stream flows remained above normal for much of the southern half of the state.

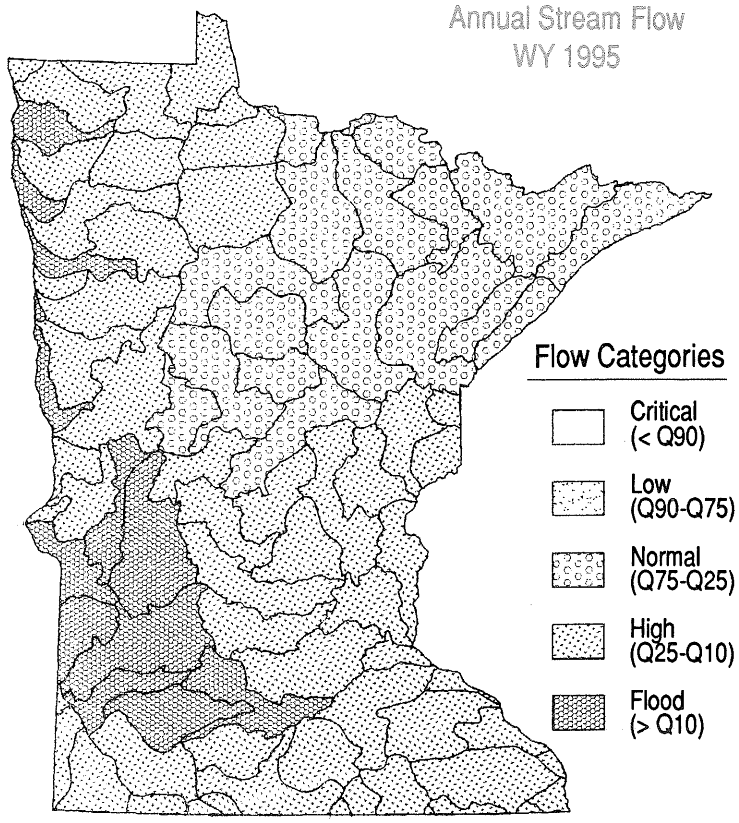
Wet weather gradually returned and conditions improved into the normal or high flow range. High flow conditions could be found throughout much of the state during the remaining days of August and most of September.

Figure 3



For WY95, flow conditions were near normal for the Upper Mississippi River basin and the Rainy River basin (Figure 4). The remainder of the state had flows greater than the annual Q25, while in the Upper Minnesota River basin and parts of the Red River basin, average flows were greater than the annual Q10.

Figure 4

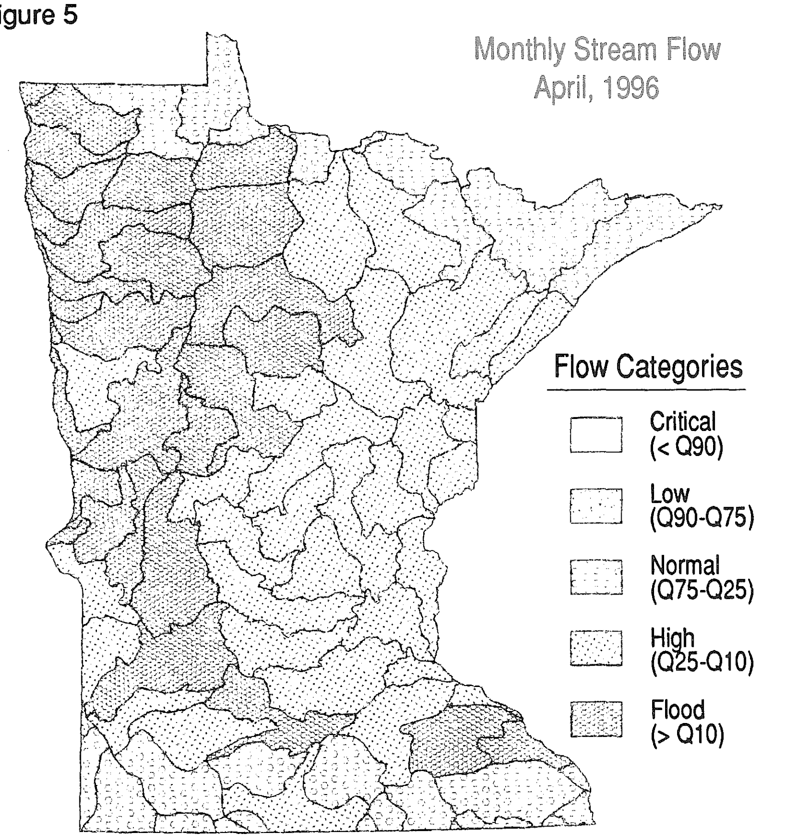


1996 Water Year

Stream flow continued well above normal for the fall of 1995 and the winter of 1996. The spring snowmelt was both early and gradual for most of the state. In the Minnesota River basin, the snowmelt led to many April high flows, but no significant flooding. Some minor flooding occurred in the Pomme de Terre, Chippewa, and Yellow Medicine River watersheds (Figure 5).

In the west and northwest, snowmelt was significantly different. A deep snow pack and cold temperatures continued well into late March. The spring snowmelt was late and rapid, causing significant flooding in much of the Red River Valley (see Figure 12 for a hydrograph of the Red River at Grand Forks, ND). The most significant flooding occurred when the Red River caused the Sandhill River to back up into the City of Climax, inundating approximately 700 structures. As a result, several counties were declared disaster areas. Total damages due to this flooding exceeded several million dollars.

Figure 5

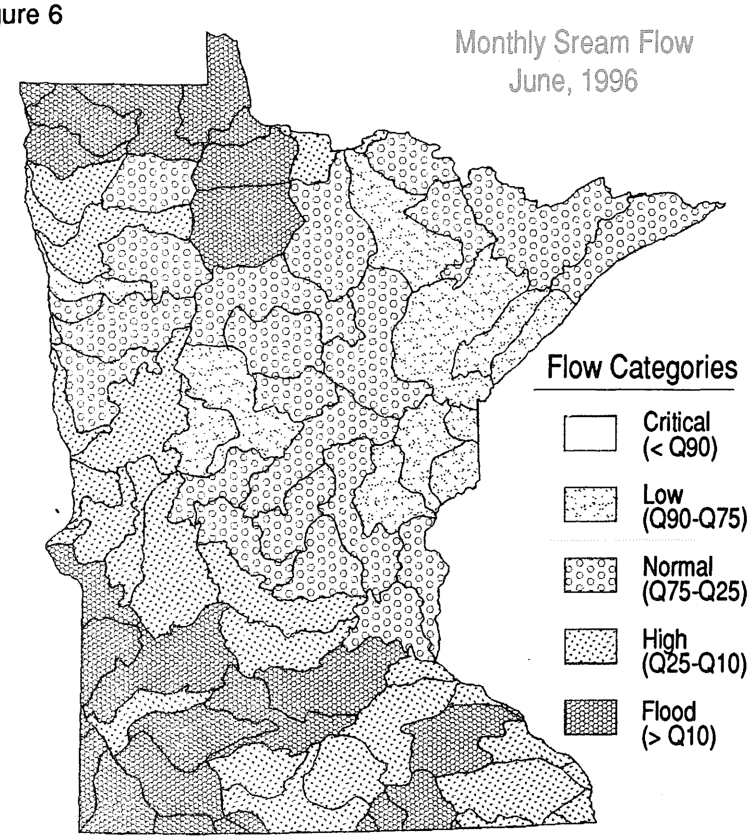


With ditches and streams blocked by heavy snow pack in the northern part of the Red River Valley, water was forced to flow overland. Overland flooding was most apparent in the Two River and Roseau River watersheds. As the Roseau River and its tributaries became blocked, some of the water spilled into the Two River watershed. In the upper reachers of the Two River, significant damage occured along roads as high velocity water overflowed ditches, washed out culverts and bridges, and eroded new channels.

In the lower parts of the Two River watershed, the Red River flooded roads with as much as 12 feet of water. While the Red was as much as six miles out of bank on the Minnesota side, the velocity component of the flow was quite low. Flood damages caused by the Red River were less than expected due to the low velocity. With the large volume of water available in the snow pack and spring rains, flooding continued in the Red River basin for much of April and May.

Early summer rains produced some flooding in the Minnesota and Lower Mississippi River basins (Figure 6). Flows in the Upper Mississippi, Great Lakes and Rainy River basins fell into the normal flow range. Low flow conditions could be found in the St. Croix River basin and the Great Lakes basin in late June.

Figure 6

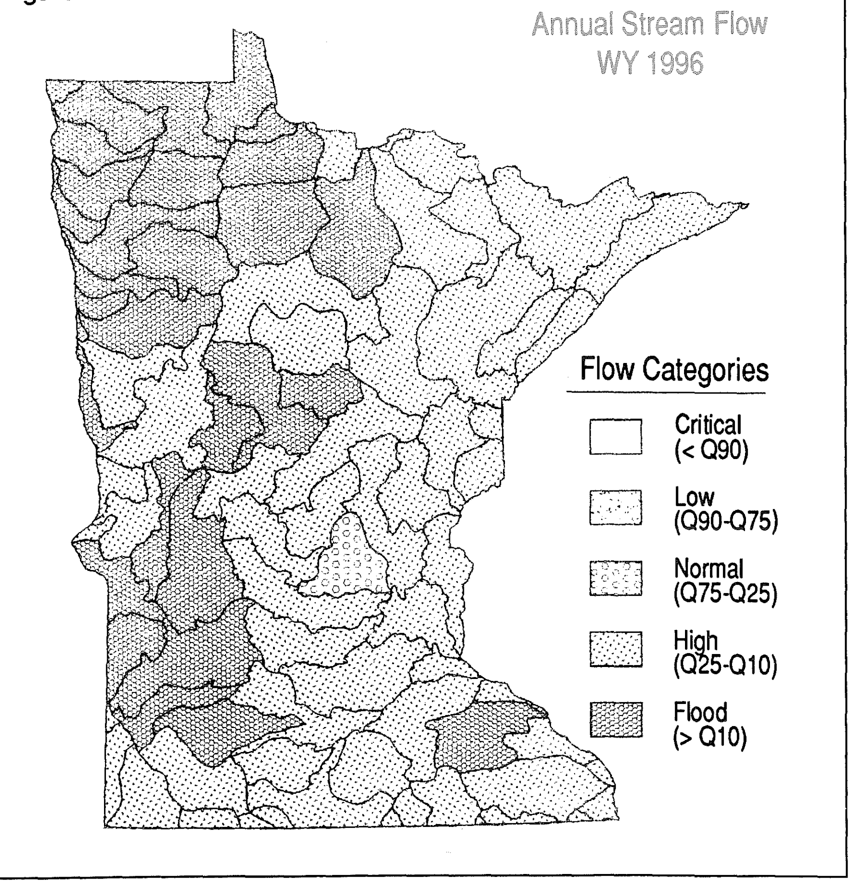


By July, both the low and high flow conditions of June had receded to near normal for much of the southern half of the state and parts of the Red River basin. However, high flow conditions could still be found in the northeastern corner of the state. This pattern continued for much of August, with the exception of an occasional low flow in the St. Croix basin.

Stream flow remained in the normal range during September. However, flows in much of the Mississippi River basin dropped to the low side of normal as some minor drought conditons started to develop.

Stream flows for WY96 were well above average for the entire state (Figure 7). The Elk River was the only watershed in the state that ended the year with an annual average in the normal flow range. The remainder of the state had flows greater than the annual Q25. In the Minnesota River basin and most of the Red River basin, the average annual flows exceeded the annual Q10. Most of the high values shown for the Red River basin are the results of runoff associated with the spring snowmelt.

Figure 7



Hydrographs

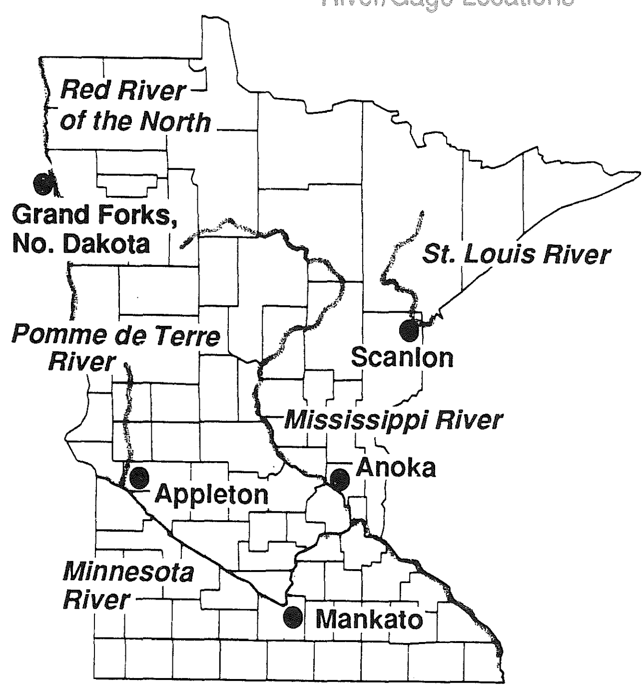
A hydrograph is a graph showing the volume of water discharged for a specific time period. For the 1995 and 1996 water years, hydrographs are shown for five rivers (Figure 8). These five rivers offer insight into the various types of rivers in Minnesota.

The two-year hydrographs (1995-1996) show the mean daily discharge and the Q25 and Q75 exceedence values. Flows greater than Q25 are considered high, below Q75 are low and between the Q25 and Q75 are considered normal. Daily exceedence values are used for these sites. Advantages of using daily exceedence values (over monthly) include the ability to identify the start of spring runoff or seasonal trends such as wet periods, and to refine Q25 and Q75 values. The ten-year hydrographs (1987-1996) show the mean daily discharge, the daily Q50 exceedence value and the mean annual discharge. The mean annual discharge is used to identify short-term trends.

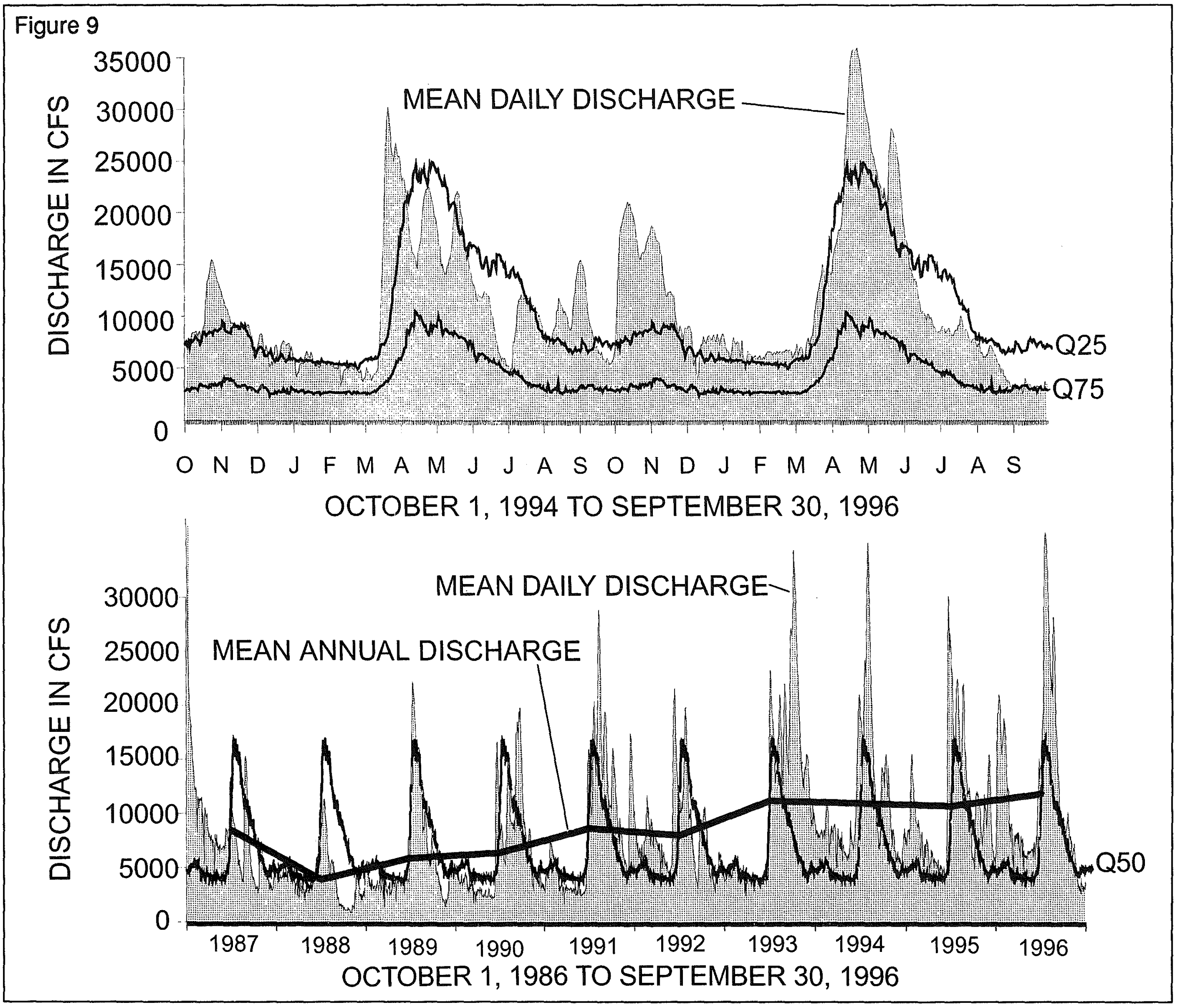
Each set of hydrographs includes a small table showing the mean annual flow statistics for the WY95 and WY96, the period of record, the last ten years and the highest and lowest mean annual discharge. These statistics are ranked against each other by percent.

Figure 8

River/Gage Locations



Mississippi River at Anoka



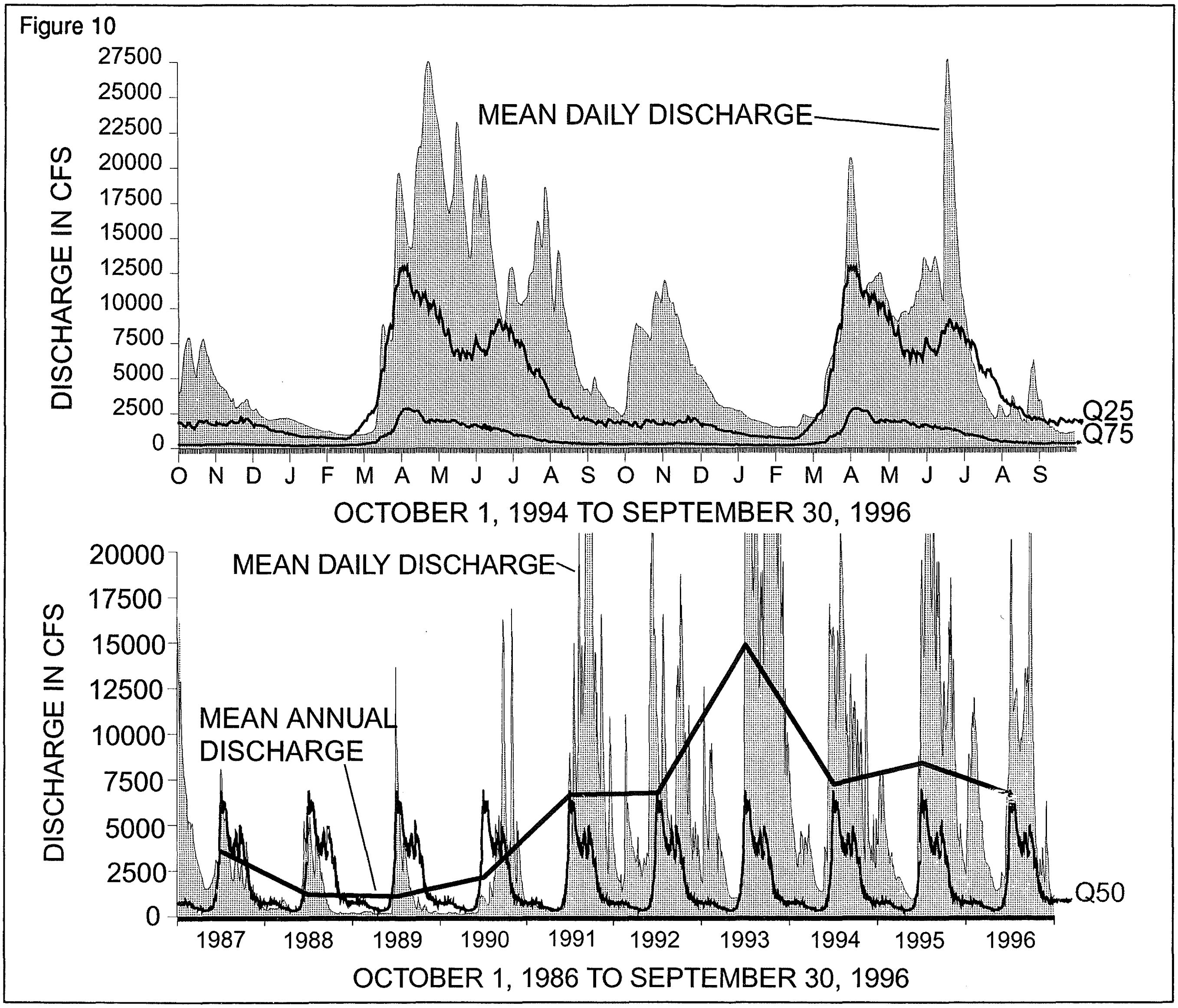
The Mississippi River is the largest river in North America and the 7th largest river in the world. Flows in the Mississippi River have steadily increased since the drought of 1988. Mean annual discharge for 1996 ranked 6th. Four of the top ten years with the largest mean annual discharge at Anoka were 1983 to 1986.

MISSISSIPPI RIVER AT ANOKA

YEAR(S) (RANK)	MEAN ANNUAL DISCHARGE(cfs)	% OF NORMAL
1932-1996(65)	8107	100 %
1987-1996	8595	106 %
1995(19)	10710	132 %
1996(6)	11850	146 %
1986(1)	17750*	219 %
1934(65)	1603**	20 %

*HIGHEST RECORDED **LOWEST RECORDED

Minnesota River at Mankato



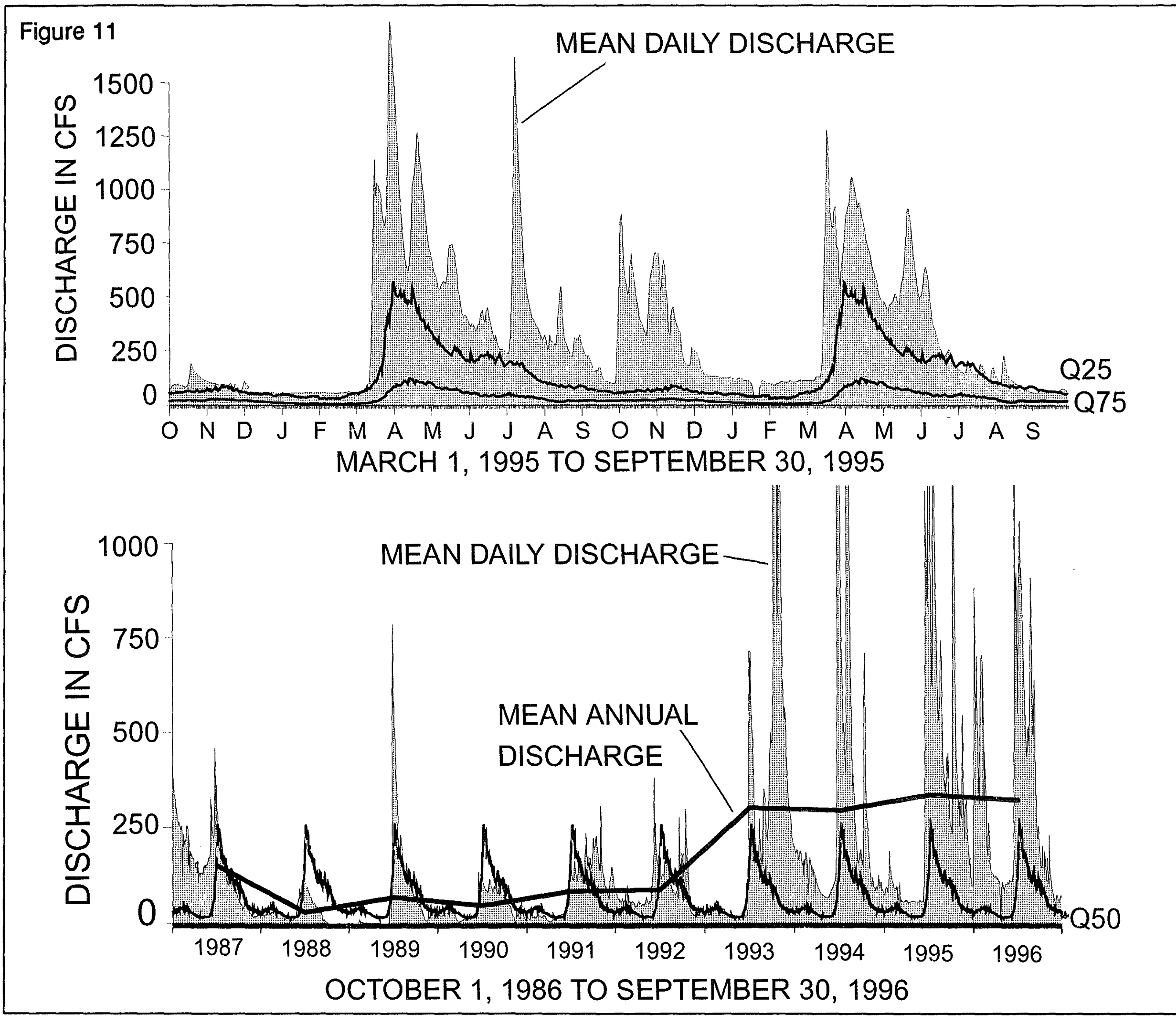
The Minnesota River flows 270 miles from its origin at Big Stone Lake to its confluence with the Mississippi River at Fort Snelling. Stream flows on the Minnesota River have increased dramatically in the last ten years. For that period, the mean annual discharge is 172% of its historic average. Every year since 1991 has ranked in the top ten in terms of mean annual discharge. The rankings for each year since 1991 are: 9th, 8th, 1st, 7th, 4th and 10th, respectively.

MINNESOTA RIVER at MANKATO

YEAR(S) (RANK)	MEAN ANNUAL DISCHARGE(cfs)	% OF NORMAL
1905-1996(75)	3398	100 %
1987-1996	5858	172 %
1995(4)	8399	247 %
1996(10)	6664	196 %
1993(1)	14890*	438 %
1934(75)	136**	4 %

*HIGHEST RECORDED **LOWEST RECORDED

Pomme de Terre River at Appleton



The Pomme de Terre is a small river beginning in the lake region of Otter Tail County and flowing approximately 100 miles due south into the Minnesota River. The upper portion of the Pomme de Terre basin is filled with lakes and small wetlands while the lower portion of the basin is more heavily drained and ditched.

Of the 61 years of continuous record at Appleton, 1995 and 1996 have had the 2nd and 3rd largest mean annual discharge, respectively. The largest mean annual discharge occurred in 1986 while 1993 and 1994 had a ranking of 4th and 5th, respectively. Flows have not been below the daily Q50 in Appleton since 1993.

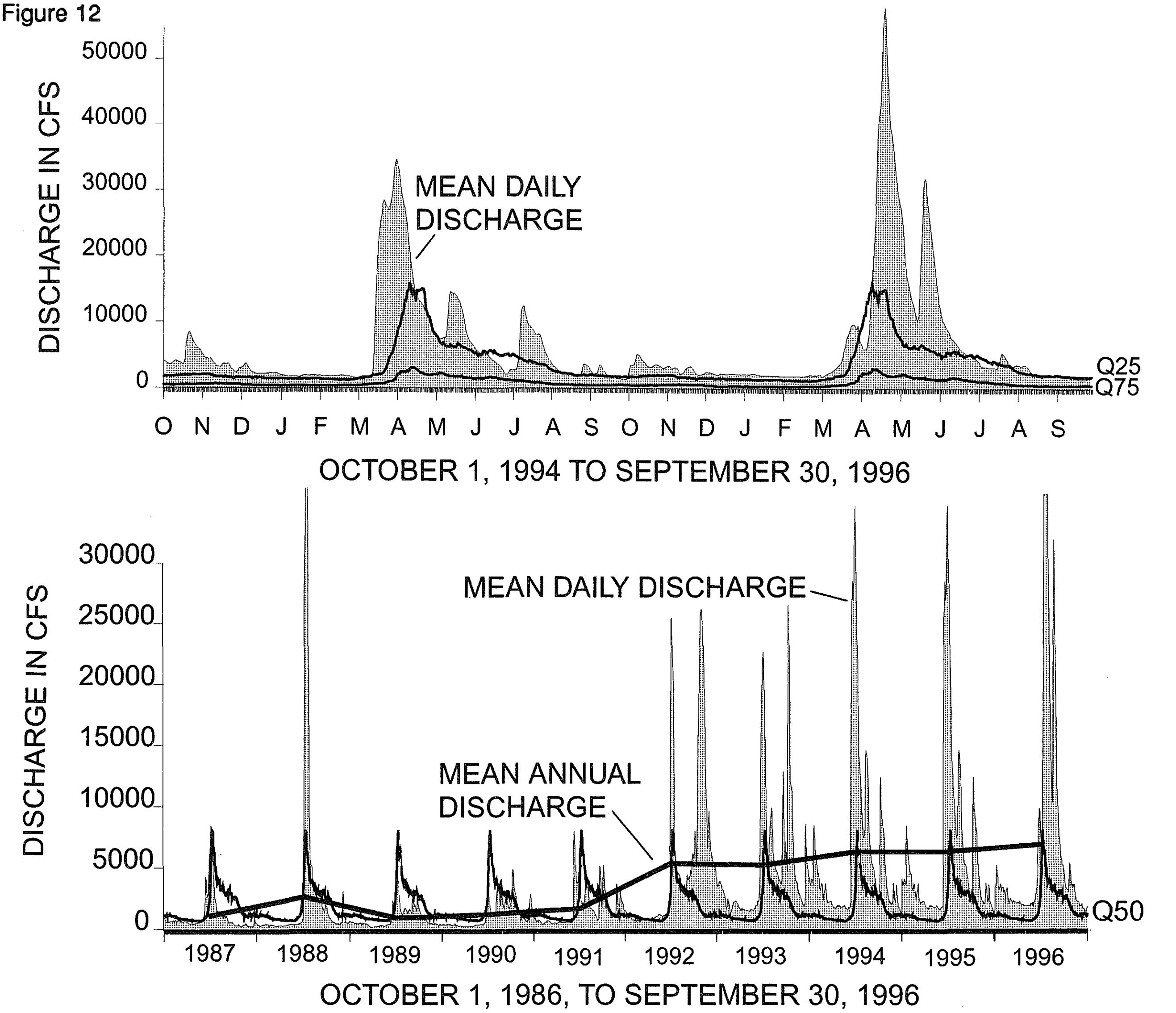
POMME DE TERRE RIVER at APPLETON

YEAR(S) (RANK)	MEAN ANNUAL DISCHARGE(cfs)	% OF NORMAL
1909-1996(61)	124	100 %
1987-1996	172	139 %
1995(2)	336	272 %
1996(3)	323	262 %
1986(1)	363*	293 %
1977(61)	21**	17 %

*HIGHEST RECORDED **LOWEST RECORDED

Red River of the North at Grand Forks, ND

Figure 12



The Red River of the North formed at the confluence of the Bois de Sioux and Otter Tail Rivers in western Minnesota and ends at Lake Winnepeg in Canada. The Red River is situated in a glacial lake bed and has a relatively young channel.

In the last ten years, both extremes of flow conditions occurred on the Red. From 1987 to 1991, low flow conditions were generally the rule while higher flow conditions have existed since 1992. The mean annual discharge for 1993, 1995 and 1996 are the 10th, 4th and 2nd largest of the 92 years of continuos records.

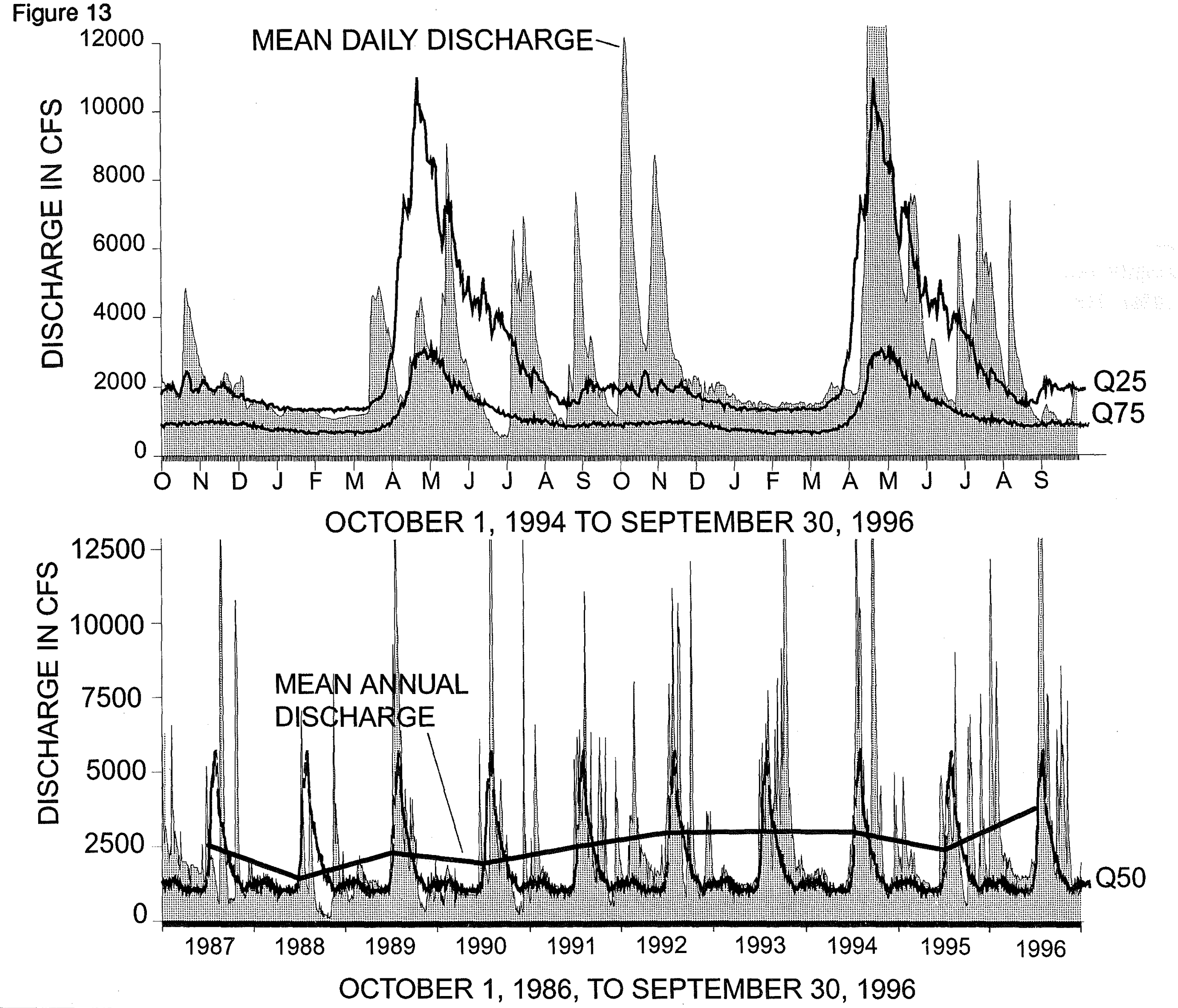
RED RIVER at GRAND FORKS, ND

YEAR(S) (RANK)	MEAN ANNUAL DISCHARGE(cfs)	% OF NORMAL
1905-1996(92)	2701	100 %
1987-1996	3429	127 %
1995(4)	6280	233 %
1996(2)	6839	253 %
1950(1)	7580*	281 %
1934(92)	244**	9 %

*HIGHEST RECORDED **LOWEST RECORDED

St. Louis River at Scanlon

Figure 13



The St. Louis River flows 160 miles from its source at Seven Beaver Lake to Lake Superior, and changes elevation by 1100 feet. The upper portion is wide and slow, dropping 600 feet over 150 miles. The lower 10 miles, where five hydroelectric plants are located, drops 500 feet in elevation.

Mean annual discharge in 1996 ranked 6th highest during the 88-year period of record. 1995 was 42nd with 101% of normal flow.

ST. LOUIS RIVER near SCANLON

YEAR(S) (RANK)	MEAN ANNUAL DISCHARGE(cfs)	% OF NORMAL
1909-1996(88)	2377	100 %
1987-1996	2591	109 %
1995(42)	2397	101 %
1996(5)	3795	160 %
1972(1)	4276*	180 %
1924(88)	945**	40 %

*HIGHEST RECORDED **LOWEST RECORDED

Lake Levels

Why Monitor Lake Levels?

Lake level data are important to water management programs in Minnesota. Lakeshore use and development are often directly controlled by fluctuations in water levels. Recording and understanding the history of water level fluctuations on lakes can help everyone cope with the water level changes.

All lakes experience water level changes throughout the course of time. Changes in surface water elevation are the results of many factors including precipitation, outlet changes, groundwater movement and watershed size. Consistent and long-term records of lake levels will capture this cause and effect relationship.

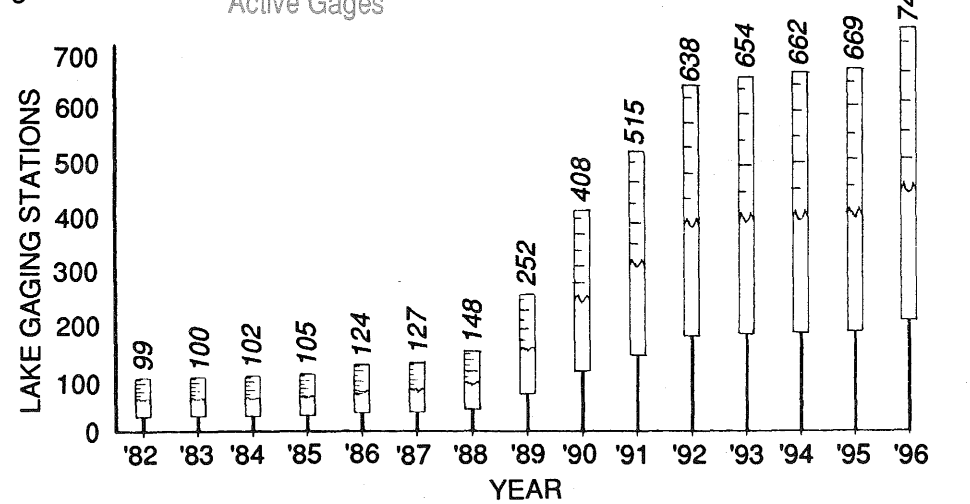
Historical water level data are helpful to calibrate computer models to simulate events that occurred, or are used to project water levels in hypothetical events. Computer models are used to estimate flood levels, which are used by local officials to set low floor elevations for new construction, locate building sites and sewage treatment sites. Historical water levels, when available, are also used as supporting evidence to establish ordinary high water level determinations for lakes.

Who Reads the Gages?

The number of lakes in the Lake Level Minnesota monitoring program is increasing as more individuals and groups become concerned about lake levels. In 1996, 744 sites were actively monitored, which is up 11% from 1995 (Figure 1). The sites are monitored by volunteers and organizations. All readings are sent to a DNR office and entered into an electronic data base.

Volunteer observers usually live on or near a lake, which makes it convenient for them to obtain weekly or more frequent readings. There is no cost to the volunteer to be in this program. The lake gages are provided by the Division of Waters and are

Figure 1 Active Gages



installed every spring near the volunteer's dock or at a public access to the lake. Each year the volunteer receives an updated water level graph and summary sheet with information they have provided.

In addition to individual volunteers, organizations are an important part of the overall success of this program. Organizations may identify lakes that need gages, find gage observers or read the lake gages themselves and report directly to the DNR. These organizations include:

Soil and Water Conservation District

Anoka County
Cass County
Douglas County
Nobles County
Polk County
Sherburne County
Washington County

Counties

Douglas
Jackson
Nobles
Ramsey
Swift

Watershed Districts

Carnelian Marine
Thirty Lakes
Valley Branch
Ramsey-Washington Metro

Other groups

DNR Cambridge Area Wildlife
City of Lakeville
City of Maple Grove
City of Waverly
City of Willmar
Freshwater Foundation
Minnesota Zoo

Lake Data Storage

Lake gage readings received from volunteers and organizations are entered in Lakes db©, a database program for easy management and access of recorded lake levels and other useful information. Lakes db software is installed on computers within the Division of Waters and also on those of many organizations. During the year, reporting organizations receive free Lakes db updates to insure their records are accurate.

Lake Level Trends

Lake levels are affected by many factors including the amount and distribution of precipitation, watershed size, outlet capacity (if any), and groundwater contribution. During 1995 and 1996, many lakes were at high levels, primarily due to several years of above-normal precipitation. 60% of all lakes checked in 1996 had higher water levels than in 1995. These higher water levels were most noticeable on landlocked lakes.

Landlocked lakes have no surface outlet channels, small watersheds and typically experience large, long-term water level fluctuations. The importance of groundwater contributions to landlocked lakes can make them a good indicator of local groundwater levels.

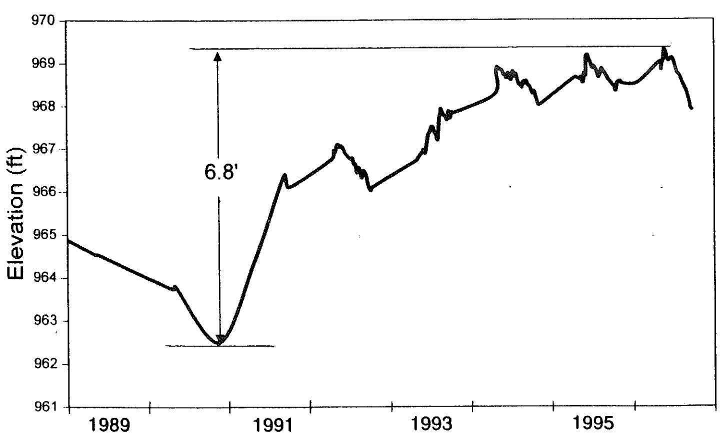
The graphs on pages 32 and 33 represent water levels for seven landlocked basins. Those in the northern part of the state generally saw a rise in water level from 1995 to 1996. In central and southern Minnesota, water levels continued high for the past two years with little change in elevation. The graphs also display, numerically, the difference (in feet) between the highest and lowest observed water levels for the period of record.

For many lakes that are presently monitored, good and reliable information has been collected for over ten years. A ten-year average is used as a reference when looking at individual water levels during that period. When using the ten-year average for a particular lake, a trend may be noticed. For the most part, all the graphs of lake levels shown on pages 34 and 35 are above the ten-year average, in recent years, which would generally correspond to above-normal precipitation in recent years.

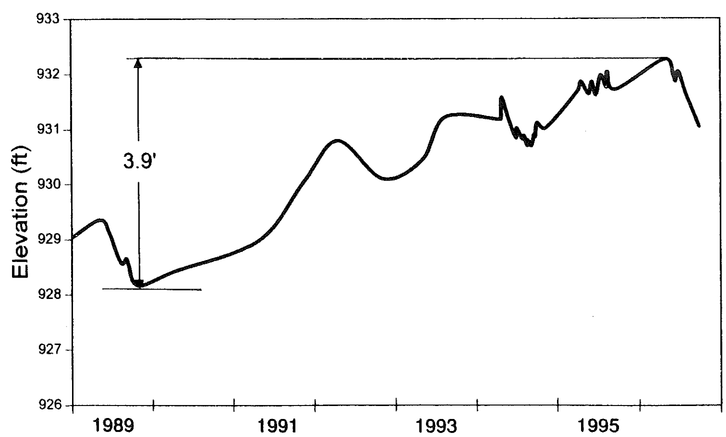
Annual Lake Level Fluctuation

Minnesota lakes typically fluctuate one to two vertical feet in a given year. Historical fluctuations have been recorded in excess of ten feet. Water Years 1993 and 1994 had an average fluctuation of 1.61 and 1.22 feet, respectively. Comparatively, Water Years 1995 and 1996 had average fluctuations of 1.03 and 1.24 feet. The table on pages 36 to 39 shows water level fluctuations for Water Years 1995 and 1996. Also dispalyed is a column of average fluctuations for the indicated periods of record. It is interesting to note how 1995 and 1996 Water Years compare to the historical fluctuations for each lake.

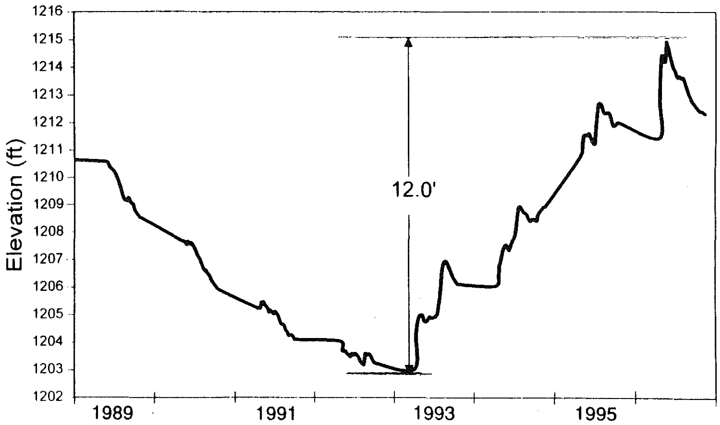
Beebe Lake (86-23) Wright County
Water Levels, 1989-1996



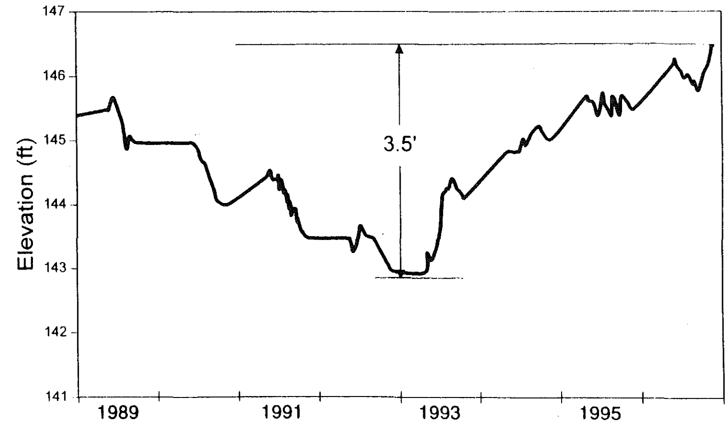
Oneka Lake (82-140) Washington County
Water Levels, 1989-1996

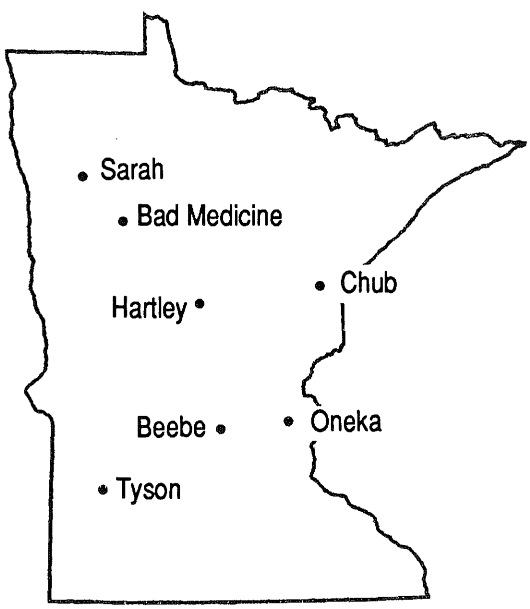


Sarah Lake (60-202) Polk County
Water Levels, 1989-1996

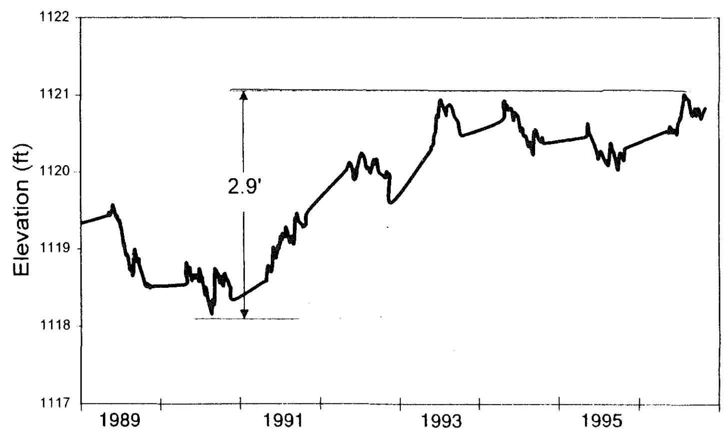


Bad Medicine Lake (3-85) Becker County
Water Levels, 1989-1996

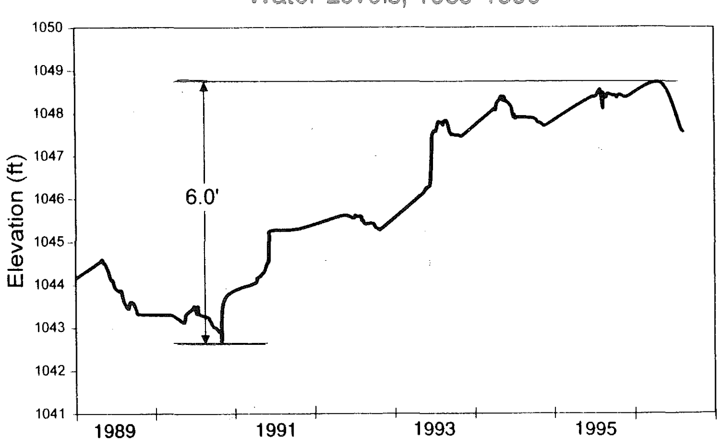




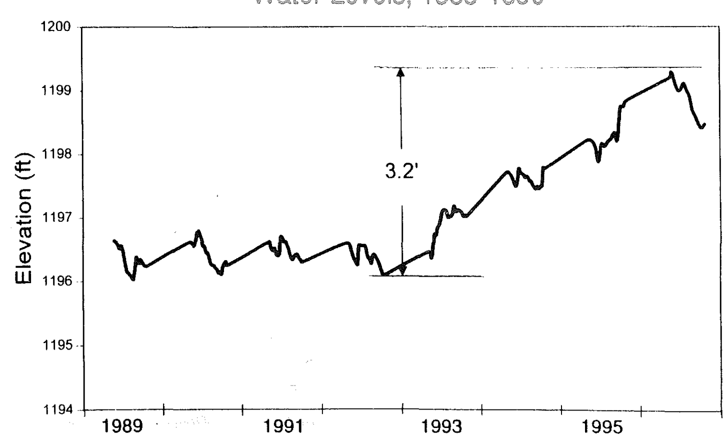
Chub Lake (9-8) Carlton County
Water Levels, 1989-1996



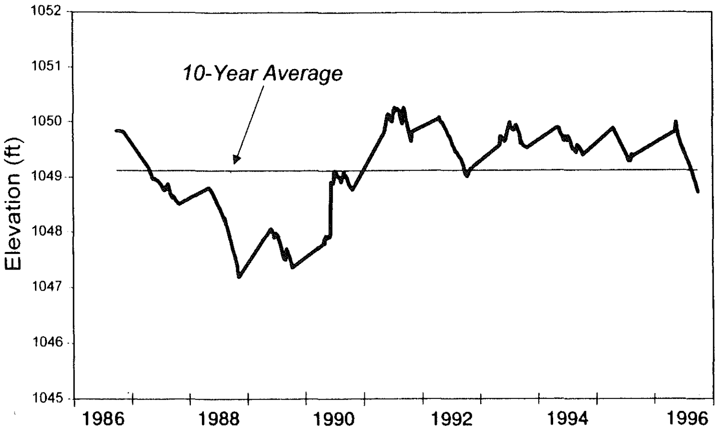
Tyson Lake (87-19) Yellow Medicine County
Water Levels, 1989-1996



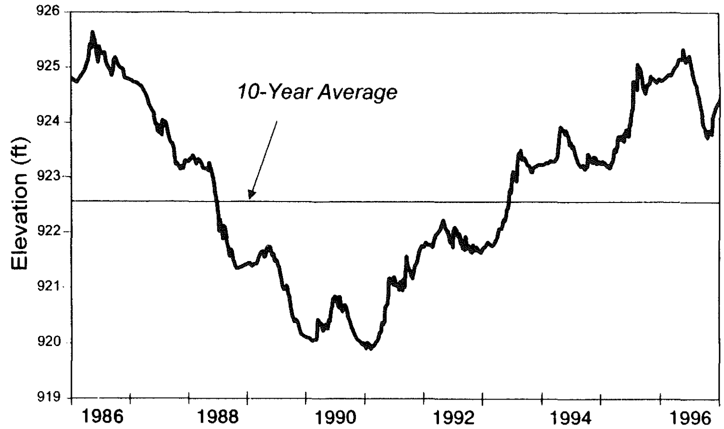
Hartley Lake (18-392) Crow Wing County
Water Levels, 1989-1996



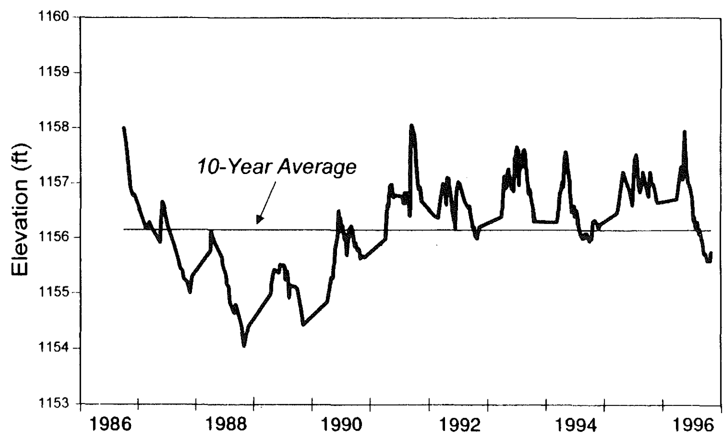
Sylvia Lake (86-289) Wright County
Water Levels, 1986-1996



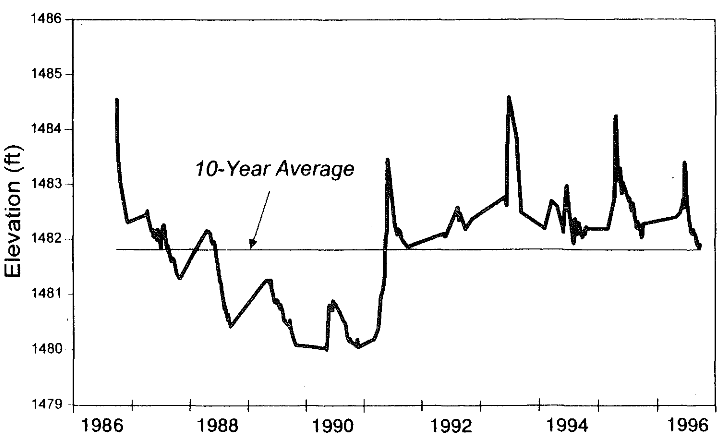
White Bear Lake (82-167) Washington County
Water Levels, 1986-1996



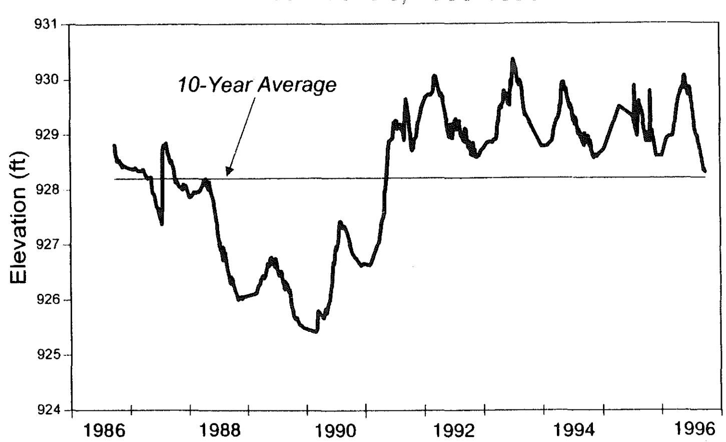
Green Lake (34-79) Kandiyohi County
Water Levels, 1986-1996



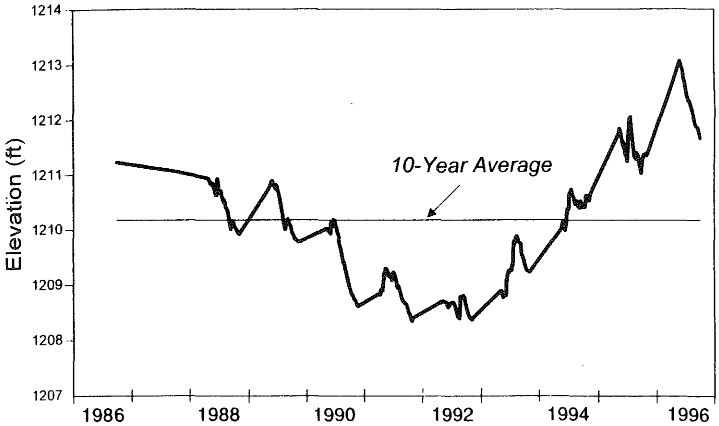
Lake Shetek (51-46) Murray County
Water Levels, 1986-1996



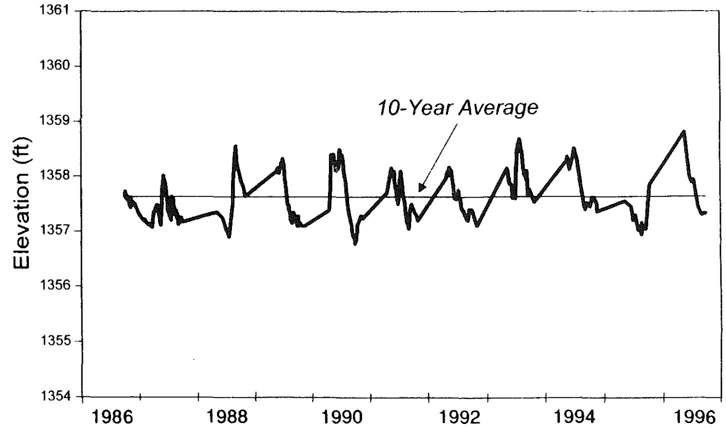
Lake Minnetonka (27-133) Hennepin County
Water Levels, 1986-1996

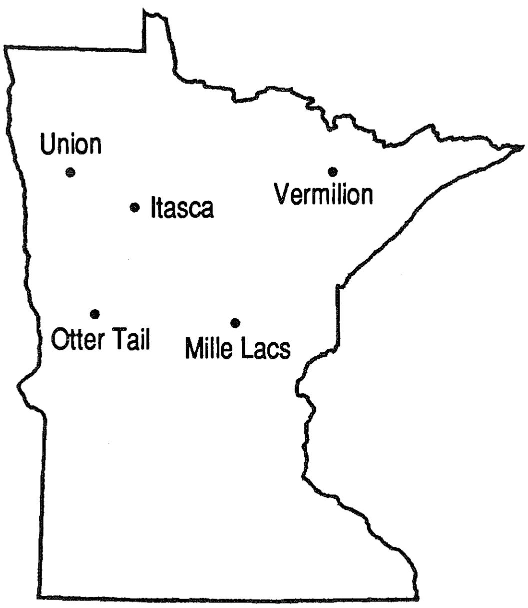


Union Lake (60-217) Polk County
Water Levels, 1986-1996

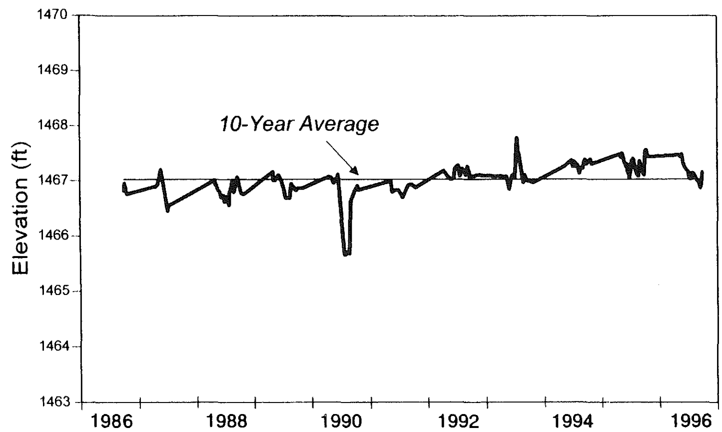


Lake Vermilion (69-378) St. Louis County
Water Levels, 1986-1996

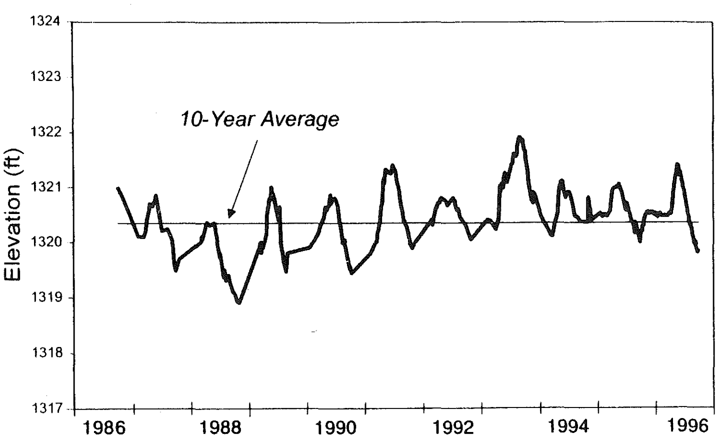




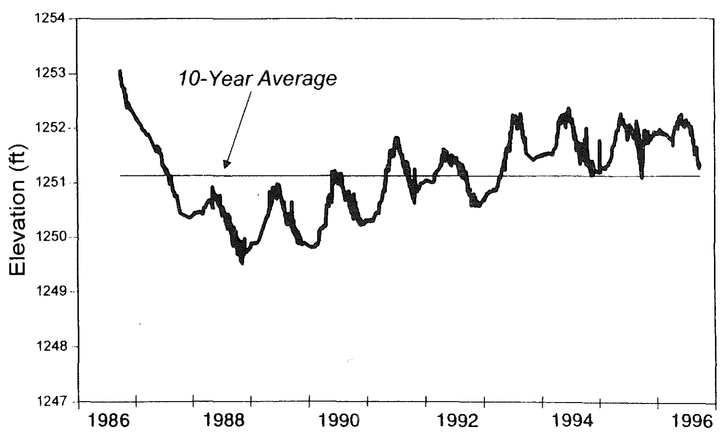
Lake Itasca (15-16) Clearwater County
Water Levels, 1986-1996



Otter Tail Lake (56-242) Otter Tail County
Water Levels, 1986-1996



Lake Mille Lacs (48-2) Mille Lacs County
Water Levels, 1986-1996



Annual Lake Level Fluctuation (feet)

Lake Name	WY95	WY96	WY Avg
AITKIN COUNTY			
Big Sandy (01-0062)	2.51	3.28	5.38 (97 yrs)
Cedar (01-0209)	1.50	1.23	1.66 (45 yrs)
Clear (01-0093)	0.46	0.74	0.87 (25 yrs)
Dam (01-0096)	0.91	0.77	1.29 (12 yrs)
Farm Island (01-0159)	1.01	0.98	0.97 (18 yrs)
Fleming (01-0105)	0.54	0.70	0.70 (6 yrs)
Hill (01-0142)	1.42	2.82	2.03 (14 yrs)
Little Pine (01-0176)	0.78	0.98	0.97 (27 yrs)
Minnewawa (01-0033)	0.80	0.76	0.80 (12 yrs)
Round (01-0204)	0.78	0.69	0.97 (6 yrs)
Spirit (01-0178)	0.60	0.63	0.54 (14 yrs)
Sugar (01-0087)	0.48	0.46	0.74 (26 yrs)
Waukenabo (01-0136)	2.04	1.48	1.44 (13 yrs)
ANOKA COUNTY			
Baldwin (02-0013)	2.40	2.82	3.46 (18 yrs)
Bunker (02-0090)	0.58	1.46	1.78 (7 yrs)
Coon (02-0042)	0.77	1.59	1.18 (21 yrs)
Crooked (02-0084)	0.43	1.18	1.02 (10 yrs)
Fawn (02-0035)	1.25	1.04	1.13 (8 yrs)
George (02-0091)	0.60	0.80	1.14 (12 yrs)
Golden (02-0045)	0.91	0.93	0.81 (8 yrs)
Ham (02-0053)	0.49	1.02	1.22 (10 yrs)
Howard (02-0016)	0.62	0.83	1.01 (7 yrs)
Itasca (02-0110)	0.84	1.20	1.28 (6 yrs)
Linwood (02-0026)	0.77	0.76	0.78 (18 yrs)
Martin (02-0034)	1.70	1.87	1.18 (17 yrs)
Moore (02-0075)	0.81	1.15	0.92 (8 yrs)
Netta (02-0052)	0.59	1.06	1.29 (9 yrs)
Otter (02-0003)	1.06	1.26	1.65 (74 yrs)
Reshanau (02-0009)	1.23	2.13	1.90 (7 yrs)
Rice (02-0008)	2.40	2.82	3.16 (7 yrs)
Rogers (02-0104)	1.39	1.56	1.34 (8 yrs)
Round (02-0089)	0.55	1.20	1.19 (9 yrs)
Sandy (02-0080)	1.90	0.97	1.46 (6 yrs)
Spring (02-0071)	0.93	1.53	1.62 (42 yrs)
BECKER COUNTY			
Bad Medicine (03-0085)	0.72	0.78	0.75 (11 yrs)
Big Cormorant (03-0576)	0.85	1.12	1.05 (29 yrs)
Buffalo (03-0350)	0.82	0.99	1.26 (14 yrs)
Cotton (03-0286)	0.90	0.71	1.03 (28 yrs)
Detroit (03-0381)	0.95	1.21	0.88 (15 yrs)
Eunice (03-0503)	0.40	0.42	0.58 (6 yrs)
Floyd (03-0387)	0.93	1.07	1.07 (6 yrs)
Height of Land (03-0195)	1.02	1.99	1.59 (36 yrs)
Ida (03-0582)	1.17	0.74	1.04 (9 yrs)
Little Floyd (03-0386)	1.27	0.99	1.09 (10 yrs)
Long (03-0383)	0.44	0.50	0.56 (10 yrs)
Melissa (03-0475)	0.64	1.26	1.10 (19 yrs)
Muskrat (03-0360)	0.82	0.95	0.87 (25 yrs)
Round (03-0155)	0.54	0.74	1.10 (14 yrs)
Sallie (03-0359)	1.09	1.83	1.22 (26 yrs)
Straight (03-0010)	0.35	0.48	0.51 (9 yrs)
Toad (03-0107)	1.00	1.44	1.39 (12 yrs)
Two Inlets (03-0017)	0.98	2.93	1.39 (13 yrs)
Upper Cormorant (03-0588)	0.84	1.04	0.98 (21 yrs)
White Earth (03-0328)	0.78	1.63	1.08 (12 yrs)
BELTRAMI COUNTY			
Bemidji (04-0130)	1.25	1.80	1.60 (12 yrs)
Gallagher (Rhoda) (04-0092)	0.60	1.00	0.77 (24 yrs)
Long (04-0076)	0.78	0.42	0.78 (8 yrs)
Movil (04-0152)	0.70	0.32	0.76 (13 yrs)
Stump (04-0130)	1.50	1.68	2.04 (12 yrs)
Turtle River (04-0111)	2.20	1.74	1.67 (23 yrs)
BIG STONE COUNTY			
Big Stone (06-0152)	1.90	1.50	2.41 (24 yrs)
BLUE EARTH COUNTY			
Crystal (07-0098)	0.20	0.80	0.89 (23 yrs)
Duck (07-0053)	0.92	1.38	0.96 (7 yrs)
Lily (07-0101)	1.19	2.80	1.93 (19 yrs)
Madison (07-0044)	0.84	1.18	1.77 (38 yrs)
BROWN COUNTY			
Hanska (08-0026)	1.26	0.50	1.95 (7 yrs)
Sleepy Eye (08-0045)	1.68	0.79	1.76 (8 yrs)
Somsen (08-0018)	1.81	1.35	3.09 (7 yrs)
CARLTON COUNTY			
Chub (09-0008)	0.60	0.86	0.85 (11 yrs)
Hanging Horn (09-0038)	2.70	2.06	2.13 (7 yrs)
Little Hanging Horn (09-0035)	2.70	2.06	2.13 (7 yrs)
Park (09-0029)	1.01	0.82	0.66 (6 yrs)
CARVER COUNTY			
Lotus (10-0006)	0.84	1.44	1.37 (26 yrs)
Riley (10-0002)	0.90	0.77	1.40 (25 yrs)
Waconia (10-0059)	0.13	1.38	1.22 (23 yrs)
Zumbra-Sunny (10-0041)	1.31	1.50	1.60 (13 yrs)
CASS COUNTY			
Ada (11-0250)	0.59	0.76	0.76 (8 yrs)
Agate (11-0216)	1.57	0.50	0.68 (6 yrs)
Birch (11-0412)	1.34	0.96	0.97 (6 yrs)
Child (11-0263)	0.80	0.80	0.84 (7 yrs)
Girl (11-0174)	0.91	0.62	0.87 (9 yrs)
Hand (11-0242)	0.75	0.54	0.87 (11 yrs)
Hay (11-0199)	0.86	0.69	0.97 (6 yrs)
Horseshoe (11-0358)	0.46	0.36	0.42 (6 yrs)
Inguadona (11-0120)	0.92	0.81	1.11 (6 yrs)
Long (11-0142)	0.74	1.02	1.01 (6 yrs)
Lower Trelipe (11-0129)	0.97	0.76	1.13 (15 yrs)
Portage (11-0476)	0.45	1.19	0.76 (6 yrs)
Ten Mile (11-0413)	0.32	0.69	0.83 (21 yrs)
Washburn (11-0059)	1.16	0.86	1.21 (16 yrs)
Woman (11-0201)	0.81	0.65	0.80 (7 yrs)
CHISAGO COUNTY			
Comfort (13-0053)	1.21	1.38	1.16 (21 yrs)
Goose (13-0083)	2.23	1.98	1.65 (8 yrs)
Green (13-0041)	0.51	1.10	1.18 (17 yrs)
North Center (13-0032)	2.52	1.90	1.67 (23 yrs)
North Lindstrom (13-0035)	2.62	1.86	1.83 (18 yrs)

Lake Name	WY95	WY96	WY Avg
CLEARWATER COUNTY			
Itasca (15-0016)	0.45	0.70	0.78 (24 yrs)
Long Lost (15-0068)	1.28	1.10	0.93 (6 yrs)
COOK COUNTY			
Flour (16-0147)	0.72	0.73	0.60 (7 yrs)
Hungry Jack (16-0227)	0.75	0.63	0.63 (6 yrs)
Poplar (16-0239)	1.11	1.64	1.01 (7 yrs)
Saganaga (16-0633)	1.32	3.07	1.87 (7 yrs)
Sea Gull (16-0629)	1.70	1.70	1.84 (6 yrs)
COTTONWOOD COUNTY			
Cottonwood (17-0022)	1.06	0.47	1.97 (9 yrs)
CROW WING COUNTY			
Bass (18-0256)	0.70	0.56	0.62 (8 yrs)
Bonnie (18-0259)	0.63	0.59	0.54 (7 yrs)
Clark (18-0374)	0.84	0.94	0.90 (8 yrs)
Crooked (18-0041)	0.80	0.80	0.78 (7 yrs)
East Fox (18-0298)	0.36	0.44	0.66 (15 yrs)
East Twin (18-0407)	0.84	0.50	0.61 (6 yrs)
Edward (18-0305)	1.07	0.74	0.88 (29 yrs)
Garden (18-0329)	0.40	0.50	0.40 (8 yrs)
Gilbert (18-0320)	0.71	1.64	0.93 (7 yrs)
Gladstone (18-0338)	0.47	0.65	0.63 (8 yrs)
Hartley (18-0392)	0.85	0.82	0.72 (8 yrs)
Horseshoe (18-0251)	0.76	0.65	0.59 (8 yrs)
Hubert (18-0375)	0.93	1.20	0.94 (15 yrs)
Little Hubert (18-0340)	0.54	0.98	0.89 (8 yrs)
Little Pelican (18-0351)	0.79	0.48	0.64 (8 yrs)
Lougee (18-0342)	0.78	0.72	0.61 (8 yrs)
Lower Cullen (18-0403)	0.41	0.26	0.36 (6 yrs)
Lower Mission (18-0243)	0.93	0.79	0.76 (16 yrs)
Middle Cullen (18-0377)	0.52	0.32	0.36 (6 yrs)
Mollie (18-0335)	0.72	0.74	0.67 (8 yrs)
North Long (18-0372)	0.62	0.73	0.98 (22 yrs)
Pelican (18-0308)	0.82	0.62	0.88 (39 yrs)
Perch (18-0304)	0.94	0.68	0.68 (8 yrs)
Portage (18-0050)	0.80	0.80	0.84 (6 yrs)
Rabbit (18-0093)	0.99	0.83	1.00 (39 yrs)
Ross (18-0165)	0.67	1.31	1.39 (13 yrs)
Ruth (18-0212)	0.56	0.99	0.90 (29 yrs)
Shaffer (18-0348)	0.64	0.84	0.60 (9 yrs)
Sorenson (18-0323)	1.01	1.51	0.87 (8 yrs)
South Long (18-0136)	1.20	1.60	1.12 (30 yrs)
Upper South Long (18-0096)	1.09	0.98	1.12 (26 yrs)
West Twin (18-0409)	0.63	0.52	0.51 (6 yrs)
Young (18-0252)	0.81	0.72	0.62 (8 yrs)
DAKOTA COUNTY			
Marion (19-0026)	0.74	1.00	2.10 (36 yrs)
Orchard (19-0031)	0.47	0.67	0.62 (6 yrs)
Sunfish (19-0050)	0.58	1.20	0.73 (6 yrs)
DOUGLAS COUNTY			
Carlos (21-0057)	0.34	1.10	1.04 (17 yrs)
Chippewa (21-0145)	1.79	1.18	1.18 (13 yrs)
Ida (21-0123)	0.93	1.04	1.32 (11 yrs)
Le Homme Dieu (21-0056)	1.14	1.06	0.91 (7 yrs)
Little Chippewa (21-0212)	1.00	1.25	1.23 (10 yrs)
Lobster (21-0144)	0.75	1.21	1.34 (17 yrs)
Louise (21-0094)	1.20	1.52	1.35 (10 yrs)

Lake Name	WY95	WY96	WY Avg
DOUGLAS COUNTY (Continued)			
Miltona (21-0083)	0.90	0.80	1.13 (19 yrs)
Moon (21-0226)	0.95	1.28	1.61 (8 yrs)
Red Rock (21-0291)	1.46	1.36	1.34 (6 yrs)
Smith (21-0016)	0.58	1.38	1.58 (8 yrs)
HENNEPIN COUNTY			
Calhoun (27-0031)	1.57	1.75	1.89 (65 yrs)
Cedar Island (27-0119)	1.02	1.28	1.23 (9 yrs)
Eagle/Pike (27-0111)	1.22	1.15	1.09 (10 yrs)
Edward (27-0121)	1.04	1.06	1.14 (9 yrs)
Fish (27-0118)	1.30	1.84	1.38 (9 yrs)
Harriet (27-0016)	0.98	1.21	1.25 (56 yrs)
Hiawatha (27-0018)	1.93	2.94	2.96 (23 yrs)
Independence (27-0176)	0.88	0.63	1.76 (14 yrs)
Long (27-0160)	0.80	1.65	1.40 (10 yrs)
Loring (27-0655)	1.11	0.98	0.94 (12 yrs)
Medicine (27-0104)	1.45	1.55	1.50 (18 yrs)
Minnetonka (27-0133)	1.04	1.76	1.38 (92 yrs)
Parkers (27-0107)	2.16	2.57	2.51 (7 yrs)
Rice (27-0116)	1.03	1.72	1.50 (10 yrs)
Weaver (27-0117)	0.77	0.95	1.06 (9 yrs)
Wirth (27-0037)	1.82	3.17	1.98 (27 yrs)
HUBBARD COUNTY			
Belle Taine (29-0146)	1.19	1.46	1.37 (41 yrs)
Big Sand (29-0185)	1.24	1.54	1.03 (6 yrs)
Eagle (29-0256)	1.04	1.66	1.41 (6 yrs)
Fish Hook (29-0242)	1.54	0.54	0.93 (6 yrs)
Island (29-0254)	1.50	2.28	2.11 (6 yrs)
Kabekona (29-0075)	1.56	0.61	1.11 (6 yrs)
Little Sand (29-0150)	0.16	0.36	0.76 (22 yrs)
Long (29-0161)	0.42	0.34	0.50 (10 yrs)
Palmer (29-0087)	0.78	0.90	0.73 (6 yrs)
Plantagenet (29-0156)	0.80	1.26	1.26 (15 yrs)
Potato (29-0243)	0.32	1.32	0.72 (6 yrs)
Spider (29-0117)	0.78	0.20	0.58 (6 yrs)
ISANTI COUNTY			
Skogman (30-0022)	0.96	2.11	1.24 (17 yrs)
Typo (30-0009)	2.66	2.60	1.66 (9 yrs)
ITASCA COUNTY			
Balsam (31-0259)	2.08	1.78	1.14 (13 yrs)
Bass (31-0576)	0.60	0.78	0.84 (16 yrs)
Beatrice (31-0058)	0.74	1.00	0.70 (6 yrs)
Bowstring (31-0813)	2.16	1.49	1.52 (11 yrs)
Buck (31-0069)	0.36	0.76	0.56 (8 yrs)
Burnt Shanty (31-0424)	0.34	0.55	0.59 (7 yrs)
Burrows (31-0413)	0.36	0.53	0.57 (8 yrs)
Caribou (31-0620)	0.58	0.42	0.65 (8 yrs)
Dora (31-0882)	2.22	2.00	1.86 (12 yrs)
Jessie (31-0786)	0.80	1.44	0.97 (7 yrs)
Johnson (31-0586)	0.66	0.68	0.84 (7 yrs)
Little Split Hand (31-0341)	1.12	3.24	1.74 (7 yrs)
Little Winnibigoshish (31-0850)	5.47	5.02	5.23 (9 yrs)
Long (31-0266)	0.74	0.84	0.79 (9 yrs)
Long (31-0570)	0.88	1.73	0.88 (32 yrs)
Loon (31-0571)	0.44	0.51	1.03 (33 yrs)
Lost Moose (31-0432)	0.53	0.59	0.53 (6 yrs)

Lake Name	WY95	WY96	WY Avg
ITASCA COUNTY (Continued)			
Natures (31-0877)	1.78	0.19	1.97 (6 yrs)
North Star (31-0653)	0.90	0.44	0.58 (8 yrs)
Owen (31-0292)	0.44	0.62	0.50 (6 yrs)
Pughole (31-0602)	0.67	0.89	0.89 (7 yrs)
Ruby (31-0422)	0.40	0.41	0.55 (6 yrs)
Sand (31-0826)	2.50	2.00	1.65 (10 yrs)
Siseebakwet (31-0554)	0.45	0.96	0.77 (46 yrs)
Smith (31-0650)	0.32	0.89	0.61 (7 yrs)
Spider (31-0538)	0.49	0.66	0.63 (8 yrs)
Trout (31-0216)	0.74	0.51	1.17 (33 yrs)
Turtle (31-0725)	0.47	1.54	0.52 (6 yrs)
White Swan (31-0260)	0.44	0.59	0.51 (7 yrs)
JACKSON COUNTY			
Clear (32-0022)	0.70	0.20	1.31 (7 yrs)
Fish (32-0018)	0.46	1.10	1.66 (7 yrs)
Heron (Duck) (32-0057)	1.22	0.25	1.99 (6 yrs)
Heron (North Marsh) (32-0057)	5.70	3.06	4.18 (21 yrs)
Heron (South Heron) (32-0057)	5.06	4.29	3.66 (26 yrs)
Loon (32-0020)	1.72	0.54	1.61 (12 yrs)
Pearl (32-0033)	2.10	0.49	2.02 (7 yrs)
Rush (32-0031)	1.48	0.53	1.91 (7 yrs)
KANDIYOHI COUNTY			
Andrew (34-0206)	1.08	0.88	1.61 (26 yrs)
Big Kandiyohi (34-0086)	0.51	1.20	1.32 (20 yrs)
Calhoun (34-0062)	1.23	1.14	1.45 (19 yrs)
Diamond (34-0044)	0.96	0.78	1.23 (9 yrs)
Eagle (34-0171)	0.66	0.98	1.13 (18 yrs)
Elizabeth (34-0022)	0.98	1.70	1.28 (10 yrs)
Elkhorn (34-0119)	0.37	0.40	0.96 (7 yrs)
Florida (34-0217)	0.76	0.40	1.68 (11 yrs)
Green (34-0079)	1.58	2.24	1.55 (37 yrs)
Long (34-0192)	0.86	1.00	1.50 (9 yrs)
Mud (34-0158)	0.79	0.58	1.33 (30 yrs)
Nest (34-0154)	0.46	1.30	1.07 (19 yrs)
Norway (34-0251)	0.91	1.12	1.23 (9 yrs)
Skataas (34-0196)	0.53	1.08	1.27 (8 yrs)
Swenson (34-0321)	1.03	0.99	1.10 (8 yrs)
LE SUEUR COUNTY			
Emily (40-0124)	0.78	1.10	1.58 (16 yrs)
Jefferson (40-0092)	0.44	0.94	1.29 (19 yrs)
Tetonka (40-0031)	0.95	1.34	1.88 (33 yrs)
Volney (40-0033)	0.70	1.10	1.21 (6 yrs)
Washington (40-0117)	0.80	1.07	1.55 (17 yrs)
West Jefferson (40-0092)	0.52	1.06	1.50 (19 yrs)
LINCOLN COUNTY			
Benton (41-0043)	1.92	1.24	1.47 (24 yrs)
MCLEOD COUNTY			
Winsted (43-0012)	1.82	1.78	1.44 (6 yrs)

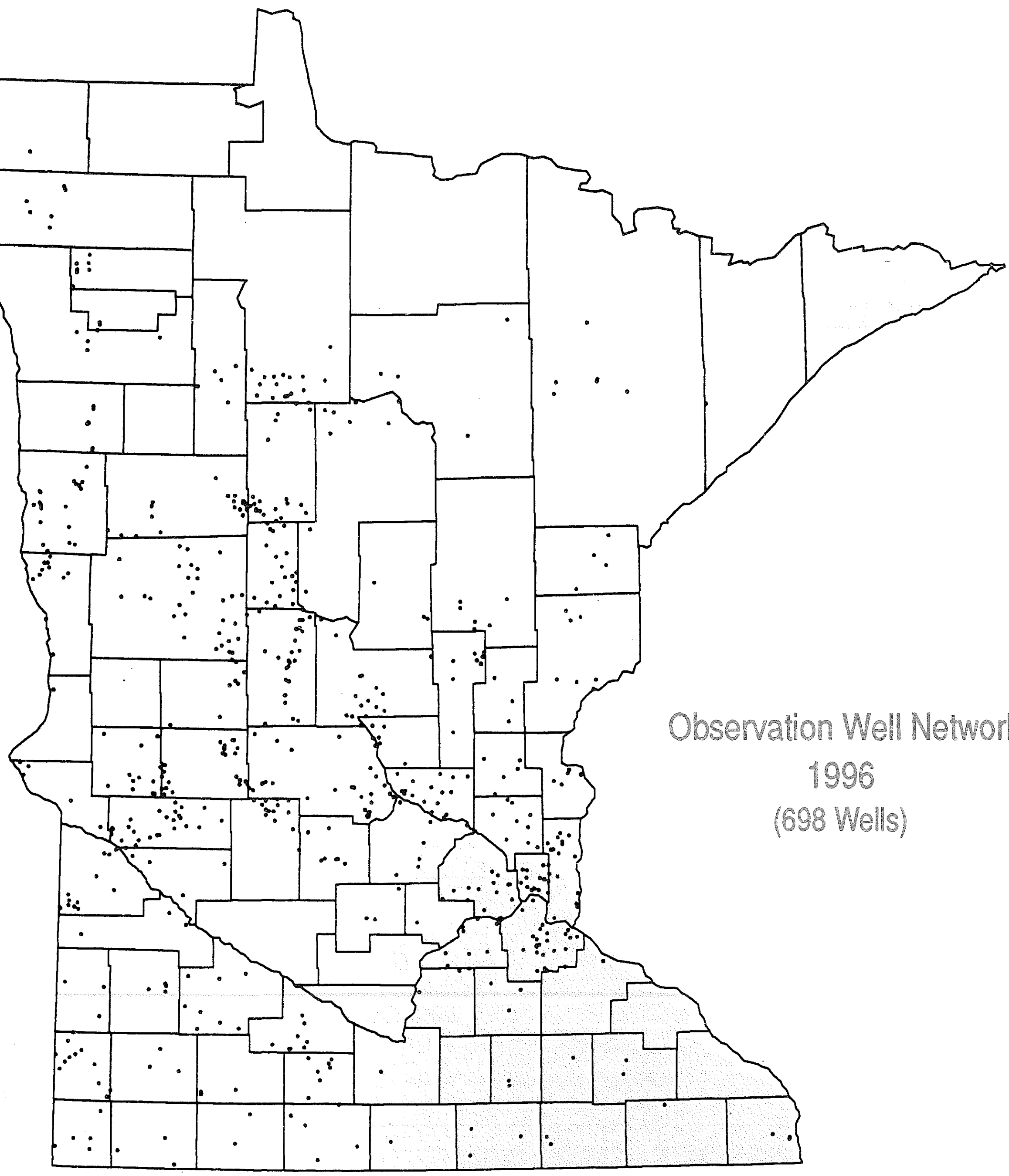
Lake Name	WY95	WY96	WY Avg
MEEKER COUNTY			
Arvilla (47-0023)	1.16	1.20	1.40 (6 yrs)
Clear (47-0095)	0.60	1.05	1.39 (7 yrs)
Francis (47-0002)	0.51	0.70	0.90 (12 yrs)
Minnie-Belle (47-0119)	0.82	1.34	1.22 (9 yrs)
Stella (47-0068)	0.74	1.12	0.78 (7 yrs)
Thompson (47-0159)	1.29	1.20	1.45 (7 yrs)
Washington (47-0046)	0.38	0.64	0.67 (8 yrs)
MILLE LACS COUNTY			
Mille Lacs (48-0002)	1.18	0.99	1.34 (66 yrs)
Onamia (48-0009)	0.66	1.22	1.63 (27 yrs)
Shakopee (48-0012)	1.63	1.84	1.34 (11 yrs)
MORRISON COUNTY			
Alexander (49-0079)	0.12	0.80	0.99 (16 yrs)
Fish Trap (49-0137)	0.25	1.05	1.09 (12 yrs)
Sullivan (49-0016)	1.08	1.02	1.33 (19 yrs)
MURRAY COUNTY			
Shetek (51-0046)	2.21	1.56	2.07 (44 yrs)
NOBLES COUNTY			
Bella (53-0045)	1.24	2.34	2.39 (7 yrs)
Indian (53-0007)	1.27	1.12	1.93 (9 yrs)
Ocheda (53-0024)	0.82	1.24	1.57 (22 yrs)
OTTER TAIL COUNTY			
Big Pine (56-0130)	0.37	1.70	1.68 (40 yrs)
East Battle (56-0138)	1.45	0.44	1.15 (13 yrs)
Little Pine (56-0142)	0.81	1.16	1.05 (30 yrs)
Lizzie (56-0760)	0.82	1.44	1.20 (44 yrs)
Long (56-0388)	1.13	0.41	0.77 (13 yrs)
Long (56-0784)	0.96	1.62	1.09 (6 yrs)
Otter Tail (56-0242)	1.07	1.60	1.46 (64 yrs)
Pelican (56-0786)	0.88	1.14	1.33 (18 yrs)
Prairie (56-0915)	0.31	0.48	0.89 (16 yrs)
Rush (56-0141)	1.02	1.55	1.59 (52 yrs)
Star (56-0385)	1.27	1.10	1.05 (19 yrs)
Ten Mile (56-0613)	1.46	1.56	1.31 (6 yrs)
West Battle (56-0239)	1.27	1.42	1.07 (25 yrs)
West Leaf (56-0114)	0.63	1.05	0.84 (14 yrs)
PINE COUNTY			
Grindstone (58-0123)	1.44	0.84	1.03 (20 yrs)
Pokegama (58-0142)	3.56	2.02	3.40 (18 yrs)
Sand (58-0081)	0.95	1.02	1.52 (19 yrs)
Sturgeon (58-0067)	0.53	0.72	0.92 (19 yrs)
POLK COUNTY			
Badger (60-0214)	1.20	1.82	1.31 (8 yrs)
Cross (60-0027)	0.83	1.78	1.58 (6 yrs)
Maple (60-0305)	0.68	1.94	1.17 (15 yrs)
Sand Hill (60-0069)	0.65	0.86	0.92 (10 yrs)
Sarah (60-0202)	4.26	3.51	2.70 (8 yrs)
Turtle (60-0032)	0.86	2.12	1.29 (8 yrs)
Union (60-0217)	1.65	1.83	1.22 (10 yrs)
POPE COUNTY			
Amelia (61-0064)	1.34	1.94	1.55 (9 yrs)
Emily (61-0180)	1.94	2.49	1.89 (17 yrs)
Gilchrist (61-0072)	2.28	1.98	1.97 (7 yrs)
Minnewaska (61-0130)	1.16	1.34	1.18 (50 yrs)

Lake Name	WY95	WY96	WY Avg
RAMSEY COUNTY			
Bald Eagle (62-0002)	0.88	1.05	1.27 (74 yrs)
Beaver (62-0016)	1.22	1.42	1.98 (42 yrs)
Bennett (62-0048)	1.92	3.41	2.87 (10 yrs)
Birch (62-0024)	1.19	1.49	1.33 (67 yrs)
Como (62-0055)	1.19	1.44	1.63 (19 yrs)
Gervais (62-0007)	1.73	1.49	2.18 (73 yrs)
Grass (62-0074)	3.21	4.50	3.69 (11 yrs)
Island (62-0075)	1.03	1.72	1.42 (51 yrs)
Johanna (62-0078)	1.10	1.32	2.03 (73 yrs)
Josephine (62-0057)	0.83	1.30	1.18 (73 yrs)
Long (62-0067)	2.02	1.78	1.71 (73 yrs)
McCarron (62-0054)	0.74	1.34	1.16 (73 yrs)
Owasso (62-0056)	1.07	1.39	1.15 (73 yrs)
Phalen (62-0013)	2.77	3.46	3.52 (73 yrs)
Pike (62-0069)	1.22	0.77	1.35 (28 yrs)
Round (62-0009)	1.08	1.26	1.91 (62 yrs)
Silver (East) (62-0001)	1.36	1.64	1.71 (72 yrs)
Silver (West) (62-0083)	1.24	1.23	1.74 (63 yrs)
Snail (62-0073)	1.59	1.41	1.61 (73 yrs)
Turtle (62-0061)	0.56	1.20	0.98 (74 yrs)
Valentine (62-0071)	1.67	1.15	1.81 (72 yrs)
Wabasso (62-0082)	1.31	1.73	1.41 (59 yrs)
Wakefield (62-0011)	1.28	1.32	2.34 (44 yrs)
Willow (62-0040)	1.31	0.95	1.02 (10 yrs)
RICE COUNTY			
Cedar (66-0052)	0.91	0.68	1.12 (10 yrs)
Circle (66-0027)	1.12	0.42	1.70 (13 yrs)
French (66-0038)	0.50	0.98	1.09 (6 yrs)
ST. LOUIS COUNTY			
Beaver (69-0501)	0.64	1.05	0.78 (9 yrs)
Big Rice (69-0669)	1.30	1.22	0.91 (8 yrs)
Birch (69-0003)	0.40	0.70	3.43 (15 yrs)
Ely (69-0660)	0.32	0.37	0.86 (41 yrs)
Embarrass (69-0496)	1.43	1.48	2.41 (35 yrs)
Esquagama (69-0565)	0.70	4.80	2.39 (19 yrs)
Jacobs (69-0231)	0.58	0.52	0.63 (6 yrs)
Leander (69-0796)	0.38	0.69	0.58 (7 yrs)
Long (69-0509)	0.90	1.27	0.96 (7 yrs)
Maple Leaf (69-0700)	0.52	1.20	0.85 (6 yrs)
Nichols (69-0627)	0.74	0.57	0.66 (8 yrs)
Pequaywan (69-0011)	0.54	0.64	0.78 (13 yrs)
Prairie (69-0848)	1.68	1.38	1.19 (14 yrs)
Sand (69-0736)	0.61	0.66	0.69 (7 yrs)
St. Mary's (69-0651)	1.24	1.30	1.24 (37 yrs)
Sturgeon (69-0939)	1.70	2.14	1.69 (9 yrs)
Vermilion (69-0378)	0.70	1.52	1.64 (46 yrs)
SCOTT COUNTY			
Spring (70-0054)	0.90	1.46	1.40 (6 yrs)
Upper Prior (70-0072)	0.99	1.94	2.28 (18 yrs)
SHERBURNE COUNTY			
Beaudry (71-0062)	0.04	0.59	1.23 (9 yrs)
Forest Pond (71-0369)	0.11	1.88	2.40 (10 yrs)
Mitchell (71-0081)	0.87	0.63	1.43 (12 yrs)
Rush (71-0147)	1.28	1.25	1.09 (8 yrs)
STEARNS COUNTY			
Big (73-0159)	0.76	0.75	1.48 (7 yrs)
Big Fish (73-0106)	0.90	1.02	0.91 (22 yrs)
Big Watab (73-0102)	0.50	1.25	0.75 (12 yrs)

Lake Name	WY95	WY96	WY Avg
STEARNS COUNTY (Continued)			
Grand (73-0055)	1.16	0.70	1.13 (17 yrs)
Horseshoe (73-0157)	1.12	2.50	1.92 (6 yrs)
Koronis (73-0200)	1.90	2.07	1.97 (16 yrs)
North Brown's (73-0147)	2.20	2.64	2.24 (6 yrs)
Pearl (73-0037)	0.58	0.16	0.68 (9 yrs)
Rice (73-0196)	3.00	3.33	3.01 (12 yrs)
Two Rivers (73-0138)	1.49	2.80	2.75 (13 yrs)
TODD COUNTY			
Big Birch (77-0084)	0.74	0.89	1.03 (17 yrs)
Fairy (77-0154)	1.28	1.68	1.22 (8 yrs)
Little Birch (77-0089)	0.48	1.20	1.16 (13 yrs)
Maple (77-0181)	1.15	1.34	1.41 (8 yrs)
Osakis (77-0215)	1.77	1.62	1.50 (28 yrs)
Sauk (77-0150)	1.70	1.89	1.60 (13 yrs)
WADENA COUNTY			
Vogels (Hazel) (80-0005)	0.33	0.80	0.91 (16 yrs)
WASECA COUNTY			
Elysian (81-0095)	0.03	0.31	1.49 (13 yrs)
WASHINGTON COUNTY			
Big Carnelian (82-0049)	1.18	0.94	1.45 (19 yrs)
Big Marine (82-0052)	0.62	0.94	1.05 (21 yrs)
Bone (82-0054)	1.48	1.51	1.22 (15 yrs)
Carver (82-0166)	0.88	0.60	1.49 (6 yrs)
Clear (82-0163)	0.96	1.23	1.25 (20 yrs)
Downs (82-0110)	2.61	2.35	2.90 (13 yrs)
Eagle Point (82-0109)	1.79	0.87	2.30 (21 yrs)
Elmo (82-0106)	0.86	2.01	1.32 (21 yrs)
Forest (82-0159)	0.59	0.78	0.77 (22 yrs)
Halfbreed (82-0080)	0.32	0.84	0.89 (7 yrs)
Horseshoe (82-0074)	3.24	0.70	1.88 (19 yrs)
Jane (82-0104)	0.58	0.72	1.72 (27 yrs)
Long (82-0118)	4.08	2.56	3.23 (21 yrs)
Oneka (82-0140)	1.02	1.22	1.10 (14 yrs)
Square (82-0046)	0.55	0.56	0.65 (18 yrs)
Sunfish (82-0107)	0.47	0.69	1.73 (22 yrs)
Tanners (82-0115)	0.62	0.58	1.23 (6 yrs)
White Bear (82-0167)	1.92	1.41	1.19 (73 yrs)
WATONWAN COUNTY			
Fedji (83-0021)	0.68	1.22	0.99 (6 yrs)
Long (83-0040)	0.52	0.60	1.18 (13 yrs)
St. James (83-0043)	0.80	1.52	1.74 (8 yrs)
WRIGHT COUNTY			
Buffalo (86-0090)	1.78	3.36	2.90 (10 yrs)
Charlotte (86-0011)	1.14	1.41	1.53 (12 yrs)
Deer (86-0107)	1.94	2.70	3.00 (16 yrs)
Indian (86-0223)	1.06	1.26	1.58 (12 yrs)
Maple (86-0134)	0.85	1.36	1.25 (11 yrs)
Pulaski (86-0053)	1.45	1.28	1.54 (18 yrs)
Sugar (86-0233)	0.67	0.50	0.85 (16 yrs)
Sylvia (86-0289)	0.60	1.28	0.96 (17 yrs)
YELLOW MEDICINE COUNTY			
Tyson (87-0019)	0.84	1.13	0.96 (8 yrs)

Chapter 3

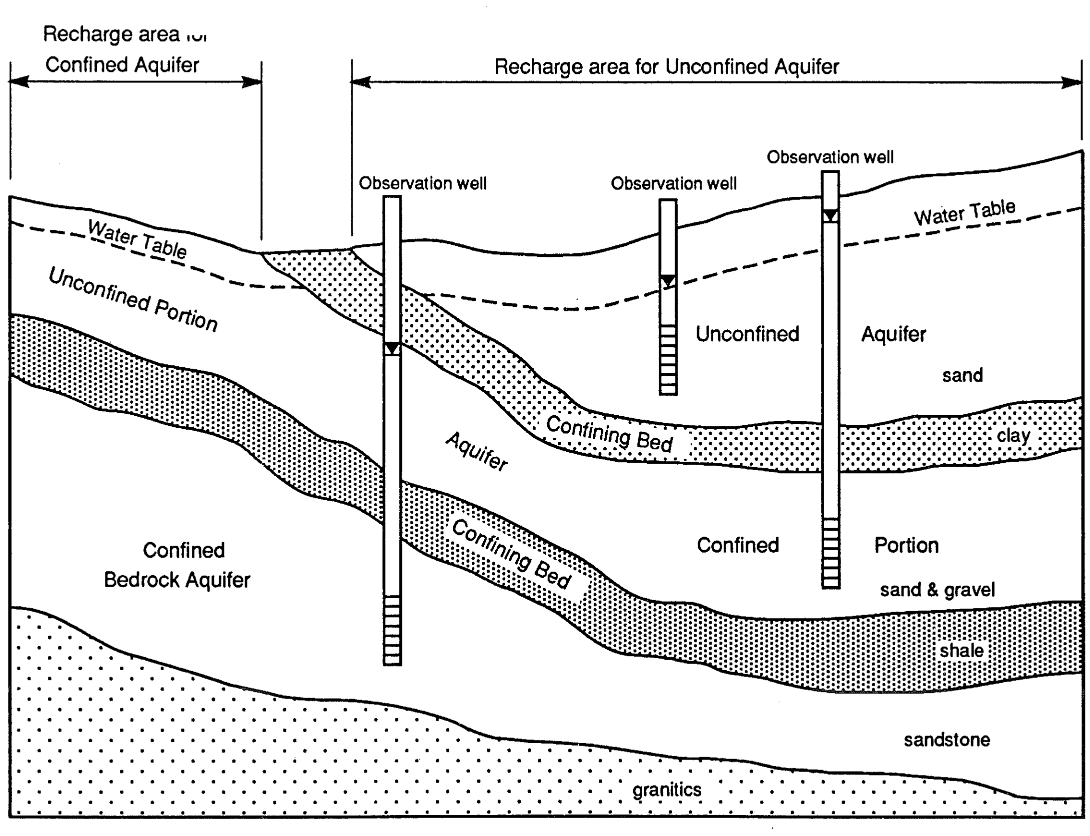
GROUND WATER



Introduction

Monitoring of ground water levels in Minnesota began in 1942 and, starting in 1947, was expanded by a cooperative program between the DNR and the United States Geological Survey (USGS). By the end of Water Year 1996 approximately 698 water level observation wells (obwells) had been established statewide. Soil and Water Conservation Districts (SWCD) and the USGS monitor these wells for the DNR. The DNR obwell network was developed to record background water levels in areas of present or expected ground water use. The data are used to assess ground water resources, interpret impacts of pumping and climate, plan for water conservation, evaluate local water complaints and otherwise support resource management programs.

Figure 1 Hypothetical Unconfined and Confined Aquifer Systems



Aquifers

An aquifer is a water-saturated geologic formation which is sufficiently permeable to transmit economic quantities of water to wells and springs. Aquifers may exist under unconfined or confined conditions (Figure 1).

UNCONFINED AQUIFERS - In an unconfined aquifer, the ground water surface that separates the unsaturated and saturated zones is called the water table. The water table is exposed to the atmosphere through openings in the overlying unsaturated geologic materials. The water level inside the casing of a well placed in an unconfined aquifer will be at the same level as the water table. Unconfined aquifers may also be called water table or surficial aquifers.

For most of Minnesota, these aquifers are composed of glacial sand and gravel. Their areal extent is not always well defined nor is their hydraulic connection. They are often locally isolated pockets of glacial outwash deposited over an area of acres to square miles. Recharge to these units may be limited to rainfall over the area of the aquifer or augmented by ground water inflow. Consequently, care must be taken in extrapolating water table conditions based upon the measurements of a single water table well.

CONFINED AQUIFERS - When an aquifer is separated from the ground surface and atmosphere by a material of low permeability, the aquifer is confined. The water in a confined aquifer is under pressure, and therefore, when a well is installed in a confined aquifer, the water level in the well casing rises above the top of the aquifer. This aquifer type includes buried artesian aquifers and bedrock aquifers.

Buried artesian aquifers are composed of glacially deposited sands and gravels, over which a confining layer of clay or clay till was deposited. Their areal extent and hydraulic connections beneath the ground surface are often unknown; therefore, an obwell placed in one of these units may be representing an isolated system. Ground water investigations involving buried artesian aquifers require considerable effort to evaluate the local interconnection between these aquifer units.

Bedrock aquifers are, as the name implies, geologic bedrock units which have porosity and permeability such that they meet the definition of an aquifer. Water in these units is either located in the spaces between the rock grains (such as sand grains) or in fractures within the more solid rock. While these aquifers can be unconfined, the ones measured in the obwell network are generally bounded above and below by low-permeability confining units. Unlike buried artesian aquifers, bedrock aquifers are fairly well defined in terms of their areal extent and the units are considered to be connected hydrologically throughout their occurrence.

Seasonal climatic changes affect the water levels in aquifer systems. Recharge, which is characterized by rising water levels, results as snow melt and precipitation infiltrate the soil and percolate to the saturated zone. Drawdown, characterized by the lowering of water levels, results as plants transpire soil water, ground water discharges into lakes, springs and streams, and/or well pumping withdraws water from the aquifer. An unconfined aquifer generally responds more quickly to these changes than a confined aquifer since the water table is in more direct contact with the surface. However, the magnitude of change in water levels will usually be more pronounced in a confined aquifer.

Statewide Summary

The remainder of this chapter discusses the ground water levels in unconfined and confined aquifers during Water Years 1995 (WY95) and 1996 (WY96). This discussion focuses on a comparison of water levels in WY95 and WY96 at two times during the year - winter and late-summer. The water levels are presented in the context of their average as well as historical high and low values. To achieve meaningful comparisons, representative obwells were chosen from the network based on their length of record and their geographical location.

During WY96, the DNR monitored water levels in approximately 698 wells throughout the state. Figures 2, 3 and 4 show the locations of these wells, identifying those that were placed in unconfined aquifers, in buried artesian aquifers and in bedrock aquifers.

Figure 2 Water Table Observation Wells

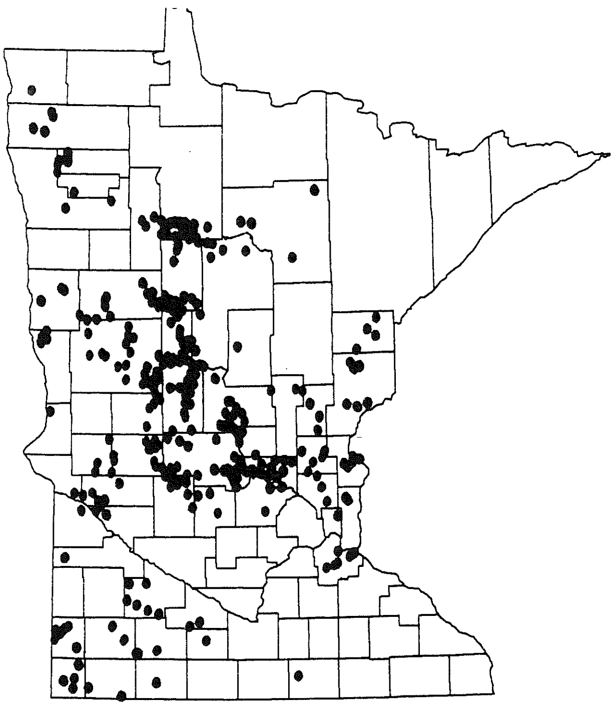


Figure 3 Buried Artesian Observation Wells

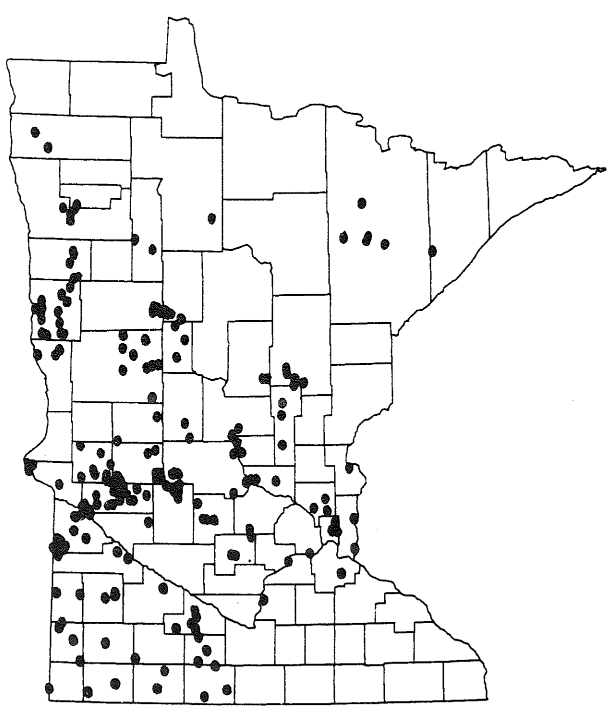
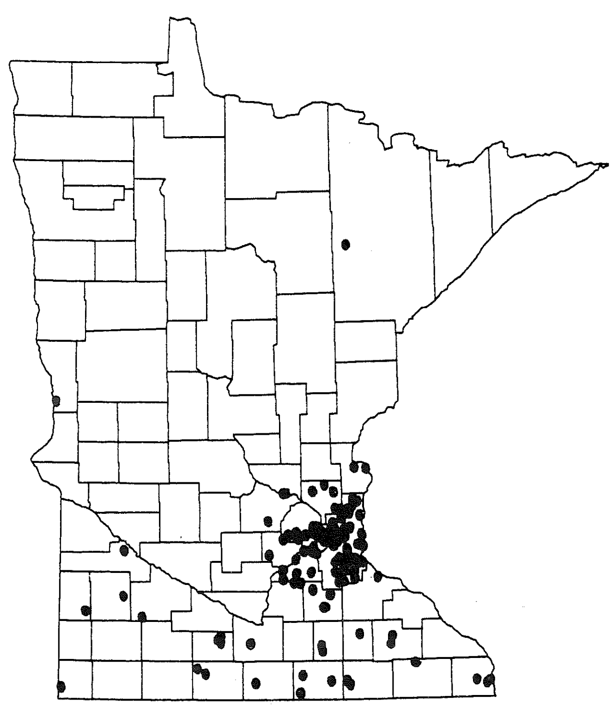


Figure 4 Bedrock Observation Wells



WY95 and WY96 Comparisons

For the selected representative obwells, water levels within each water year are compared. These levels are also compared to the historical average. Where data was available, water levels were analyzed twice per water year, usually in March and August. These months were chosen because they most likely show the aquifer's condition at the end of winter before snow melt and spring rains and again late in the summer season before the onset of fall rains. Where data was not available for one or both of these months, comparisons for other months were made. These exceptions are shown in the listing of actual measured water levels referenced later.

Historical averages used in these comparisons are computed for the appropriate month using data over the period of record for each well. Such periods are generally from 15 to 30 years, with the shortest being 11 years and a couple being more than 40 years.

The representative water table and buried artesian wells are identified with rough geographic areas representing western, southwest, central, north central or northeast, east central and Twin Cities metro regions of the state of Minnesota. These regional groupings are identified on the graphs.

One series of graphs labeled "Water Level Comparisons" (Figures 5, 9, 13, and 16) are intended to standardize all the data and present it relative to individual well averages. For each well, the average water level was computed for each of the two seasonal periods. The highest and lowest water levels during the period of record were also noted for each season. In the graphs, the highs and lows, as well as the measured WY95 and WY96 water levels, are presented as deviations from the computed average which is represented as the "0" baseline value on the Y-axis. In all cases, the record high water level is represented by the solid bar above the baseline, the record low water level is represented by the dashed bar below the baseline, and the WY95 and WY96 water levels are indicated by a triangle and diamond respectively.

Unconfined Aquifers

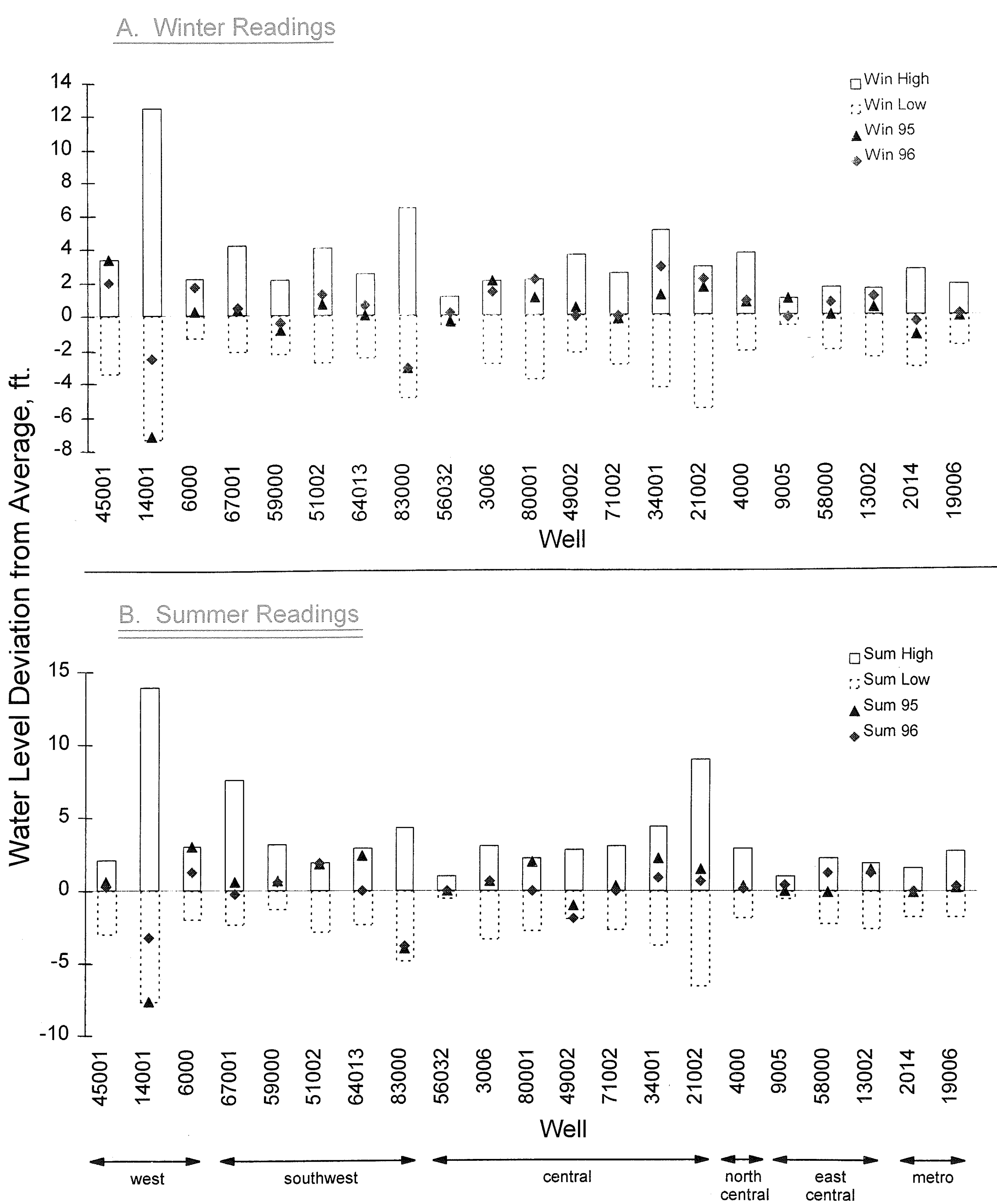
Figure 5a compares water levels during the winter months of WY95 and WY96 for selected water table wells throughout the state of Minnesota; Figure 5b does the same for the late-summer months.

Winter water table levels in both WY95 and WY96 tended generally to be higher than average (Figure 5a). There were, however, a few exceptions, but these were not associated with any particular geographic region. This variation most likely results from the individual characteristics of isolated unconfined aquifers. Comparing water years, winter water tables in WY96 tended to be higher than those in WY95, but again, there are a few instances where the opposite is true.

Summer water table levels in WY95 and WY96 (Figure 5b) generally were average or higher, and again, there were a few exceptions. Two of the exceptions, wells number 14001 and 83000, were also below average in winter readings, showing a wide range for readings as illustrated by the bars on the graphs. Both wells at one time in their history had quite high water tables and have also registered large deviations below the average. Current water levels are well below average. In fact, WY95 was either the lowest reading obtained or quite close to it for both of these wells. Since the other water table wells in the state are at or above average, something is occurring locally to cause a declining water level in these two wells.

In contrast to the winter readings, summer water levels in WY95 were, in general, higher than those in WY96 (Figure 5b). And again, there were exceptions.

Figure 5. Water Level Comparisons, Water Table Wells: A.Winter, B. Summer

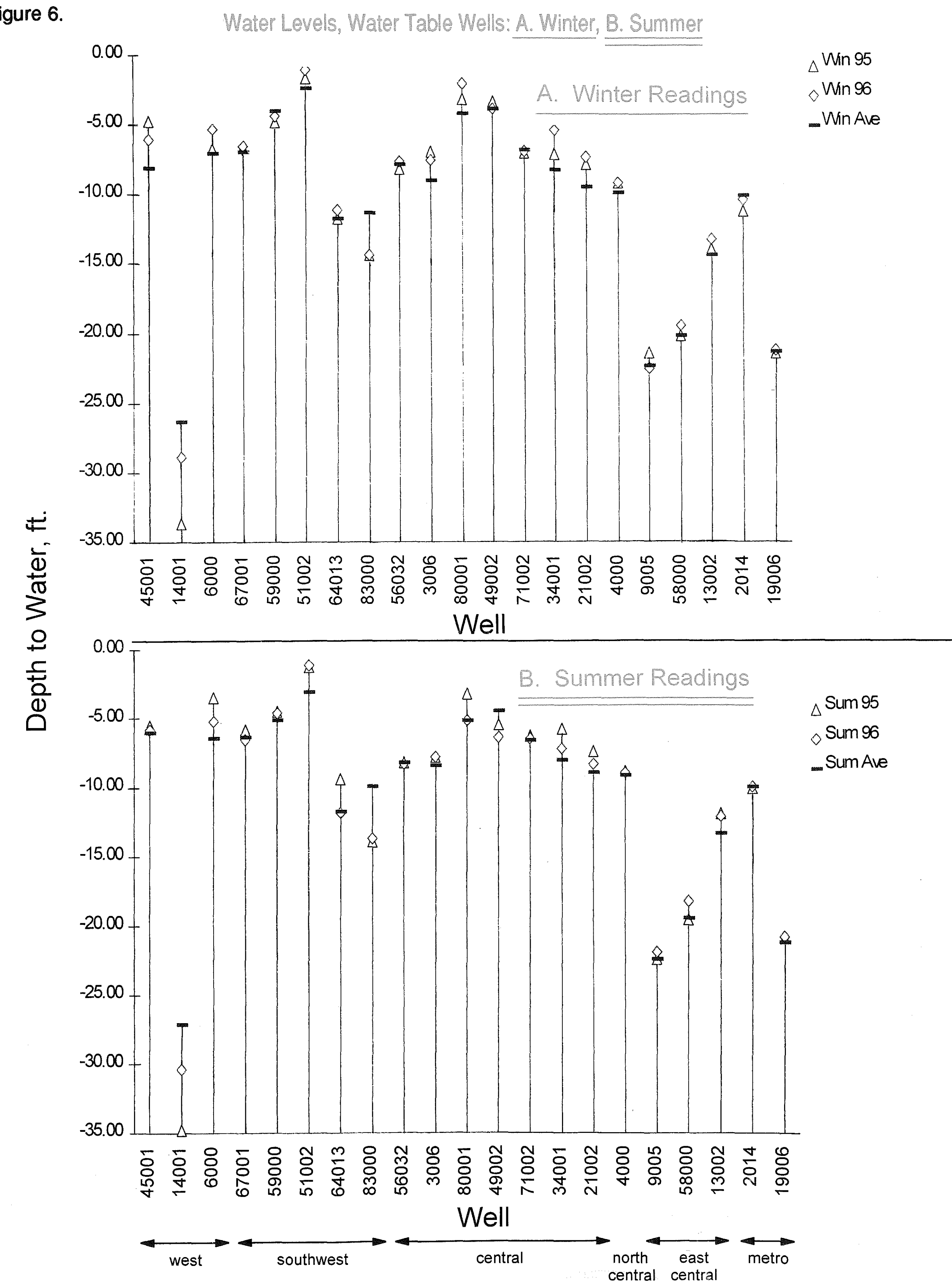


Figures 6a and 6b show the measured depth to water for the water table wells included here. While the water year relationships shown are the same as in Figures 5a and 5b, these graphs are provided for the benefit of those interested in the actual water table depths. Due to the individual characteristics of isolated unconfined aquifers, regional patterns are not evident. Measured depths included in this summary are presented in Table 1.

Table 1. Measured Depths to Water (ft) in Selected Water Table Observation Wells

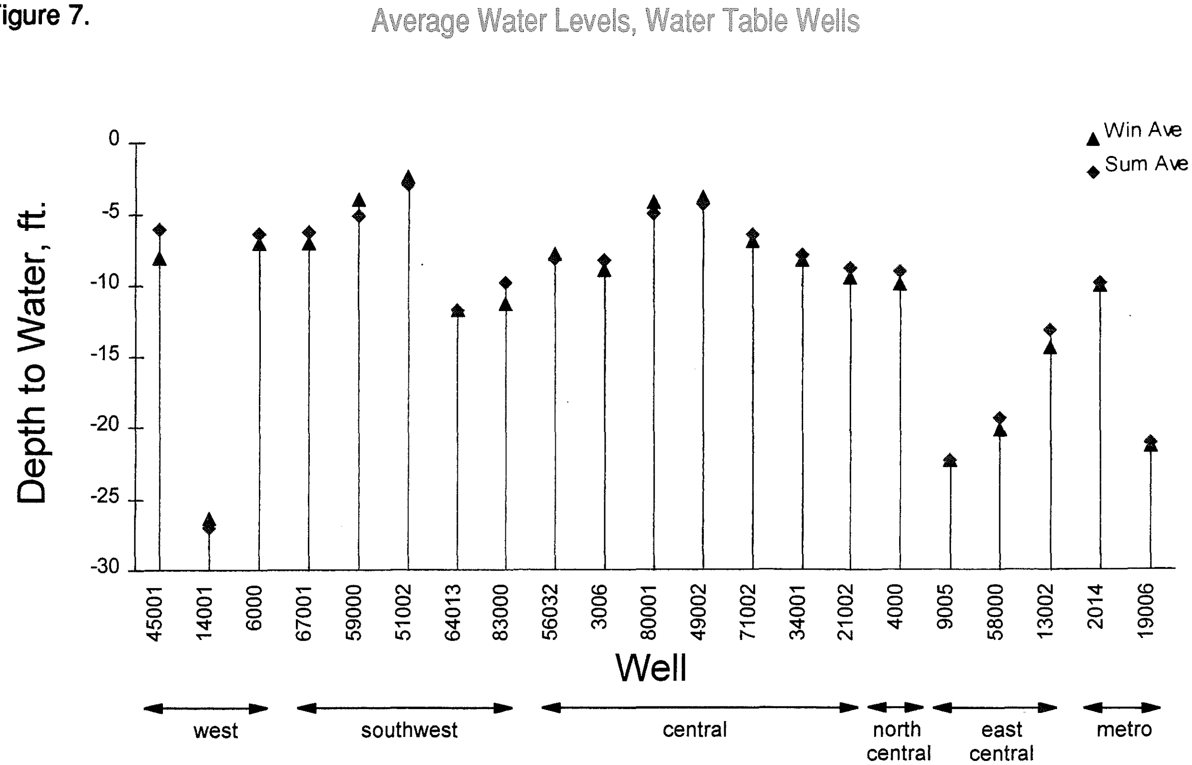
	WY95				WY96			
Well	Month	Depth	Month	Depth	Month	Depth	Month	Depth
2014	3	11.29	8	9.98	3	10.52	8	9.93
3006	3	7.00	8	7.71	3	7.65	8	7.72
4000	3	9.29	8	8.75	3	9.21	8	8.86
6000	3	6.85	8	3.44	3	5.41	8	5.18
9005	3	21.45	8	22.35	3	22.54	8	21.87
13002	3	13.99	8	11.81	3	13.36	8	12.09
14001	4	33.63	8	34.79	3	28.91	8	30.37
19006	4	21.45	8	20.82	3	21.28	8	20.76
21002	3	7.96	8	7.35	3	7.42	8	8.23
34001	3	7.20	8	5.70	3	5.50	8	7.10
45001	3	4.75	8	5.47	3	6.13	8	5.82
49002	3	3.47	8	5.44	3	3.99	8	6.30
51002	3	1.73	8	1.19	3	1.15	8	1.15
56032	3	8.24	8	8.20	3	7.76	8	8.22
58000	3	20.28	8	19.49	3	19.52	8	18.12
59000	3	4.90	8	4.50	3	4.50	8	4.60
64013	3	11.80	8	9.38	3	11.16	8	11.80
67001	3	6.72	8	5.78	3	6.61	8	6.56
71002	3	7.17	8	6.19	3	6.97	8	6.46
80001	4	3.29	10	3.14	4	2.13	10	5.11
83000	3	14.46	9	13.88	3	14.45	8	13.69

Figure 6.


Water Levels, Water Table Wells: A. Winter, B. Summer
A. Winter Readings
B. Summer Readings
Depth to Water, ft.
0.00
-5.00
-10.00
-15.00
-20.00
-25.00
-30.00
-35.00
Win 95
Win 96
Win Ave
Sum 95
Sum 96
Sum Ave
45001
14001
6000
67001
59000
51002
64013
83000
56032
3006
80001
49002
71002
34001
21002
4000
9005
58000
13002
2014
19006
Well
west
southwest
central
north central
east central
metro

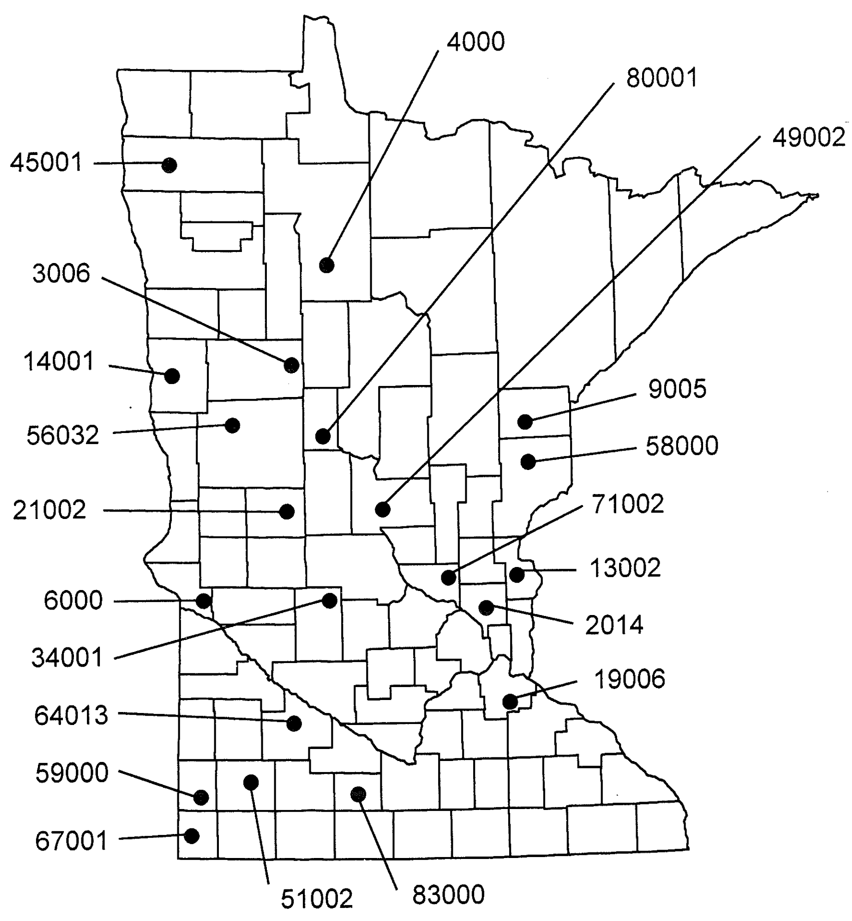
In general, winter precipitation is stored as snowpack and frozen soil prevents or slows the infiltration and percolation of spring snow melt. By the end of winter, water table levels would be expected to be at a low point. As the soil thaws and spring rains occur, the aquifers are recharged resulting in the higher water levels. A comparison of March and August average water levels (Figure 7) tends to corroborate this theory. Fifteen of the twenty-one representative water table wells have higher average water levels in summer than in the winter.

Figure 7.



The approximate location of the water table wells used in this report are shown in Figure 8.

Figure 8. Location of Selected Water Table Wells

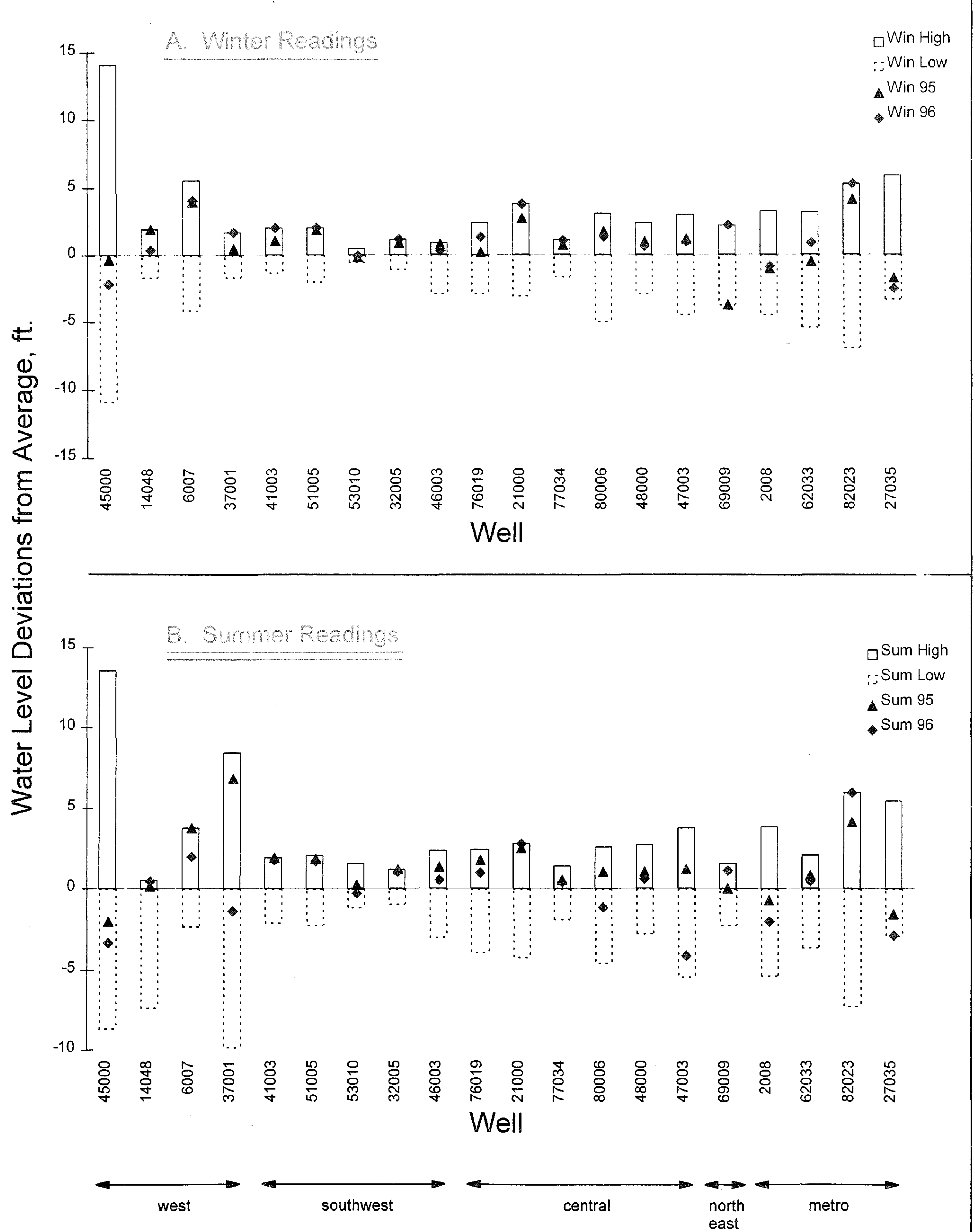


Confined Aquifers - Buried Artesian

Seasonal water levels in buried artesian aquifers are compared to historical averages in Figures 9a and 9b. With a few exceptions, winter and summer water levels tended to be higher than average during both WY95 and WY96. Among these exceptions were wells broadly classed as Twin Cities metropolitan area. Two of the four metro wells were below average in winter and summer during both water years, with WY96 being the lowest. Another of the metro wells was below average in winter of WY95. The large amount of water use in the metro area, generally from bedrock aquifers, may be impacting these buried artesian wells.

Winter water levels were generally higher in WY 96 than WY95 (Figure 9a). However, the opposite is true for summer water levels where WY95 tended to be the higher of the two years (Figure 9b). The exceptions in both seasons appeared random and showed no association with a particular geographic region.

Figure 9. Water Level Comparisons, Buried Artesian Wells: A. Winter, B. Summer



As with the water table wells, the actual measured depths to water are shown in Figures 10a and 10b. Table 2 lists the measured depths included in this summary.

Table 2. Measured Depths to Water (ft) in Selected Buried Artesian Observation Wells

	WY95				WY96			
Well	Month	Depth	Month	Depth	Month	Depth	Month	Depth
2008	3	12.73	8	14.37	3	12.58	8	15.67
6007	3	4.17	8	4.39	3	4.11	8	6.15
14048	3	31.40	8	33.30	3	33.00	8	33.00
21000	3	76.72	8	76.11	3	75.70	8	75.79
27035	3	71.65	8	72.16	3	72.44	8	73.54
32005	3	85.72	8	85.59	3	85.43	8	85.76
37001	3	21.11	8	25.62	3	19.85	8	33.80
41003	3	104.50	8	103.80	3	103.50	8	103.90
45000	3	20.45	8	22.22	3	22.23	8	23.56
46003	4	23.40	8	23.88	3	23.98	8	24.66
47003	4	25.03	10	25.12	4	25.17	10	30.45
48000	3	38.86	8	38.88	3	39.23	8	39.29
51005	3	77.95	8	78.67	3	77.77	8	78.82
53010	3	26.47	8	25.77	3	26.43	8	26.30
62033	3	23.11	8	23.13	3	21.74	8	23.51
69009	3	18.51	8	13.15	4	11.41	8	12.03
76019	3	9.58	8	7.29	3	8.47	8	8.10
77034	3	20.01	8	19.55	3	19.70	8	19.75
80006	4	1.79	10	2.51	4	2.22	10	4.71
82023	3	125.84	7	125.28	3	124.73	8	123.45

Figure 10. Water Levels, Buried Artesian Wells: A. Winter, B. Summer

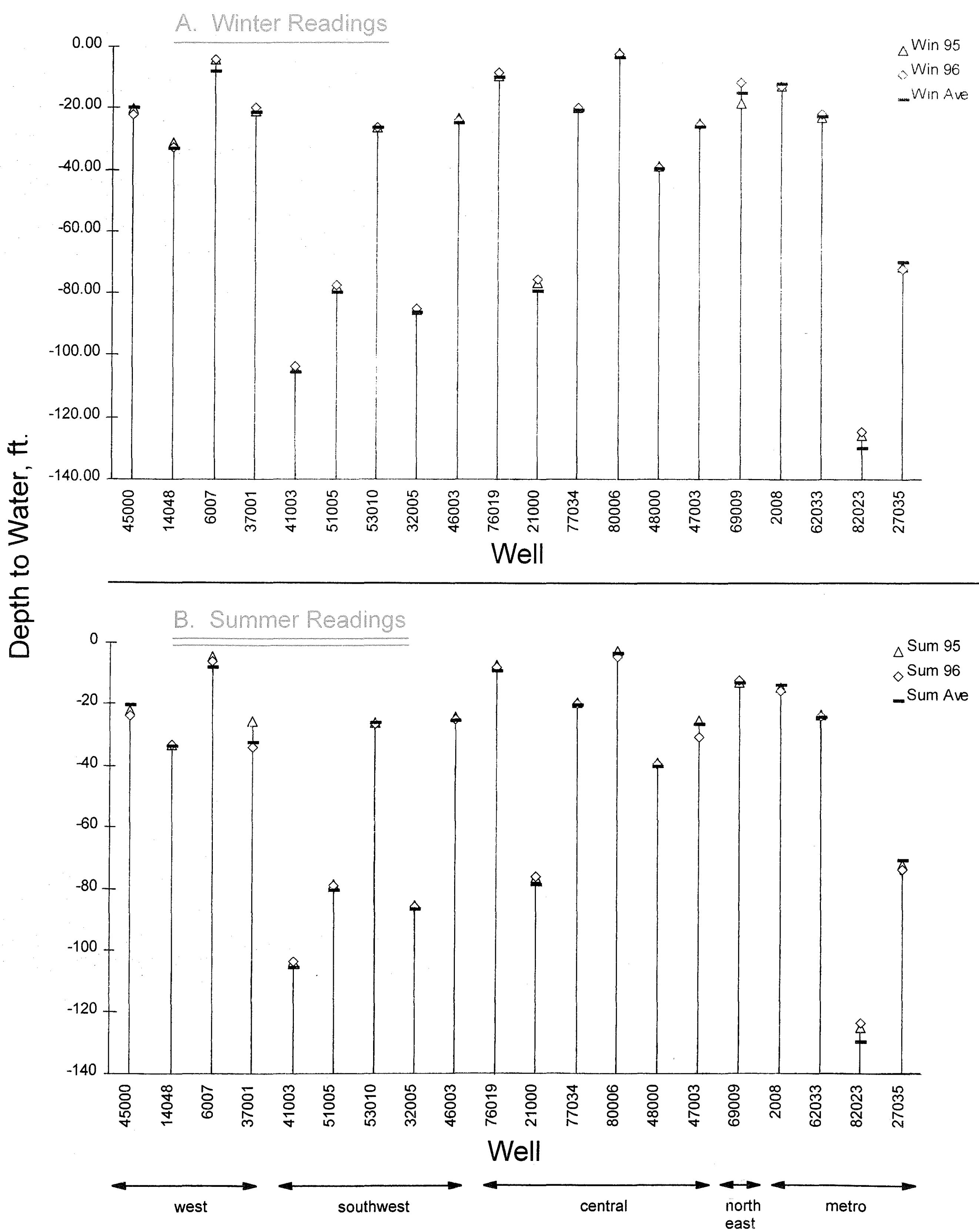
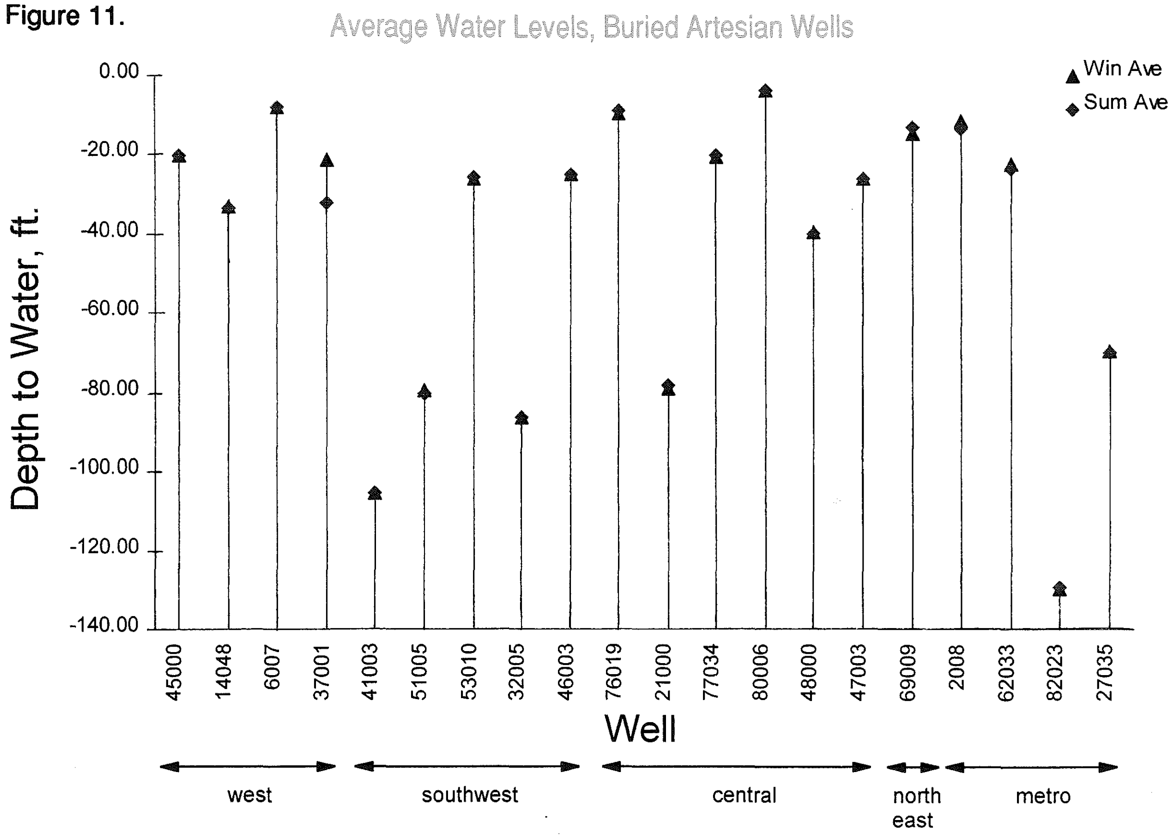


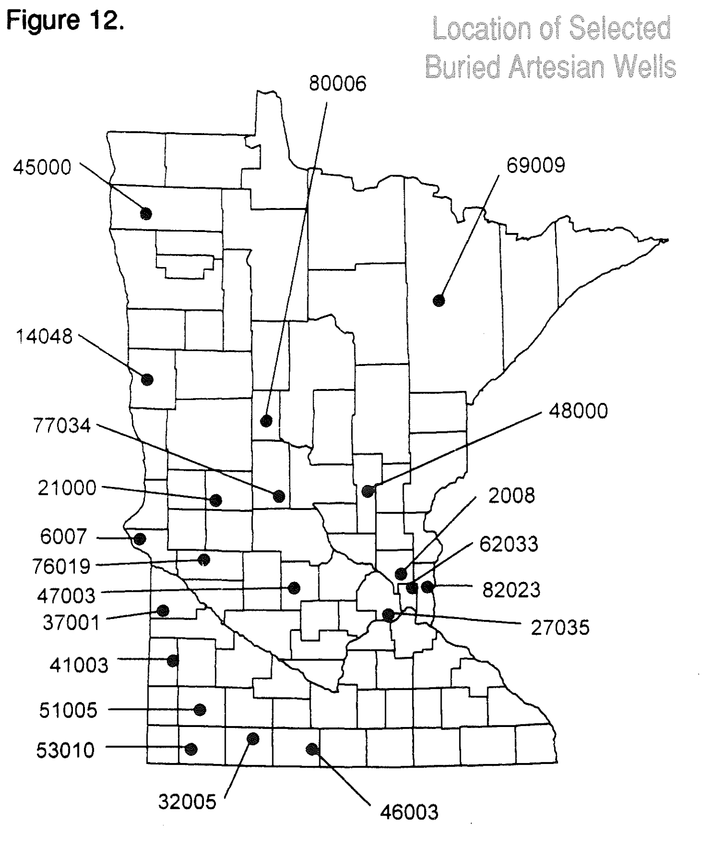
Figure 11.



A comparison of historical winter and summer average water levels for buried artesian wells is presented in Figure 11. The small scale of the Y-axis may tend to mask some differences, but generally the two seasonal averages are similar. Under confined conditions, these aquifers generally respond more slowly to seasonal inputs from snow melt and precipitation than water table aquifers. However, buried artesian aquifers are often near the surface with their extent poorly defined and they may be connected with adjacent unconfined aquifers. As a result, individual responses of buried artesian aquifers to recharge are difficult to predict.

The approximate location of the buried artesian wells used in this summary are shown in Figure 12.

Figure 12.

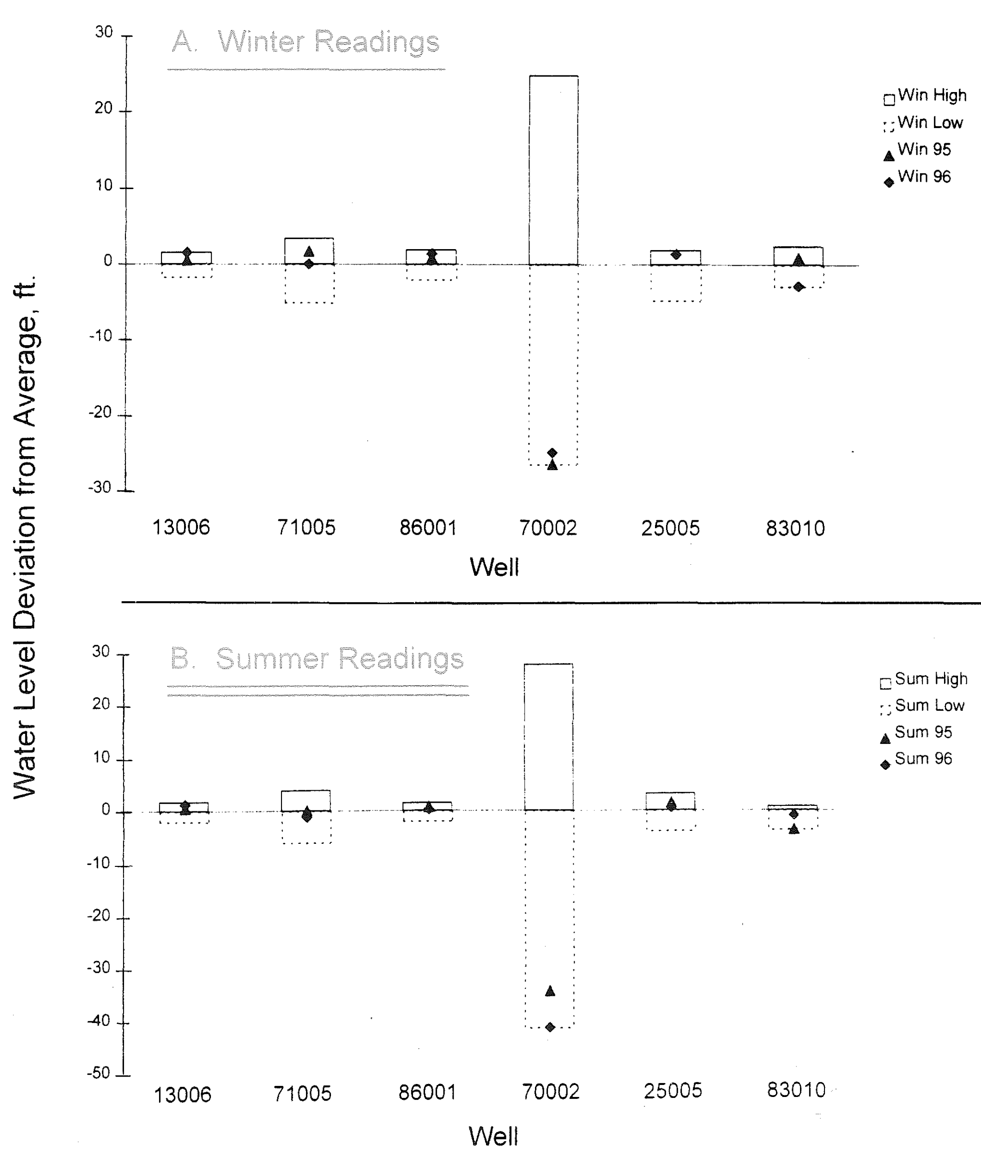


Confined Bedrock - Mt. Simon Aquifer

Figures 13a and 13b present a comparison of winter and summer water levels with seasonal averages for the Mt. Simon aquifer wells in this report. Water levels were, for the most part, above average in these wells, however, two exceptions are worth noting. Well 83010, used for irrigation in Watonwan County, showed lower than average summer water levels during both water years, indicating heavy irrigation use. Well 70002, located near Savage, MN, has been experiencing a decline in water levels since 1980. Evidence of this is shown in the range between the historical high and low levels indicated by the bars on the graph. Also, the fact that readings for WY95 and WY96 established new record low levels support the interpretation of declining levels.

Differences between water years for either season were not evident. In winter, water levels in two of five wells were higher in WY95 while three of the five had higher levels in WY96 (Figure 13a). A similar situation occurred in the summer season where three of six wells were higher in WY95, two of six were higher in WY96 and one was about the same in both years (Figure 13b).

Figure 13. Water Level Comparisons, Mt. Simon Aquifer: A. Winter, B. Summer



Seasonal average water levels (Figure 14a) would indicate that water levels in the Mt. Simon aquifer tend to be slightly lower in winter. This was not the case, however, in WY95 or WY96 where summer water levels were lower (Figure 14b). Water levels measured during the WY95 - WY96 period for these Mt. Simon wells is presented in Table 3.

Locations of the Mt. Simon wells used for this summary are shown in Figure 15.

Figure 14.

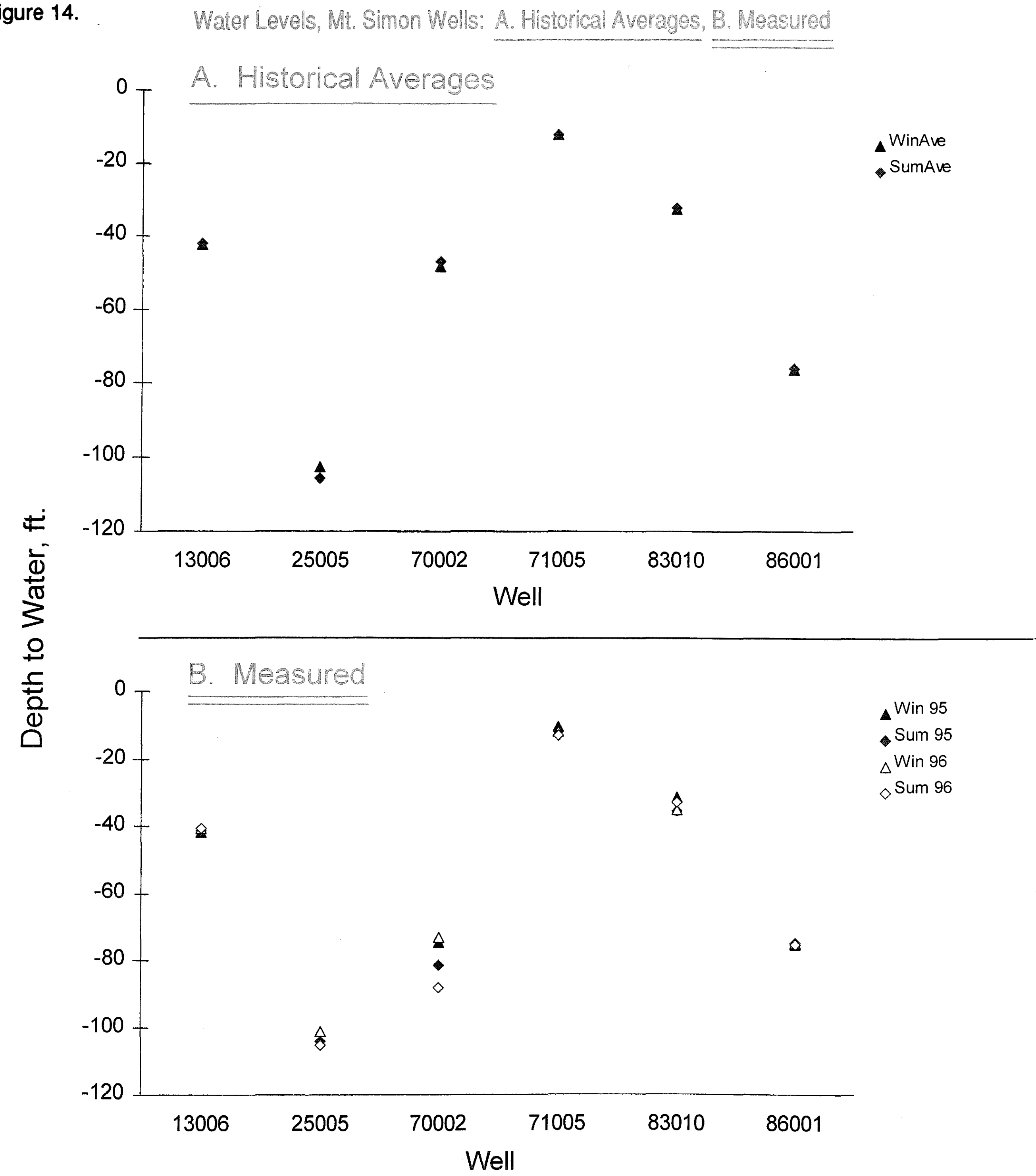
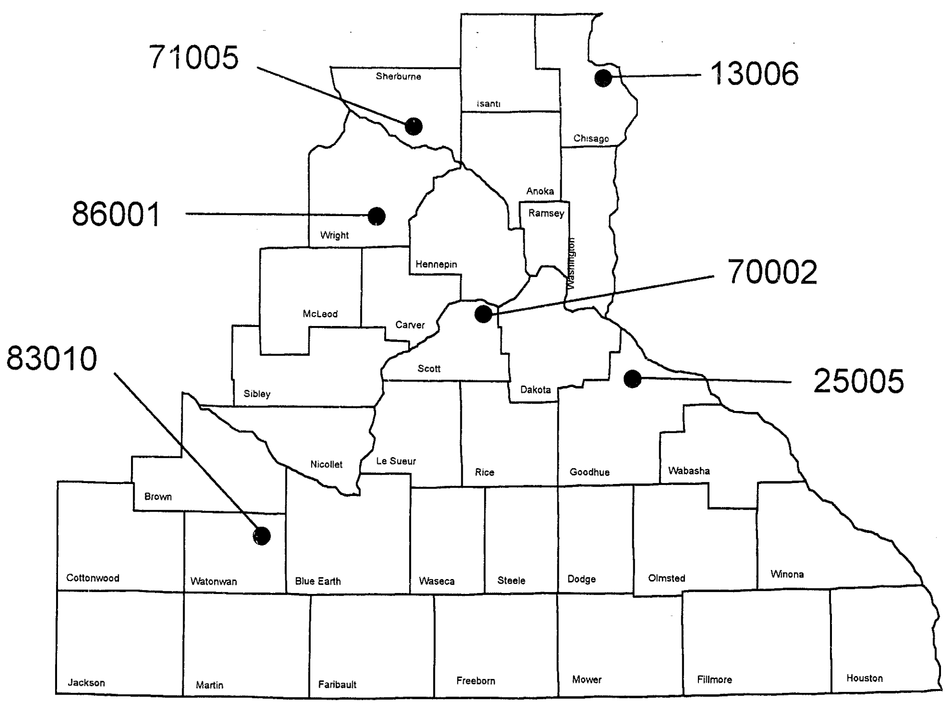


Table 3. Measured Depths to Water (ft) in Selected Mt. Simon Observation Wells

	WY95				WY96			
Well	Month	Depth	Month	Depth	Month	Depth	Month	Depth
13006	3	41.95	8	41.45	3	40.88	8	40.69
25005			9	104.43	3	101.47	9	105.44
70002	3	74.72	8	81.41	3	73.25	8	88.37
71005	4	10.43	10	12.03	4	12.02	10	13.17
83010	4	31.53	9	37.73	4	35.3	10	32.96
86001	3	75.43	8	74.99	3	75.03	8	75.45

Figure 15. Location of Selected Mt. Simon Aquifer Wells



Confined Bedrock - Prairie du Chien-Jordan Aquifer

Seasonal water levels in the Prairie du Chien-Jordan Aquifer system (hereafter referred to as Jordan) are compared to historical averages in Figures 16a and 16b. With the exception of two wells, winter and summer water levels in WY95 and WY96 were generally above average in the Jordan system. The noted exceptions are well 27001 in Hennepin County and well 55000 in Rochester, Olmsted County. For both of these wells, water level averages incorporate an earlier period of time when water levels were higher. In more recent years these levels have steadily maintained a lower level, presumably as the result of an increased pumping demand in a developed urban area. Therefore, WY95 and WY96 readings are shown compared to an average which is skewed toward a higher water level; when compared to averages reflecting the more current trend , WY95 and WY96 water levels were close to average.

Neither WY95 nor WY96 showed a major influence over the winter water levels in the Jordan wells (Figure 16a). Of the eight wells, two had higher levels in WY95, two others were higher in WY96 and the remaining four were about equal for both years. During the summer season however, WY95 generally showed higher water levels (Figure 16b).

Table 4 presents the WY95 - WY96 water levels measured for these Jordan wells.

Table 4. Measured Depths to Water (ft) in Selected Jordan Observation Wells

	WY95				WY96			
Well	**Month**	**Depth**	**Month**	**Depth**	**Month**	**Depth**	**Month**	**Depth**
2012	3	9.2	8	8.48	3	8.74	8	10.73
19007	3	12.95	8	14.35	3	13.81	8	14.9
27001	3	78.45	8	79	3	78.6	8	81.52
55000	3	67.6	8	66.67	3	64.8	8	70.9
62001	3	136.27	8	142.49	3	140.62	8	139.25
66015	3	7.32	8	8.14	3	7.59	8	8.87
70008	3	82.58	8	82.26	3	82.43	8	82.34
82016	3	62.4	9	61.78	3	62.72	9	79.53

Figure 16. Water Level Comparisons, Jordan Aquifer: A. Winter, B. Summer

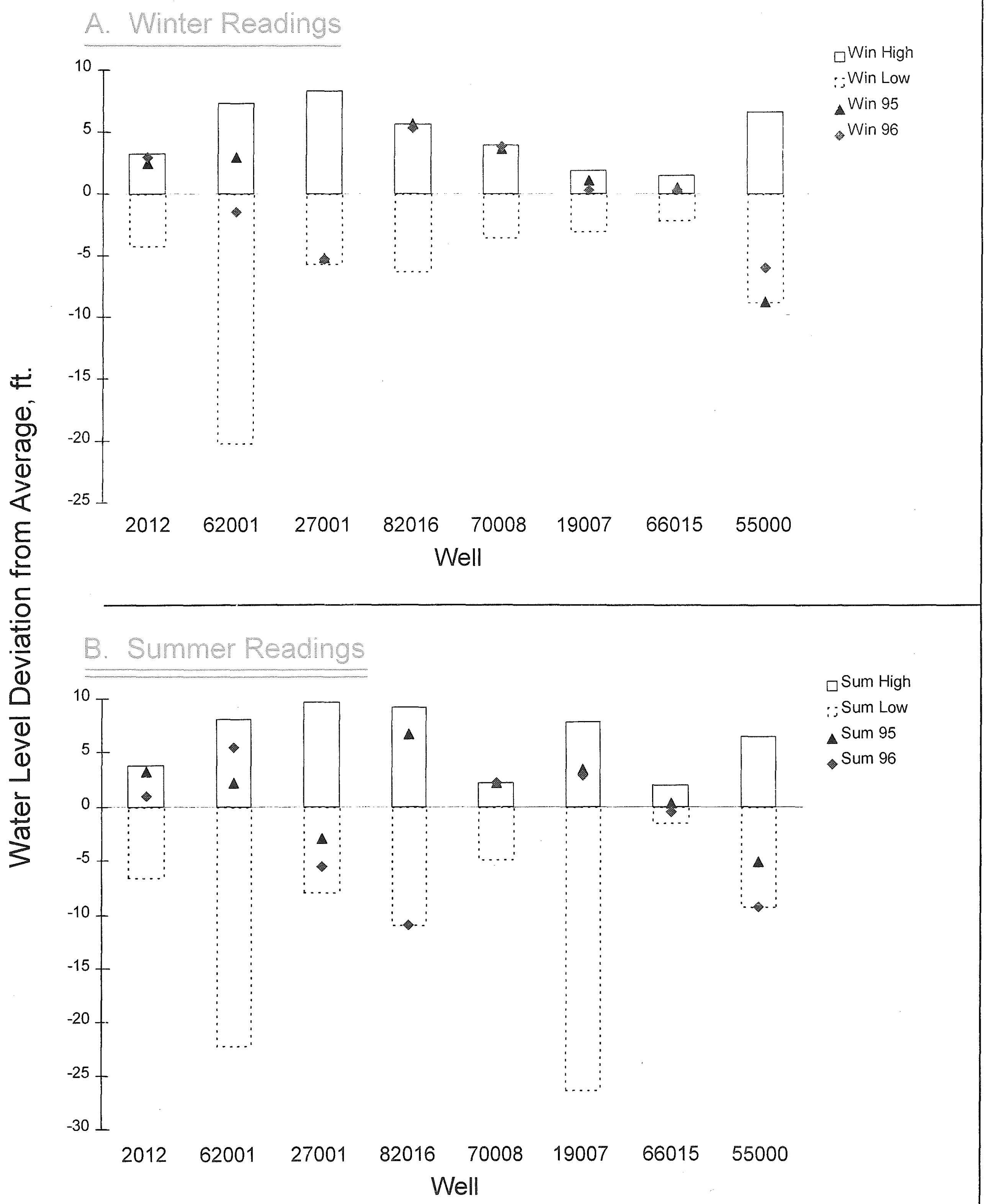
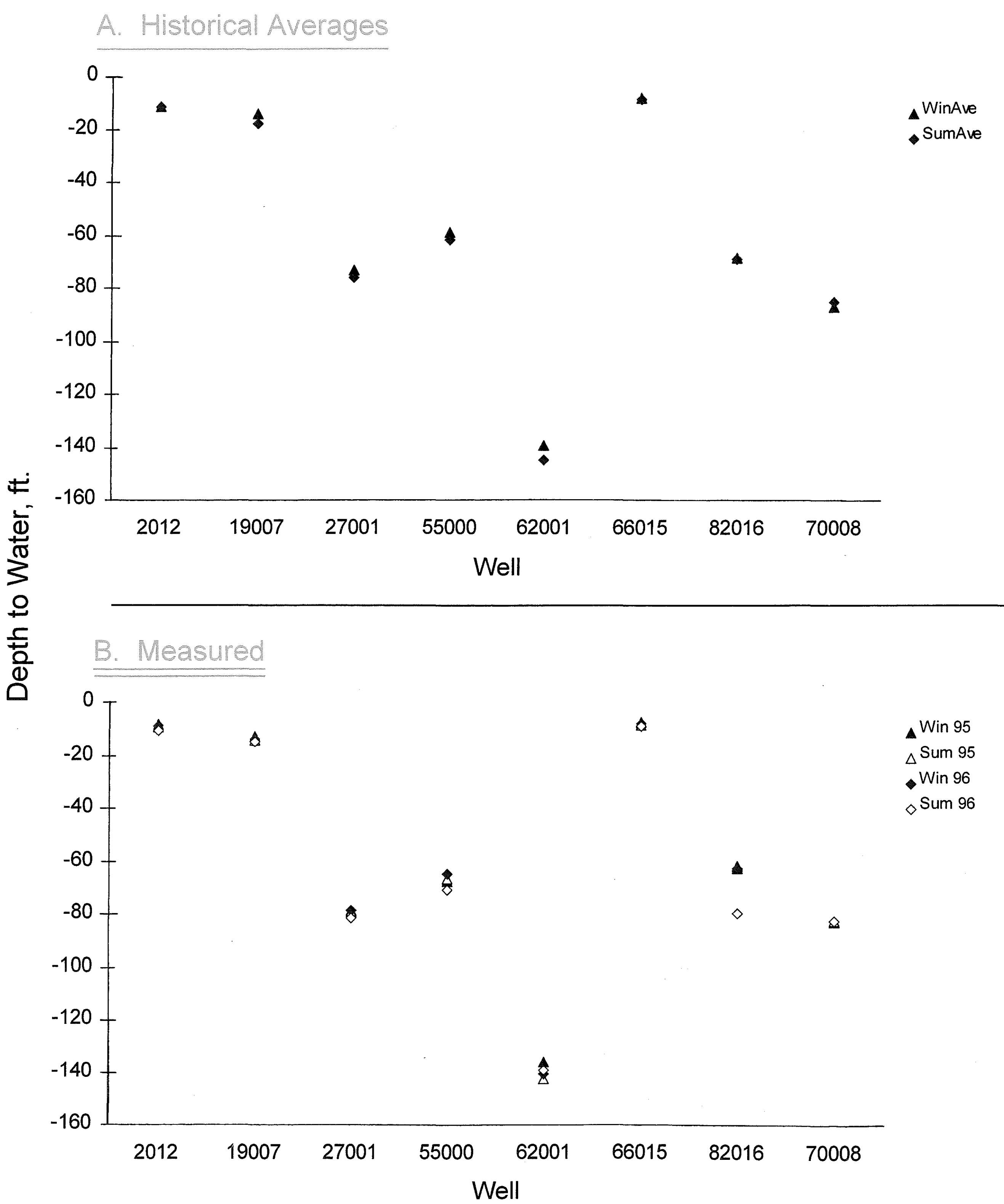


Figure 17. Water Levels, Jordan Wells: A. Historical Averages, B. Measured



Average Jordan water levels tend to be higher in winter than in summer (Figure 17a). This is especially true where wells are located in more urbanized locations where summer demands on this aquifer increase. Water levels in WY95 did not show any real tendency toward higher winter levels, but WY96 did show winter water levels that were higher than those in summer (Figure 17b). Locations of the Jordan wells used in this report are shown in Figure 18.

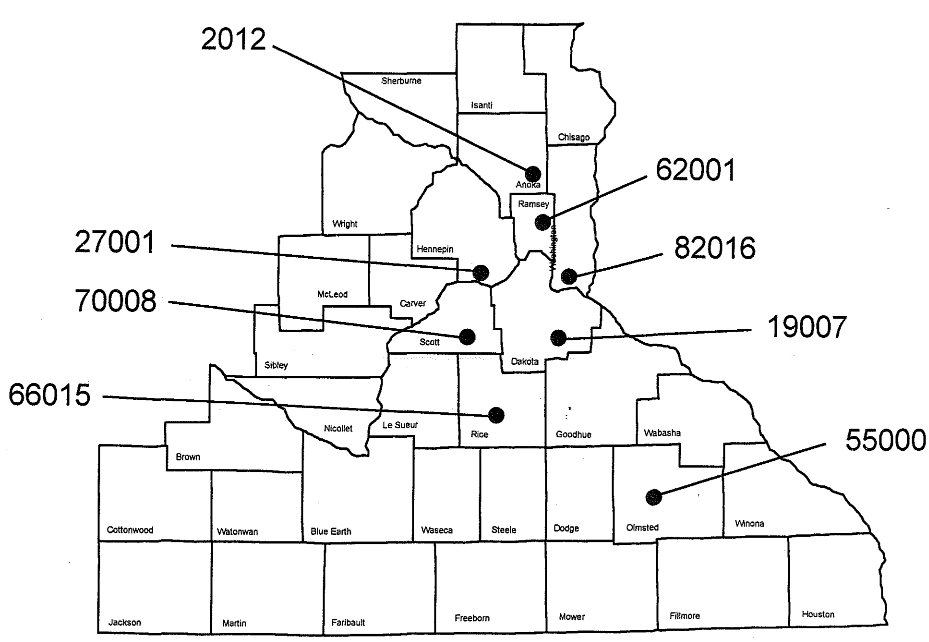
Obwell Network Expansion

Expansion of the Obwell Network is still a priority of the Division of Waters. However, no new wells have been drilled during the last biennium. Three Mt. Simon wells will soon be added as the result of refitting older, out of production wells that were slated for sealing. Plans to drill one more Mt. Simon well are in discussion. Several existing obwells were lost during the last biennium due to a variety of circumstances such as inadvertent sealing, road construction, and well owners' decisions to eliminate the wells from their property. Plans are in motion to replace some of these lost wells.

Summary

Water levels were generally higher than average in all aquifer systems for both WY95 and WY96. In water table and buried artesian aquifers, winter levels were higher in WY 96 while summer levels were generally higher in WY95. Mt. Simon aquifers exhibited no difference between water years relative to winter or summer water levels. The Jordan aquifer system showed no difference between water years relative to the winter water levels, but during summer season, WY95 had higher levels than WY96.

Figure 18. Location of Selected Jordan Aquifer Wells

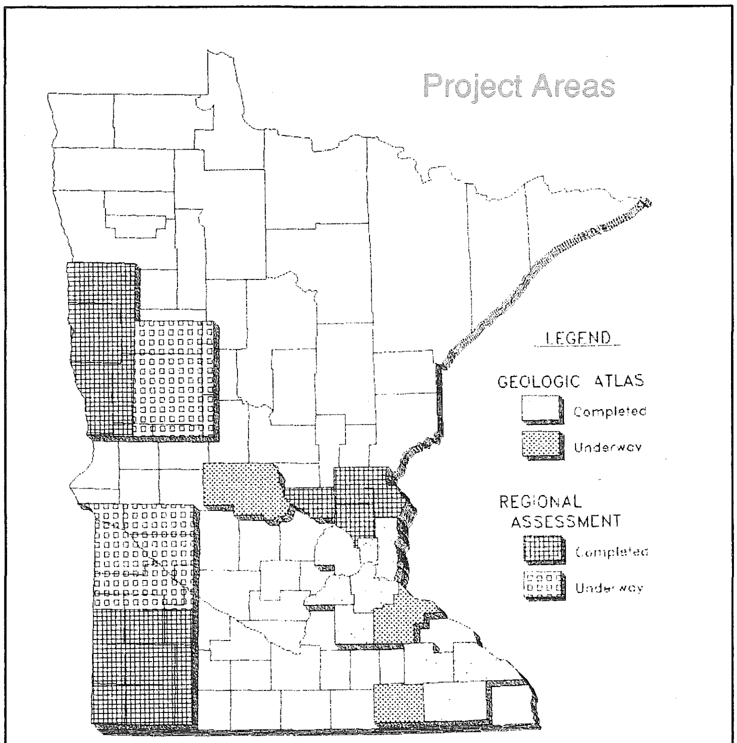


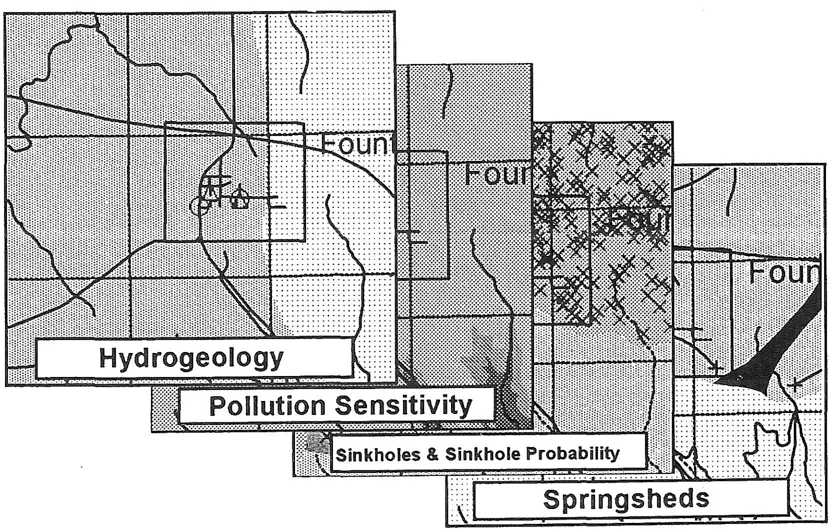
County Geologic Atlas and Regional Hydrogeologic Assessment Program

Ground Water Data Use

For fifteen years the Minnesota Geological Survey (MGS) has been conducting county and regional-scale basic geologic and hydrogeologic data gathering and interpretation. Beginning in 1991, the Division of Waters (DOW) joined the MGS in this effort, concentrating on the hydrogeology of the study areas. The results of this work are the County Geologic Atlases and Regional Hydrogeologic Assessments.

In addition to the well and geologic data collected by the MGS, project staff utilize DOW databases, particularly data available from the Observation Well Program. Other DOW data sources are also used, including climatology, water use permits, and geophysical study reports. Project staff also measure water levels in wells and collect water samples for chemical and isotopic analysis.





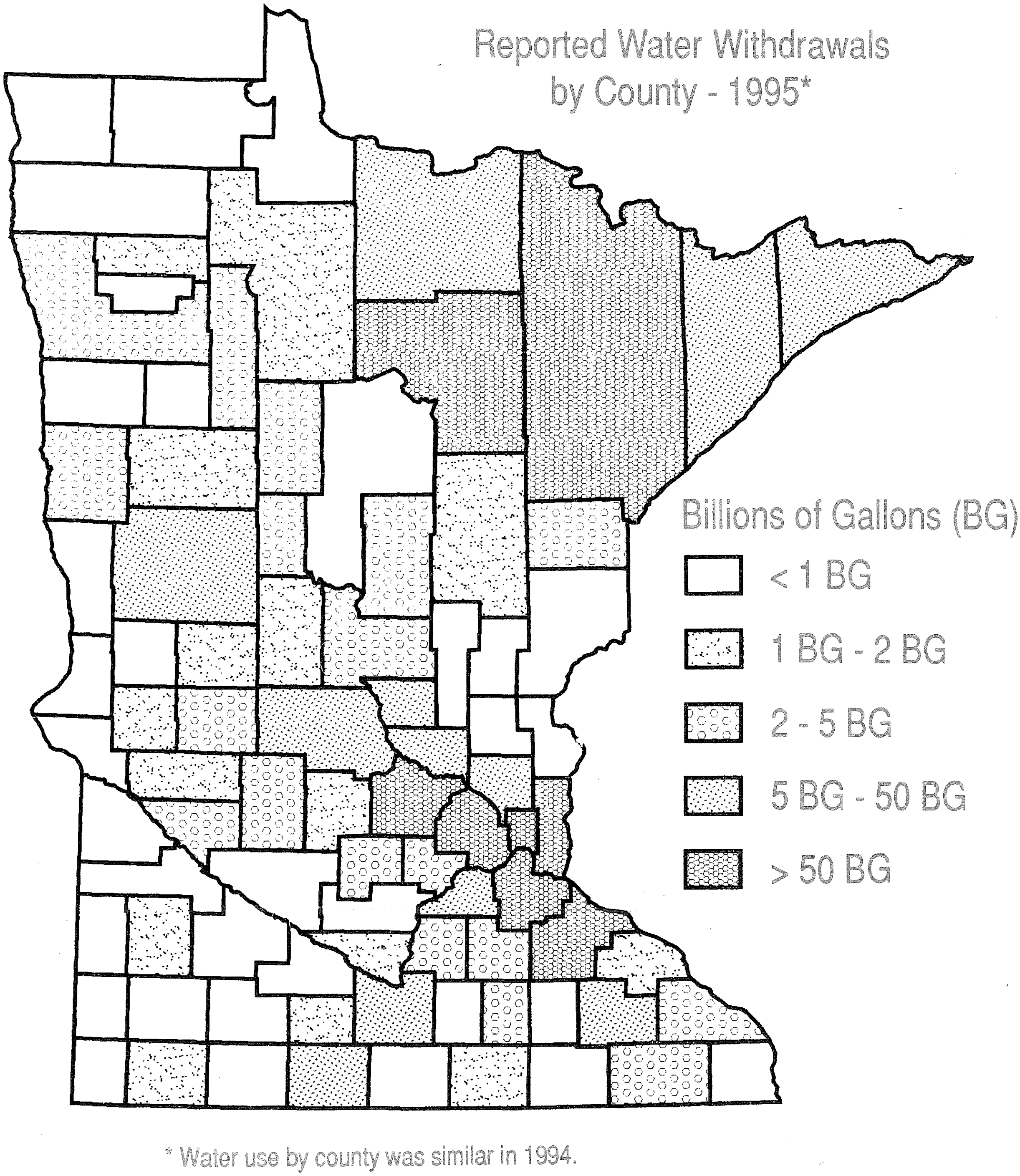
Layers show the area around the town of Fountain, Fillmore County; from *Fillmore County Geologic Atlas, Part B, 1996*

GIS-Based Mapping

The information collected is organized, displayed and analysed using Geographic Information System (GIS) technology, a computer-based tool for manipulating spatial information. Since 1993, all atlas and regional assessment reports have been developed using GIS coverages and project data are filed for distribution at the Land Management Information Center, Department of Administration.

Chapter 4

WATER USE



* Water use by county was similar in 1994.

Introduction

DNR water appropriations permits are required for all users withdrawing more than ten thousand gallons of water per day or one million gallons per year. Uses less than this, such as rural domestic use, do not require a permit from the DNR and therefore are not included in this chapter.

As a condition of each permit, the holder must report the volume withdrawn for the previous year within an accuracy of 10%. The data collected is used for many purposes, such as documenting water rights, understanding the hydrology of aquifers from which water is withdrawn, and evaluating existing water supplies by monitoring use and the impact of that use. The data are reported on a calendar year basis. This chapter summarizes the reported water use data for calendar years (CY) 1994 and 1995.

Major Water Use Categories

THERMOELECTRIC POWER GENERATION - water used to cool power generating plants. This is historically the largest volume use and relies almost entirely on surface water sources. Thermoelectric power generation is primarily a nonconsumptive* use in that most of the water withdrawn is returned to its source.

PUBLIC WATER SUPPLY - water distributed by community suppliers for domestic, commercial, industrial and public users. This category relies on both surface water and ground water sources.

INDUSTRIAL PROCESSING - water used in mining activities, paper mill operations, food processing, etc. Three-fourths or more of withdrawals are from surface water sources. Consumptive use varies depending on the type of industrial process.

IRRIGATION - water withdrawn from both surface water and ground water sources for major crop and noncrop uses. Nearly all irrigation is considered to be consumptive use.

OTHER - large volumes of water withdrawn for activities including air conditioning, construction dewatering, water level maintenance and pollution confinement.

* *Consumptive use* is defined as water that is withdrawn from its source and is not directly returned to the source (M.S. 103G.005, Subd.8). Under this definition, all ground water withdrawals are consumptive unless the water is returned to the same aquifer. Surface water withdrawals are considered consumptive if the water is not directly returned to the source so that it is available for immediate further use.

Statewide Water Use Comparison for 1994 and 1995

Total water use for calendar years 1994 and 1995 remained relatively stable. The totals for these two years average about 6% higher than the previous two-year average. The reported water use in 1995 was 1196 billion gallons (BG), up slightly from 1183 BG in 1994. Figure 1 is a comparison of the two years showing use by major category and the volume and percent change between the years. The largest increase in use was for industrial processing, increasing by 41 BG or 34%. The largest decrease in use was for power production, decreasing by 18 BG or 2%.

A comparison of surface water versus ground water use for 1995 (Figure 2) shows that the majority of appropriations are from surface water sources. 83% of withdrawals in Minnesota are from surface water, which

Figure 1

Water Use Comparison by Major Use Category: 1994 & 1995 (Billions of Gallons)

Use Category	1994 BG	1994 % of Total	1995 BG	1995 % of Total	BG Change	% Change
Power Generation	765	65%	747	62%	-18	-2%
Public Supply	178	15%	174	15%	-4	-2%
Industrial Processing	120	10%	161	13%	41	34%
Irrigation	56	5%	57	5%	1	2%
Other	64	5%	57	5%	-7	-11%
Totals	**1,183**	**100%**	**1,196**	**100%**	**13**	**1%**

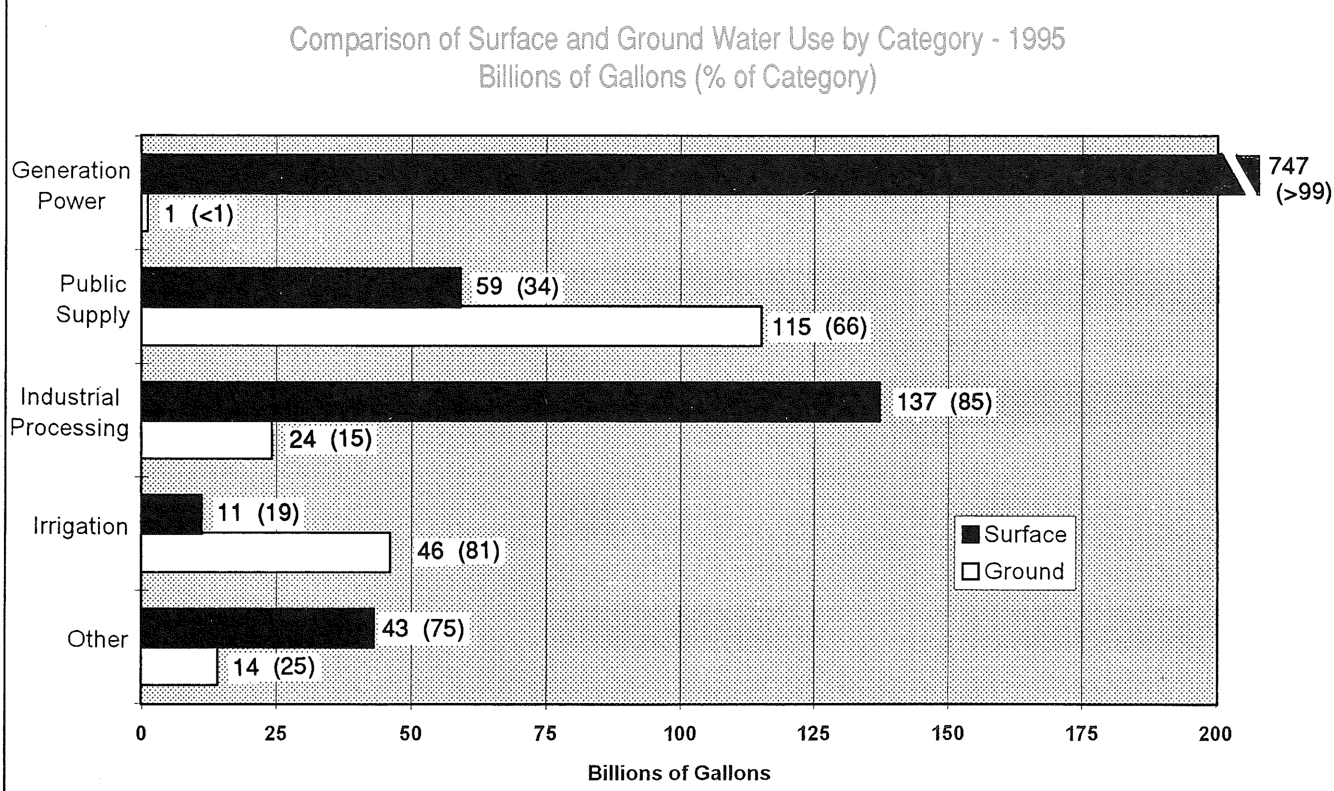
Minnesota Water Use - 1986 to 1995 (Billions of Gallons)

	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
Power Generation	539	637	663	664	698	694	679	722	765	747
Public Supply	170	192	203	174	164	170	175	164	178	174
Industrial Processing	76	69	94	120	102	115	158	127	120	161
Irrigation	30	67	103	86	71	60	63	30	56	57
Other	42	38	42	48	53	52	58	63	64	57
Total	**857**	**1003**	**1105**	**1092**	**1088**	**1091**	**1133**	**1106**	**1183**	**1196**

compares closely with the national average of 80% (USGS data). However, if the non-consumptive use for most power generation is removed, use of ground water and surface water are more even (non-consumptive use means water that is immediately returned to its source after use). 60 to 65% of water use in Minnesota is for power plant cooling, a relatively non-consumptive use.

Surface water use increased slightly from 1994 to 1995, primarily due to increased appropriation for industrial processing. Surface water withdrawals for power generation decreased, offsetting the industrial processing increases. Ground water use remained stable from 1994 to 1995. The majority of ground water use is for public water supplies and irrigation.

Figure 2



Surface Water Total: 996 BG 83% of 1995 Use

Ground Water Total: 201 BG 17% of 1995 use

Figure 3

Appropriations by the Counties
with the Greatest Use in CY 1995
(Billions of Gallons)

	County	Surface Water	Ground Water	Total	Primary Use
1)	Goodhue	203	3	205	Nuclear Power Cooling
2)	Wright	123	2	125	Nuclear Power Cooling
3)	Washington	99	11	110	Steam Power Cooling
4)	Hennepin	60	32	92	Steam Power Cooling
5)	St. Louis	90	2	92	Steam Power Cooling
6)	Dakota	68	19	88	Steam Power Cooling
7)	Itasca	64	1	65	Steam Power Cooling
8)	Ramsey	35	17	52	Steam Power Cooling
9)	Lake	49	<1	49	Mine Processing
10)	Anoka	37	9	46	Municipal Waterworks
11)	Cook	46	<1	46	Mine Processing
	Total	**874**	**96**	**970**	
		88% of SW Use	*48% of* GW Use	*81% of* Total Use	

Power Generation

Power generation (nuclear power cooling and steam power cooling) was the primary use in 8 of the 11 counties with the highest total use in 1995 (Figure 3). Power generation in those counties accounted for 69% of all use reported in Minnesota for the year. Power generation in Goodhue and Wright Counties alone accounted for 28% of all reported use in that 1995, largely due to nuclear power plant cooling. Surface water sources supply almost all of the water used for power generation. Most of the water is used for cooling purposes and is returned to the surface water source after use.

Public Water Supply

Water use for public supplies has remained fairly constant from 1989 to 1995 (Figure 3), dipping slightly in 1990 and 1993. Reported water use for 1994 and 1995 was 178 BG and 174 BG respectively. 66% of public water supply use comes from ground water, compared to 39% nationally (USGS data, 1986-1990). Public water supply varies by the month of the year, with more water use in the summer months. Very dry years, like 1988, show a great increase in water use for summer months compared to wetter years, such as 1993 (Figure 4). This increased use is due to lawn watering and other outside water uses that create large demands on local water utilities. Water supply treatment and storage facilities are often built two, three and even four times larger to supply additional demands caused by lawn watering. This extra capacity is not used for most of the year and can add significant costs to the design, construction, and operation of a water system.

Improving water use efficiencies can be a low cost alternative compared to the costs for new wells or expanding water and wastewater treatment plants. Public water suppliers that serve more than 1,000 people were required to develop water emergency and conservation plans by January 1, 1996. Measures that include a public education program and an evaluation of conservation rate structures must be implemented before approval of new municipal wells or increased volumes. These efforts will help water customers and communities save money and protect Minnesota's water resources for future domestic and economic uses.

Figure 4

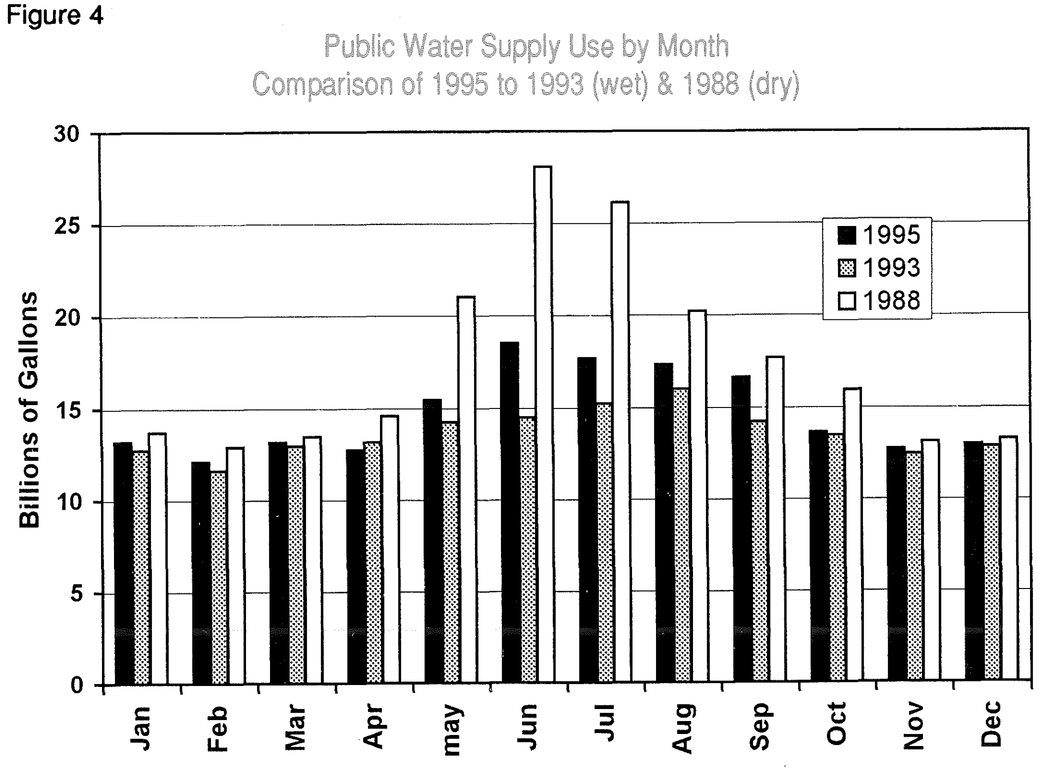
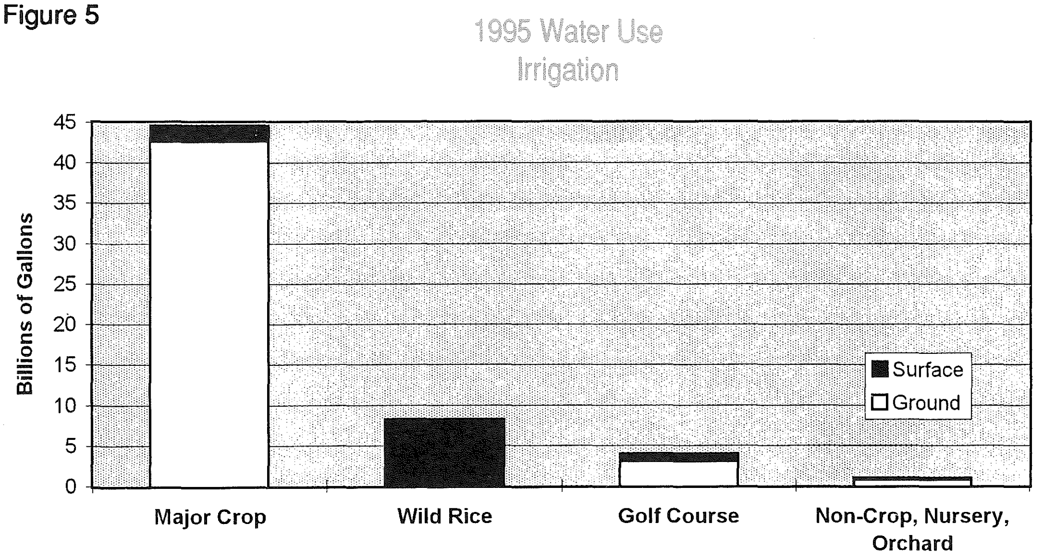


Figure 5



Irrigation

Water use for irrigation has dropped considerably since the peak usage of 103 BG in 1988. 1994 and 1995 irrigation use was very constant at 56 BG and 57 BG respectively. These values are very close to the 1991 and 1992 use of 60 BG and 63 BG.

Irrigation accounts for only a small percentage of the total water use in Minnesota (5%). However, this use is significant because it is almost entirely consumptive and the majority is from ground water sources (81%).

Otter Tail and Sherburne Counties reported the most water use for irrigation in 1995, using 9.9 BG and 7.1 BG respectively. Mahnomen County was the only county that reported no water use for irrigation in 1994 and 1995. Traverse, Lake, and Carlton Counties reported less than 2 million gallons used for irrigation in 1995. Major crop irrigation accounted for 77% of the reported irrigation total with wild rice irrigation at 14% and golf course irrigation at 7% (Figure 5).

Industrial Processing

Industrial processing showed a 33% increase in use from 1994 to 1995 primarily due to increased use for mine processing in Lake County. Counties with the highest industrial processing use for 1995 include: Lake (48.1 BG, mine processing), Cook (45.5 BG, mine processing), Koochiching (15.1 BG, pulp and paper processing), St. Louis (10.5 BG, mine processing), Itasca (8.7 BG, pulp and paper processing), Ramsey (5.2 BG, general and agricultural processing), and Dakota (4.0 BG, petroleum and chemical processing). Mine processing accounted for 65% of the reported irrigation total. Pulp/ paper processing and agricultural processing accounted for 16% and 7% of the total respectively (Figure 6).

Other Uses

Other uses include air conditioning, water level maintenance, fisheries, temporary construction dewatering, pollution confinement, and other specialty uses. These uses represent only a small portion of Minnesota's total water use, about 5%.

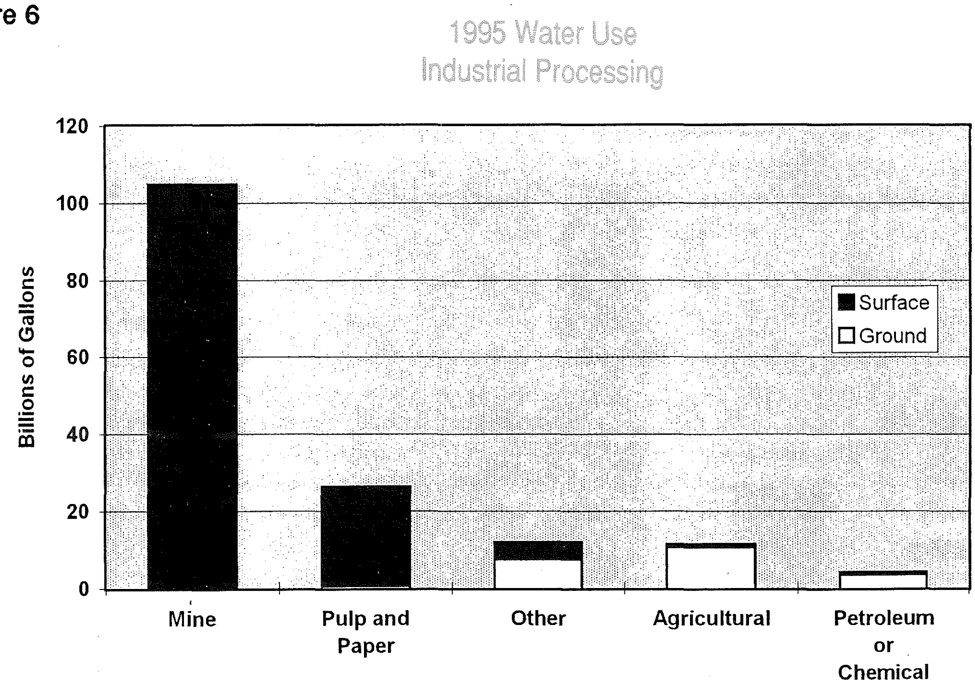
In 1988, there were approximately 100 water appropriation permits for office buildings and other types of structures that used ground water for heating and air-conditioning purposes. These "once-through systems" pump water through the heating, ventilation or air conditioning systems, then discharge the water without recalculating or reusing it for another purpose.

Once-through systems used almost 11 BG per year and accounted for approximately 19% of the total ground water use in the Twin Cities Metropolitan Area in 1988. A 1990 law required once-through systems to be phased out at the end of the design life of the equipment, but no later than the year 2010. 1995 ground water withdrawals for this purpose had dropped to 5.5 BG. Over half of the once-through systems were converted to water efficient alternatives by the end of 1996.

Summary

Total water use from 1994 to 1995 remained relatively constant, increasing by about 1% overall. Power generation continues to account for the majority of use totaling 747 BG of the 1196 BG reported for 1995 (62%). Surface water is used for 83% of all appropriations.

Figure 6



Reported Water Use by County
1994 - 1995 (Millions of Gallons)
Reported Pumpage

County		1994 Surface	1994 Ground	1994 Total	1995 Surface	1995 Ground	1995 Total	Primary Use	Percent of 1995 Total
1	Aitkin	1,253.3	115.1	1,368.4	1,570.5	126.8	1,697.3	Wild Rice Irrigation	87
2	Anoka	37,727.7	9,128.1	46,855.8	36,716.3	9,162.1	45,878.4	Municipal Waterworks	97
3	Becker	6.3	1,089.7	1,096.0	18.1	1,752.2	1,770.3	Major Crop Irrigation	59
4	Beltrami	1,124.1	739.8	1,863.9	1,027.4	683.4	1,710.8	Wild Rice Irrigation	57
5	Benton	3,414.6	2,608.8	6,023.4	3,472.9	2,455.1	5,928.0	Industrial Processing	57
6	Big Stone	36.2	315.9	352.1	14.3	291.1	305.4	Municipal Waterworks	68
7	Blue Earth	5,098.7	4,140.2	9,238.9	7,480.9	4,091.0	11,571.9	Steam Power Cooling	64
8	Brown	96.1	876.9	973.0	160.3	610.3	770.6	Municipal Waterworks	35
9	Carlton	2,972.5	644.9	3,617.4	2,491.0	630.1	3,121.1	Pulp/Paper Processing	73
10	Carver	21.1	2,266.0	2,287.1	10.2	2,322.2	2,332.4	Municipal Waterworks	81
11	Cass	36.6	874.7	911.3	42.7	847.4	890.1	Hatcheries & Fisheries	27
12	Chippewa	3,800.1	438.2	4,238.3	2,913.2	396.7	3,309.9	Steam Power Cooling	86
13	Chisago	105.5	710.7	816.2	70.4	667.9	738.3	Municipal Waterworks	73
14	Clay	1,027.5	1,260.3	2,287.8	1,497.8	1,104.1	2,601.9	Municipal Waterworks	71
15	Clearwater	2,786.5	140.5	2,927.0	3,175.5	132.7	3,308.2	Wild Rice Irrigation	95
16	Cook	51,514.7	6.4	51,521.1	45,642.2	3.5	45,645.7	Mine Processing	99.8
17	Cottonwood	61.3	762.9	824.2	60.4	814.5	874.9	Municipal Waterworks	40
18	Crow Wing	1,134.3	1,431.4	2,565.7	1,201.0	1,448.6	2,649.6	Pulp/Paper Processing	42
19	Dakota	67,993.7	18,389.2	86,382.9	68,038.5	19,475.7	87,514.2	Steam Power Cooling	72
20	Dodge	12.5	306.8	319.3	47.1	316.7	363.8	Municipal Waterworks	87
21	Douglas	168.1	1,178.9	1,347.0	137.0	989.1	1,126.1	Municipal Waterworks	56
22	Faribault	0.0	754.8	754.8	0.0	725.5	725.5	Municipal Waterworks	66
23	Fillmore	4,153.1	560.8	4,713.9	3,556.2	672.9	4,229.1	Hatcheries & Fisheries	84
24	Freeborn	5.0	1,990.7	1,995.7	21.4	1,920.8	1,942.2	Municipal Waterworks	72
25	Goodhue	211,861.4	2,529.7	214,391.1	202,811.9	2,572.2	205,384.1	Nuclear Power Cooling	91
26	Grant	0.0	529.3	529.3	0.0	456.9	456.9	Major Crop Irrigation	57
27	Hennepin	61,182.8	33,619.3	94,802.1	59,716.5	32,374.2	92,090.7	Steam Power Cooling	64
28	Houston	1.9	540.9	542.8	3.2	511.8	515.0	Municipal Waterworks	75
29	Hubbard	9.5	2,345.8	2,355.3	18.7	3,794.2	3,812.9	Major Crop Irrigation	78
30	Isanti	0.0	580.6	580.6	0.0	505.7	505.7	Municipal Waterworks	57
31	Itasca	67,392.6	964.4	68,357.0	64,226.2	1,002.8	65,229.0	Steam Power Cooling	83
32	Jackson	57.3	254.9	312.2	97.0	247.4	344.4	Municipal Waterworks	68
33	Kanabec	2.1	168.5	170.6	7.9	169.4	177.3	Municipal Waterworks	74
34	Kandiyohi	583.2	2,121.5	2,704.7	527.2	1,913.0	2,440.2	Municipal Waterworks	55
35	Kittson	47.3	224.1	271.4	48.2	80.4	128.6	Municipal Waterworks	29
36	Koochiching	15,602.5	38.3	15,640.8	15,140.0	43.9	15,183.9	Pulp/Paper Processing	99
37	Lac Qui Parle	26.2	1,027.2	1,053.4	13.6	910.5	924.1	Agricultural Processing	66
38	Lake	3,719.5	0.1	3,719.6	48,780.2	0.2	48,780.4	Mine Processing	99
39	Lake of the Woo	267.9	87.6	355.5	260.4	80.1	340.5	Wild Rice Irrigation	76
40	Le Sueur	2,693.6	1,029.1	3,722.7	2,713.3	864.1	3,577.4	Quarry Dewatering	49
41	Lincoln	4.2	449.3	453.5	5.0	427.3	432.3	Rural Waterworks	98
42	Lyon	85.3	1,401.3	1,486.6	103.9	1,459.4	1,563.3	Municipal Waterworks	93
43	McLeod	228.8	1,962.6	2,191.4	168.8	2,030.5	2,199.3	Municipal Waterworks	54
44	Mahnomen	0.0	153.1	153.1	0.0	130.6	130.6	Municipal Waterworks	100

Reported Water Use by County
1994 - 1995 (Millions of Gallons)
Reported Pumpage

County		1994 Surface	1994 Ground	1994 Total	1995 Surface	1995 Ground	1995 Total	Primary Use	Percent of 1995 Total
45	Marshall	34.9	194.4	229.3	41.2	225.9	267.1	Municipal Waterworks	49
46	Martin	12,848.8	245.2	13,094.0	15,724.4	229.7	15,954.1	Steam Power Cooling	95
47	Meeker	65.3	1,080.5	1,145.8	58.7	936.5	995.2	Municipal Waterworks	48
48	Mille Lacs	88.1	499.8	587.9	84.1	515.8	599.9	Municipal Waterworks	68
49	Morrison	53.9	2,621.3	2,675.2	86.0	2,874.9	2,960.9	Major Crop Irrigation	73
50	Mower	66.1	2,175.6	2,241.7	17.4	2,246.7	2,264.1	Municipal Waterworks	53
51	Murray	38.7	235.2	273.9	43.1	236.0	279.1	Municipal Waterworks	85
52	Nicollet	15.9	1,876.2	1,892.1	14.8	1,832.4	1,847.2	Municipal Waterworks	86
53	Nobles	67.1	1,213.4	1,280.5	37.5	1,166.4	1,203.9	Municipal Waterworks	97
54	Norman	0.0	148.0	148.0	0.0	145.2	145.2	Municipal Waterworks	94
55	Olmsted	5,193.0	5,314.1	10,507.1	5,392.7	5,529.6	10,922.3	Steam Power Cooling	47
56	Ottertail	18,054.7	8,414.5	26,469.2	15,195.3	10,763.0	25,958.3	Steam Power Cooling	54
57	Pennington	915.5	23.5	939.0	988.7	16.5	1,005.2	Wild Rice Irrigation	52
58	Pine	15.5	354.8	370.3	4.8	491.1	495.9	Municipal Waterworks	57
59	Pipestone	37.4	598.8	636.2	8.0	539.5	547.5	Rural Waterworks	55
60	Polk	4,524.3	459.6	4,983.9	4,086.5	494.6	4,581.1	Municipal Waterworks	58
61	Pope	76.3	4,097.2	4,173.5	53.5	3,384.2	3,437.7	Major Crop Irrigation	93
62	Ramsey	37,330.7	17,915.9	55,246.6	34,706.1	17,315.0	52,021.1	Steam Power Cooling	66
63	Red Lake	48.1	246.8	294.9	25.9	262.5	288.4	Municipal Waterworks	90
64	Redwood	421.2	445.1	866.3	163.2	506.4	669.6	Municipal Waterworks	71
65	Renville	21.9	719.8	741.7	20.2	543.8	564.0	Municipal Waterworks	78
66	Rice	109.1	2,151.7	2,260.8	59.4	2,406.0	2,465.4	Municipal Waterworks	82
67	Rock	38.4	781.6	820.0	29.1	788.1	817.2	Municipal Waterworks	69
68	Roseau	0.0	354.9	354.9	0.0	392.6	392.6	Municipal Waterworks	93
69	St. Louis	98,020.8	1,467.4	99,488.2	90,052.7	1,741.7	91,794.4	Steam Power Cooling	51
70	Scott	5,887.9	2,984.6	8,872.5	2,914.7	3,044.2	5,958.9	Quarry Dewatering	45
71	Sherburne	24,702.1	6,815.4	31,517.5	23,646.8	7,879.1	31,525.9	Steam Power Cooling	50
72	Sibley	31.1	498.0	529.1	42.7	536.1	578.8	Municipal Waterworks	86
73	Stearns	6,094.7	5,581.5	11,676.2	3,192.4	5,162.2	8,354.6	Municipal Waterworks	46
74	Steele	600.5	1,700.6	2,301.1	573.7	1,759.1	2,332.8	Municipal Waterworks	72
75	Stevens	93.9	1,110.6	1,204.5	87.2	967.0	1,054.2	Major Crop Irrigation	55
76	Swift	17.6	2,764.1	2,781.7	0.0	1,182.6	1,182.6	Major Crop Irrigation	73
77	Todd	118.5	1,750.7	1,869.2	103.5	1,874.4	1,977.9	Major Crop Irrigation	70
78	Traverse	1.9	136.4	138.3	0.7	139.0	139.7	Municipal Waterworks	99.5
79	Wabasha	23.9	960.4	984.3	28.3	1,008.5	1,036.8	Municipal Waterworks	76
80	Wadena	455.9	2,019.4	2,475.3	368.8	2,299.5	2,668.3	Major Crop Irrigation	83
81	Waseca	28.3	824.7	853.0	29.7	706.1	735.8	Municipal Waterworks	93
82	Washington	106,653.2	10,208.1	116,861.3	99,490.7	11,008.1	110,498.8	Steam Power Cooling	87
83	Watonwan	7.5	820.2	827.7	7.9	1,053.6	1,061.5	Municipal Waterworks	82
84	Wilkin	98.2	240.7	338.9	28.5	232.1	260.6	Municipal Waterworks	67
85	Winona	1,082.1	2,574.7	3,656.8	1,003.1	2,576.6	3,579.7	Municipal Waterworks	48
86	Wright	113,620.7	1,687.4	115,308.1	123,362.6	1,856.6	125,219.2	Nuclear Power Cooling	98
87	Yellow Medicine	66.0	312.7	378.7	46.5	430.9	477.4	Municipal Waterworks	48
	Total			1,183,370			1,196,343		

Minnesota Reported Water Use

Category	1994	1995
Power Generation	(Millions of Gallons)	
Nuclear Power		
surface	312599.3	310432.7
ground	0.0	0.0
Steam Power Cooling		
surface	350403.9	340175.3
ground	413.1	370.8
Other Power		
surface	101106.6	95746.8
ground	790.5	790.9
Subtotal	**765313.4**	**747516.5**
Percent of Total	**65%**	**62%**
surface	764109.8	746354.8
ground	1203.6	1161.7
Public Supply		
Municipal Water Works		
surface	62697.4	58764.5
ground	110753.8	111053.5
Private Water Works		
surface	1.6	3.9
ground	834.9	801.8
Comercial & Institutional		
surface	0.0	0.0
ground	1339.9	2133.9
Cooperative Water Works		
surface	0.0	0.0
ground	2.1	0.2
Fire Protection		
surface	0.0	0.0
ground	731.8	31.2
State Parks, Waysides, Rest Areas		
surface	0.0	0.0
ground	27.7	34.4
Rural Water Districts		
surface	0.0	0.0
ground	1272.6	1357.9
Subtotal	**177661.8**	**174181.3**
Percent of Total	**15%**	**15%**
surface	62699.0	58768.4
ground	114962.8	115412.9

Irrigation		
Golf Course		
surface	699.4	778.1
ground	3110.6	3097.3
Cemetary		
surface	0.0	0.0
ground	43.1	25.5
Landscaping		
surface	52.1	27.3
ground	377.4	370.3
Sod		
surface	24.2	8.5
ground	56.0	9.3
Nursery		
surface	25.7	16.9
ground	235.7	305.2
Orchard		
surface	0.0	0.0
ground	1.3	15.2
Non Crop		
surface	17.0	20.6
ground	19.3	94.7
Major Crop		
surface	1848.9	1815.0
ground	40409.0	42680.2
Wild Rice		
surface	8620.4	8174.6
ground	0.01	6.1
Subtotal	**55540.1**	**57444.8**
Percent of Total	**5%**	**5%**
surface	11287.7	10841.0
ground	44252.4	46603.8

Industrial Processing		
Agricultural		
surface	424.8	419.5
ground	10851.2	10784.4
Pulp and Paper		
surface	25035.9	25476.2
ground	707.1	661.1

Mine		
surface	65326.1	104599.2
ground	27.0	37.7
Sand and Gravel Washing		
surface	1813.4	1673.6
ground	874.1	1069.6
Sewage Treatment		
surface	1.9	1.0
ground	770.6	736.7
Petroleum or Chemical		
surface	347.9	420.1
ground	3453.8	3573.8
Metal		
surface	0.0	0.0
ground	864.1	917.1
Non-Metal		
surface	29.8	36.1
ground	586.8	639.3
Other		
surface	4076.2	4198.2
ground	5181.5	5303.1
Subtotal	**120372.2**	**160546.7**
Percent of Total	**10%**	**13%**
surface	97056.0	136823.9
ground	23316.2	23722.8

Other

Air Conditioning

Commercial & Institutional Building AC		
surface	0.0	0.0
ground	92.7	105.9
Heat Pumps & Coolant Pumps		
surface	411.1	455.2
ground	123.5	149.7
District Heating		
surface	0.0	0.0
ground	80.0	104.3
Once Through Heating or AC		
surface	0.0	0.0
ground	5601.7	5525.9

Other AC		
surface	106.6	82.9
ground	0.0	0.0
Temporary		
Temporary Construction Non-Dewatering		
surface	0.0	1.6
ground	0.0	0.0
Temporary Construction Dewatering		
surface	0.0	588.1
ground	0.0	8.7
Temporary Pipeline and Tank Testing		
surface	0.0	0.0
ground	0.0	0.0
Other Temporary		
surface	29.2	12.9
ground	0.0	0.0
Water Level Maintenance		
Basin (Lake) Level Maintenance		
surface	744.5	1189.9
ground	140.5	134.3
Mine Dewatering		
surface	21802.2	19865.2
ground	73.5	0.0
Quarry Dewatering		
surface	20018.1	14273.1
ground	0.0	0.0
Sand/Gravel Pit Dewatering		
surface	529.4	590.8
ground	0.0	0.0
Tile Drainage & Pumped Sumps		
surface	36.8	26.6
ground	0.0	0.0
Other Water Level Maintenance		
surface	715.9	281.1
ground	331.9	456.9
Special Categories		
Pollution Confinement		
surface	0.0	0.0
ground	5780.8	6005.9

Hatcheries & Fisheries		
surface	6325.0	5537.8
ground	1008.8	719.4
Snow Making		
surface	103.5	134.0
ground	279.3	205.4
Peat Fire Control		
surface	0.0	0.0
ground	1.0	0.05
Livestock Watering		
surface	0.0	0.0
ground	93.6	141.2
Other Special Categories		
surface	10.5	0.6
ground	42.7	55.8
Subtotal	**64482.8**	**56653.3**
Percent of Total	**5%**	**5%**
surface	50832.8	43039.8
ground	13650.0	13613.5
Grand Total (Millions of Gallons)	1,183,370	1,196,343
surface	**985,985**	**995,828**
ground	**197,385**	**200,515**