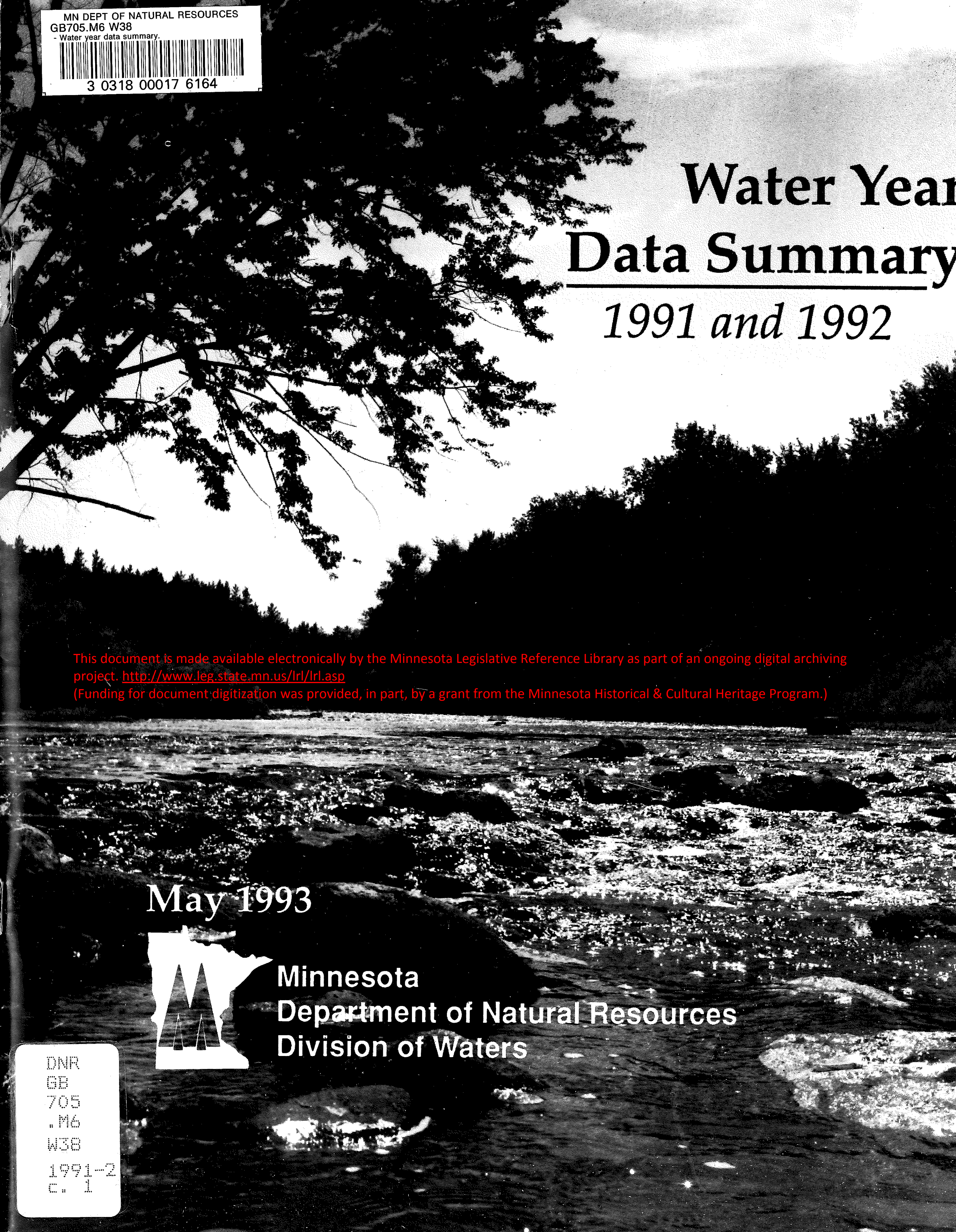

Water Year Data Summary

1991 and 1992

May 1993

Minnesota
Department of Natural Resources
Division of Waters

Water Year Data Summary

1991 and 1992

October 1, 1990 - September 30, 1992
by the Division of Waters Staff

St. Paul, MN
May 1993

Minnesota
Department of Natural Resources
Division of Waters

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(612) 296-5484
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Introduction

This publication provides a review and summary of basic hydrologic 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 on next page) 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 and 1991.

Water Year

The climatology, surface water and ground water data presented is for Water Years 1991 and 1992.

WY 1991: October 1, 1990 - September 30, 1991
WY 1992: October 1, 1991- September 30, 1992

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

I wish to express my gratitude to the authors who contributed to this report. Special thanks to:

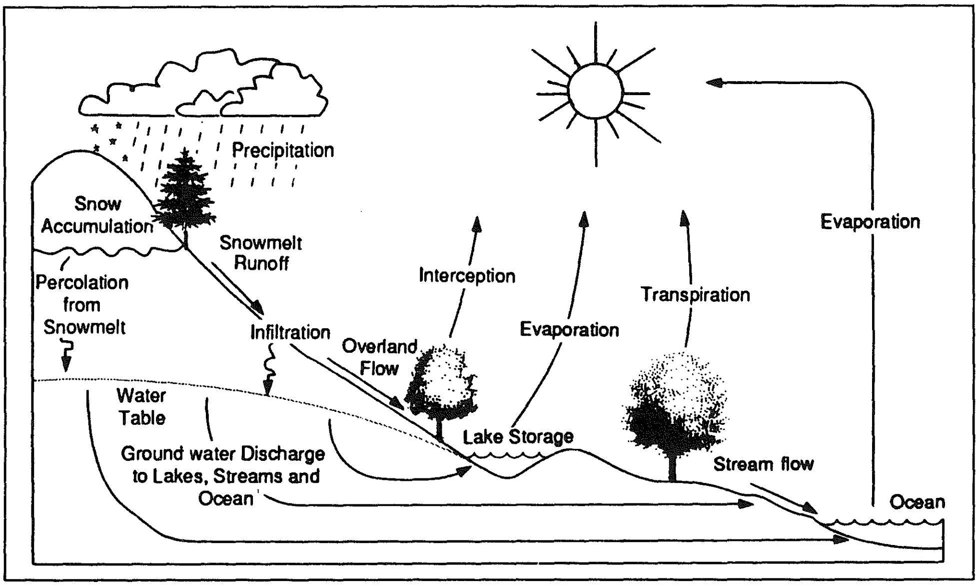
Jerry Johnson - mapping
Felicia White - word processing
Jim Zicopula - graphic arts
Mary Beth Braun - text editing

Glen Yakel, Editor

Department of
Natural Resources
Division of Waters

Kent Lokkesmoe, Director

Hydrologic Cycle

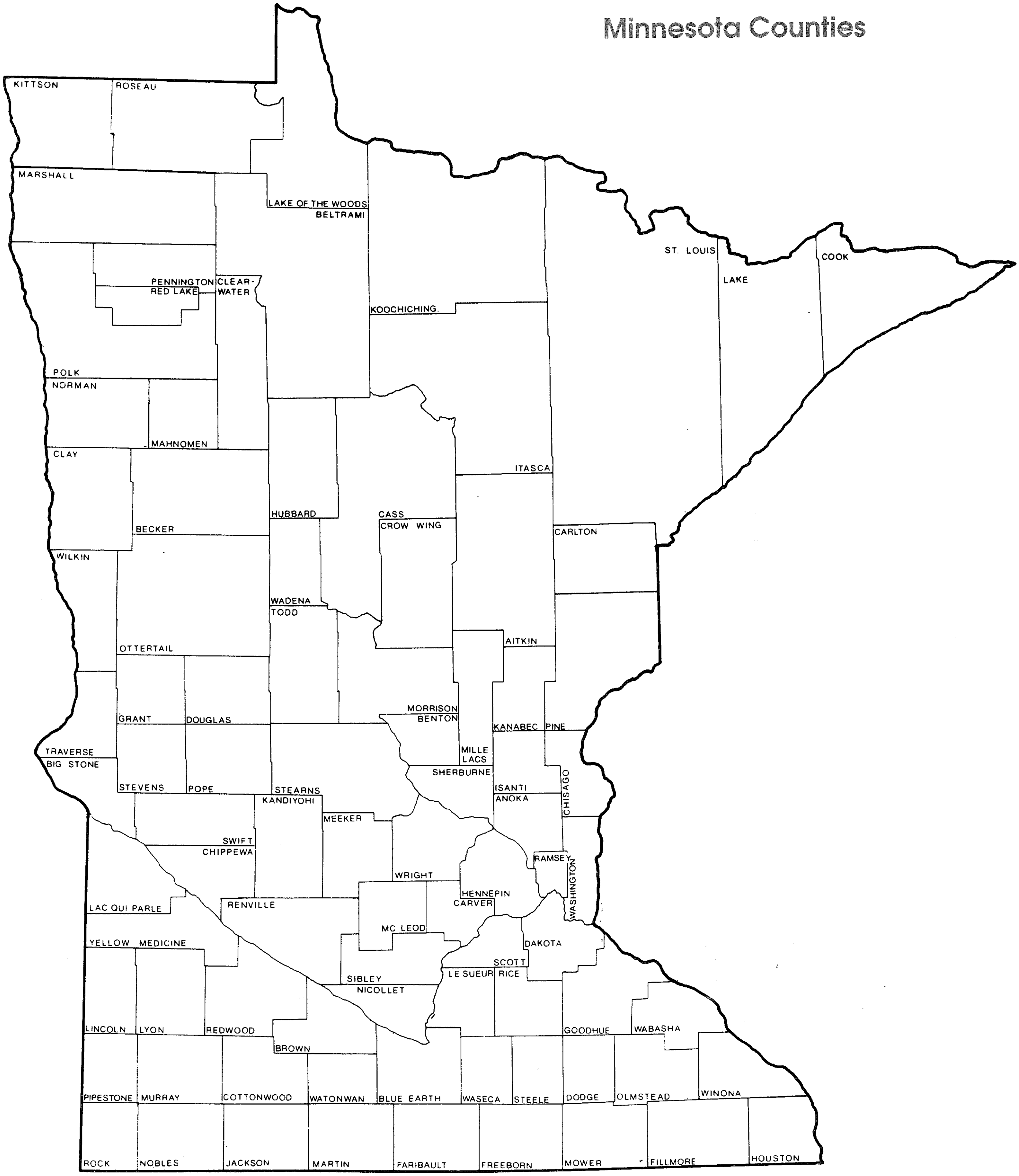


The hydrologic cycle is a concept used to explain the movement of water around the earth. This movement is continuous and has no beginning or end. Affecting it at any point in the cycle will be reflected later in the cycle.

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.

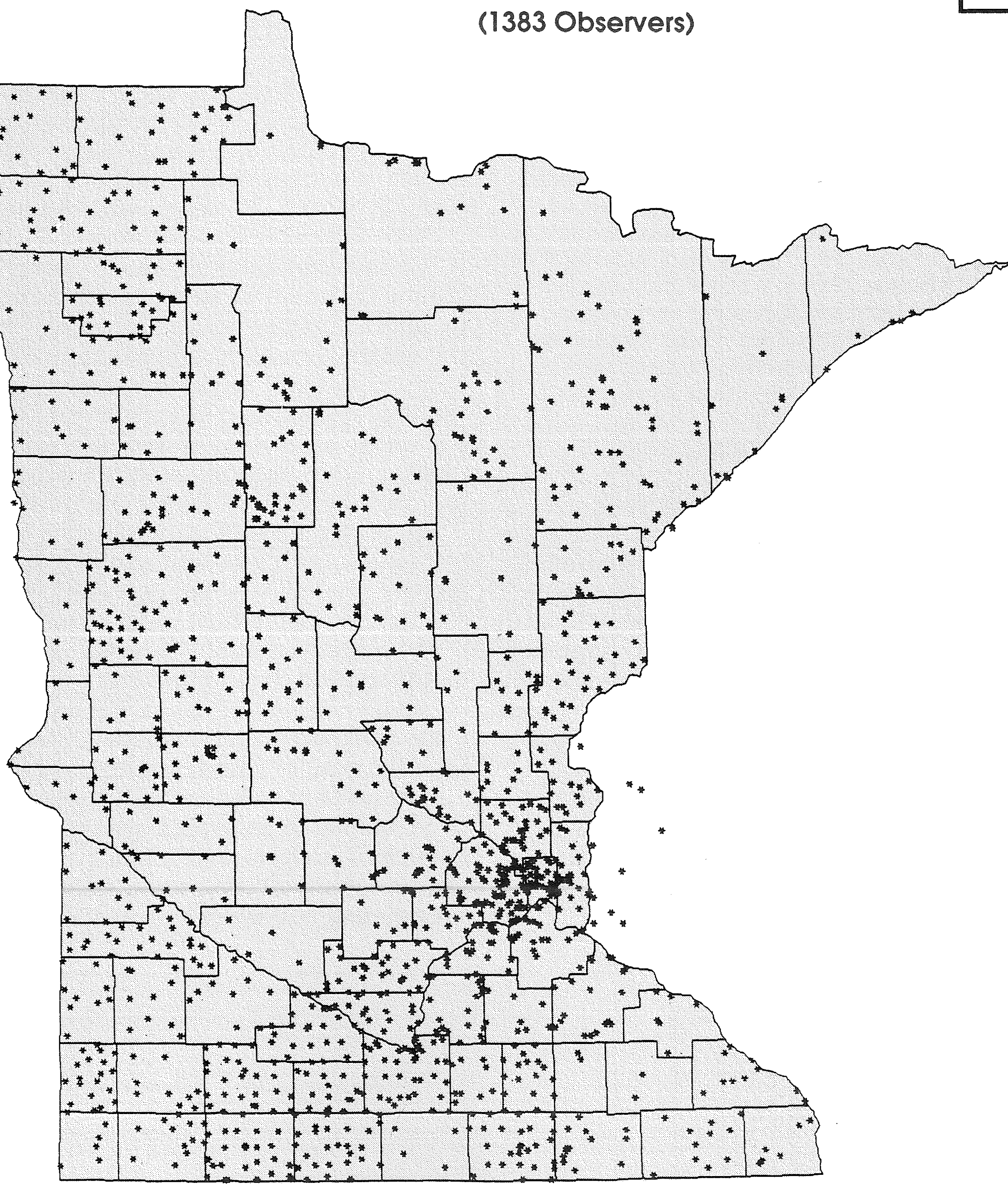
Minnesota Counties



CLIMATOLOGY

Chapter 1

Precipitation Observer Network
June, 1992
(1383 Observers)



Introduction

The State Climatology Office exists to gather and analyze climate data in Minnesota. Climate data is provided by a variety of organizations (see side bar) which rely primarily on the efforts of volunteer observers. The data is consolidated into a unified data base and climate information is distributed to many users.

A review of climate information can assist in explaining a prior event or condition. Climate information can aid in 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 (radio, television, print); private sector professionals and the general public. Specifically, engineers use temperature and precipitation extremes to design roads and storm sewers. Architects use snow load data to design roofs for buildings. Wildlife managers use temperature and snow depth information to identify emergency feeding needs of deer, while agricultural specialists use temperature and precipitation data to determine the types of crops that will grow in Minnesota. Other disciplines interested in climate information include hydrologists, foresters, meteorologists, attorneys, insurance adjustors, journalists and recreation managers.

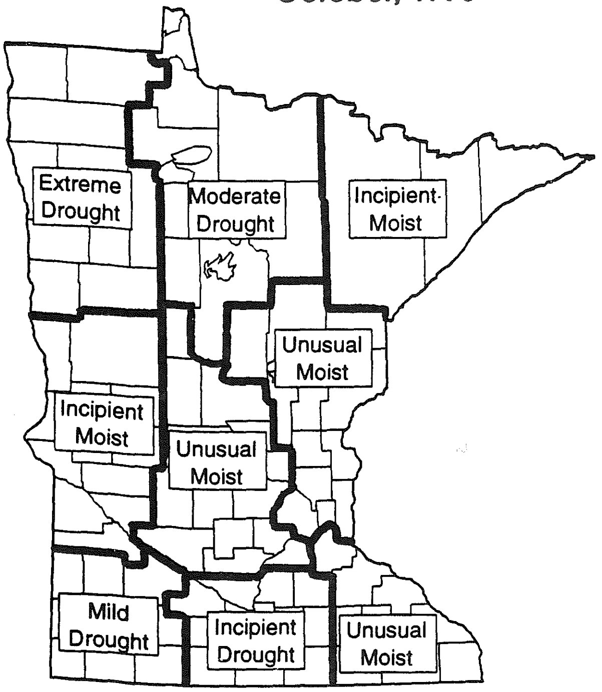
Climate Data Sources:

Soil and Water Conservation Districts
National Weather Service
DNR - Forestry
State Climatology Office Back Yard Network
Metropolitan Mosquito Control District
Watershed Districts
Metropolitan Waste Control Commission
Deep Portage Conservation Reserve
Minnesota Power and Light Company
Future Farmers of America
University of Minnesota

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

Water Year Climate Summary
October 1990 - September 1991

Figure 1. *Palmer Drought Severity Index October, 1990*



PALMER DROUGHT SEVERITY INDEX

The Palmer Drought Severity Index (PDSI) was introduced in 1961 by Wayne C. Palmer of the National Weather Service in a paper titled "Meteorological Drought: Its Measurement and Classification". The index attempts to describe the length and intensity of dry or moist spells by combining antecedent conditions with precipitation departure from normal and the influence of temperature on evaporation.

The PDSI is calculated weekly by the Climate Analysis Center of the National Weather Service for several specific applications:

- measuring the disruptive effects of prolonged dryness or wetness on water sensitive economies

- designating disaster areas of drought or wetness

- reflecting the general, long-term (several months) status of water supplies in shallow aquifers, reservoirs and streams.

The PDSI is not generally indicative of the short-term (a few weeks) status of drought or wetness that frequently affects agricultural activities.

The PDSI is standardized so that a designation of "extreme drought" would have the same relative meaning anywhere in the nation.

The PDSI categories are arranged in the following order:

- extreme moist spell
- very moist spell
- unusual moist spell
- moist spell
- incipient moist spell
- near normal
- incipient drought
- mild drought
- moderate drought
- severe drought
- extreme drought

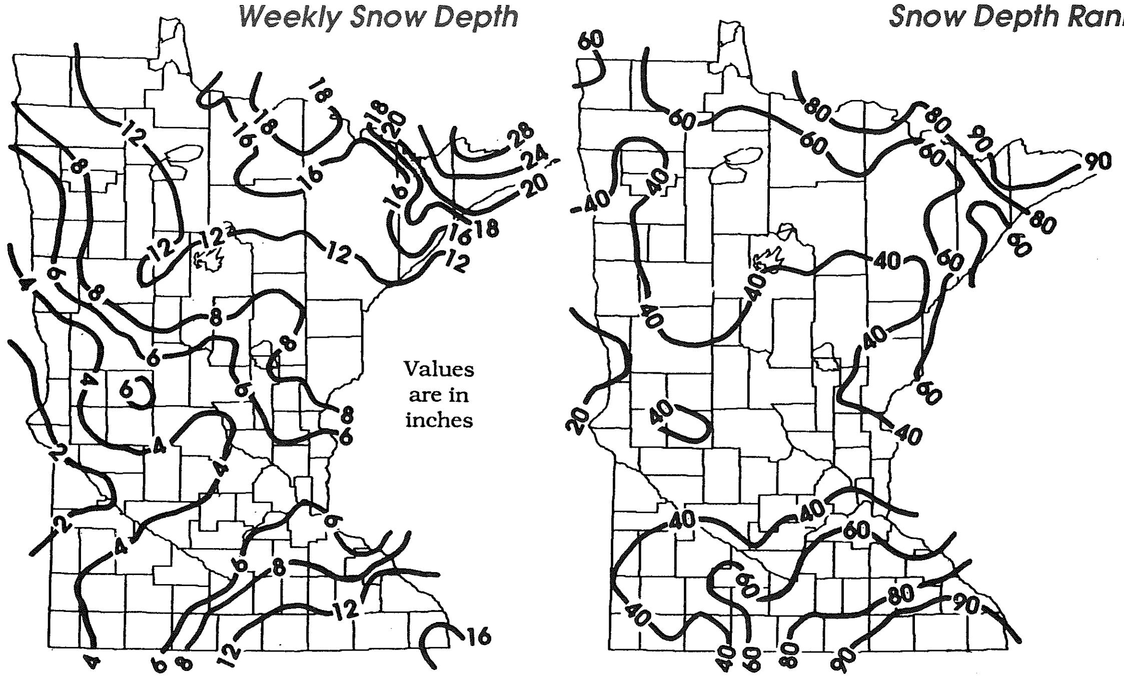
Minnesota began the 1991 Water Year with sharp contrasts between areas of the state. The northwest continued to be impacted by the lingering effects of one the state's worst droughts. The summer of 1990 did not intensify the drought in the northwest nor did it alleviate the hydrologic deficits accumulated over the previous four years. In contrast, much of the southern two thirds of the state experienced a wet spring and summer. Those areas experienced a strong recovery in the overall hydrologic situation. The October, 1990 Palmer Drought Severity Index, a measure of climate "spells", shows the extreme drought situation persisting in the northwest, with unusually moist conditions in many other areas (Figure 1).

Winter 1990-1991

The winter weather of 1990-1991 was rather unremarkable. Generally, snow cover across the state was at or below the median throughout the winter, although some heavier snows fell in northeast and southeast Minnesota (Figure 2). The state experienced a typical late December cold snap, but adequate snow cover prevented significant frost depths. An early February thaw reduced snow cover to near zero in the southern half of Minnesota.

Figure 2. *January 16,1991*

Weekly Snow Depth *Snow Depth Rank**

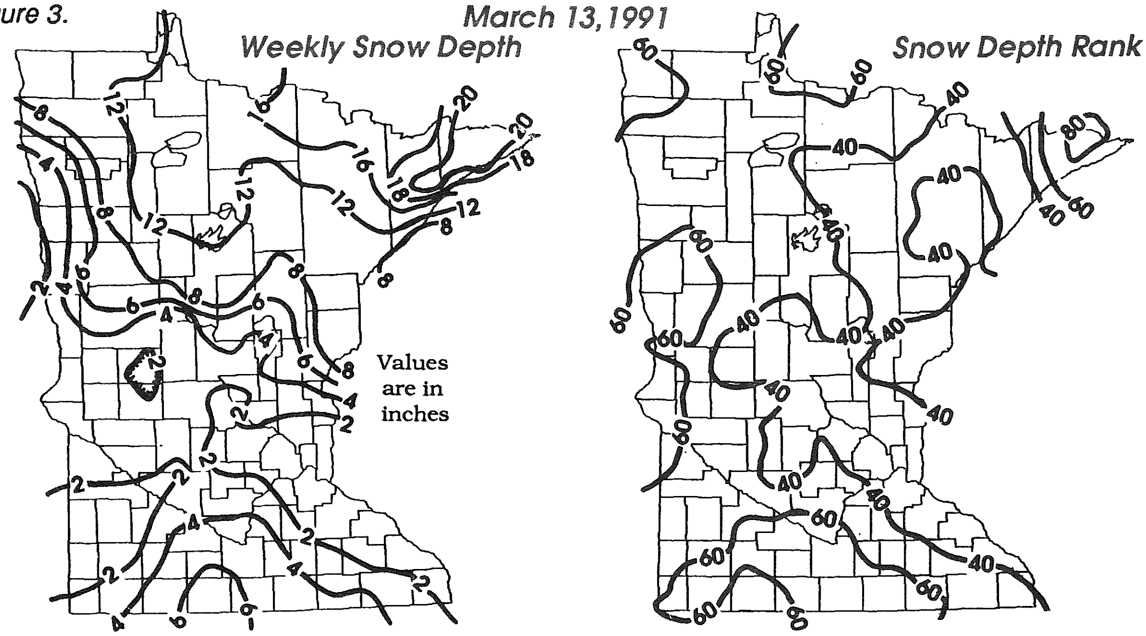


Snow depths are generally measured on grassy and otherwise protected areas. Data: National Weather Service and the DNR.

Values are a ranking relative to historical record for this date: 0=lowest, 100=highest.

* Snow Depth Rank is a measure of the rarity of the absolute snow depth. The numbers represent an estimate of the <u>number of years out of 100 in which the depth is less</u> 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.

Figure 3.



Snow depths are generally measured on grassy and otherwise protected areas. Data: National Weather Service and the DNR.

Values are a ranking relative to historical record for this date: 0=lowest, 100=highest.

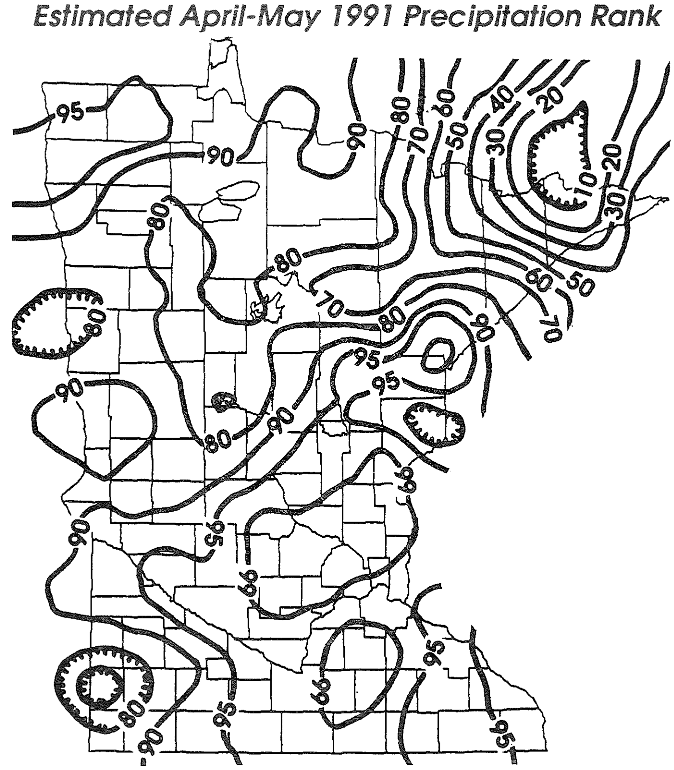
A lack of mid-March snow cover (Figure 3) and above-normal temperatures led to an insignificant spring flood season and early lake ice-out. The most significant weather event of the season was a powerful March storm, where ice and high winds resulted in tree and structure damage in east central and northeast Minnesota.

Spring 1991

Unusual weather was the norm in the spring of 1991, with 70 and 80 degree temperatures in the first week of April. Soil temperatures climbed dramatically, quickly clearing the ground of frost.

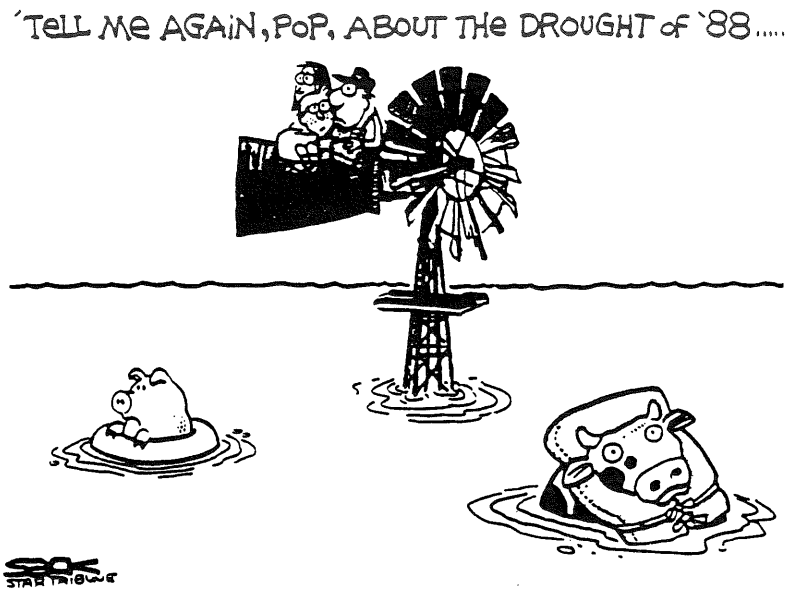
Extraordinarily wet weather followed. The April - May precipitation totals broke all-time records in some communities, ranking in the 90th percentile over large areas of the state (Figure 4).

Figure 4.
Estimated April-May 1991 Precipitation Rank



Values are a ranking relative to historical record for this date: 0=lowest, 100= highest .

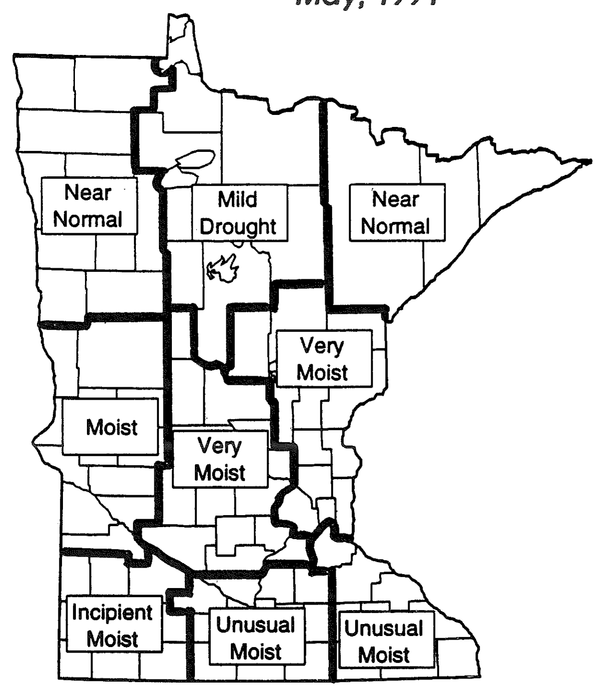
Figure 5.



Reprinted with permission of the Minneapolis Star Tribune.

The heavy rains led to problems, creating mud slides, local flooding, and significant delays in agricultural field work (Figure 5). The PDSI shows much of Minnesota approaching unusual wetness (Figure 6).

Figure 6. Palmer Drought Severity Index May, 1991



Summer 1991

The heavy rains of spring continued into the month of June. Portions of southwest and south central Minnesota were inundated with six or more inches of rain on June 3-4 (Figure 7), leading to flooded roads, basements and continued difficulties for the agricultural community.

Figure 7. ***Flash Floods in Southwest and South Central MN, June 3-4, 1991***

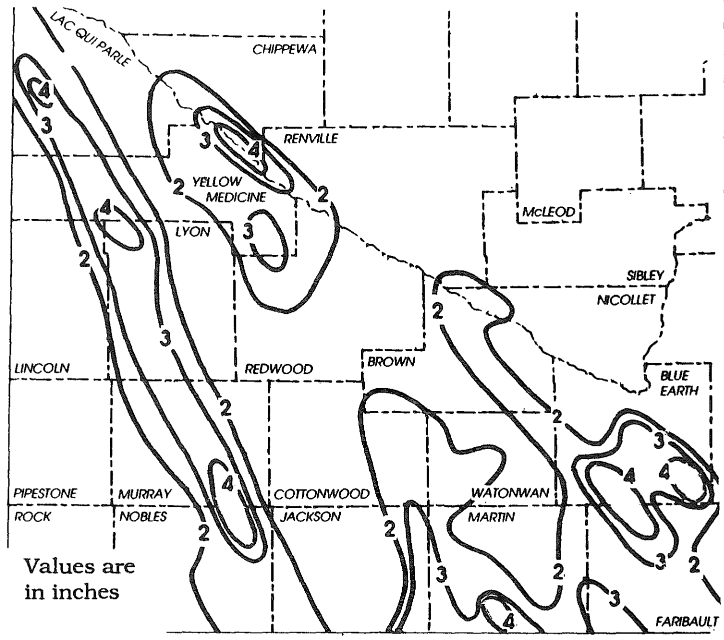
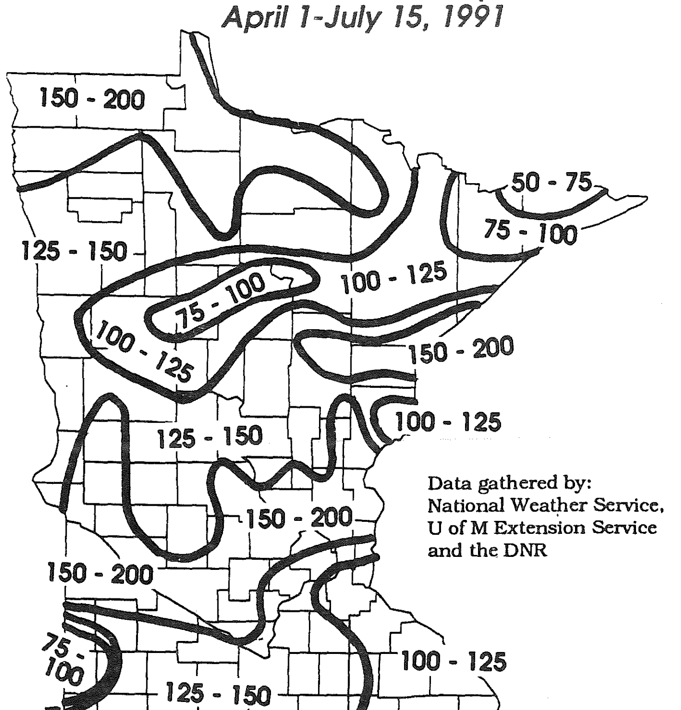


Figure 8. ***Percent of Normal Precipitation April 1-July 15, 1991***



The rains tapered off for the remainder of June and into early July. However, the net effect of the April, May, and early June downpours was that large areas of Minnesota were well above historical precipitation averages by mid-summer (Figure 8).

July 21 brought heavy rains to southeast Minnesota (Figure 9). Precipitation amounts that exceeded six inches combined with the steep terrain around Stockton in Winona County and produced destructive flooding. Elsewhere, significant rains in west central and central Minnesota led to near record July totals in some communities.

Figure 9. Flash Floods in Southeast MN July 21, 1991

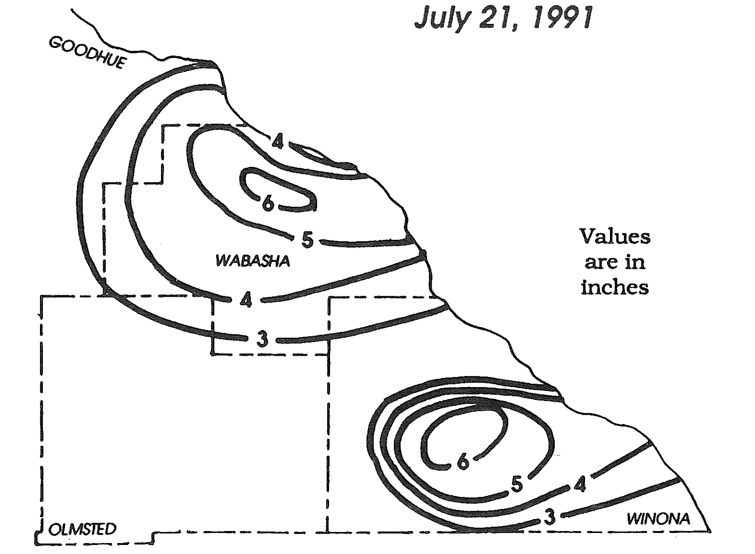
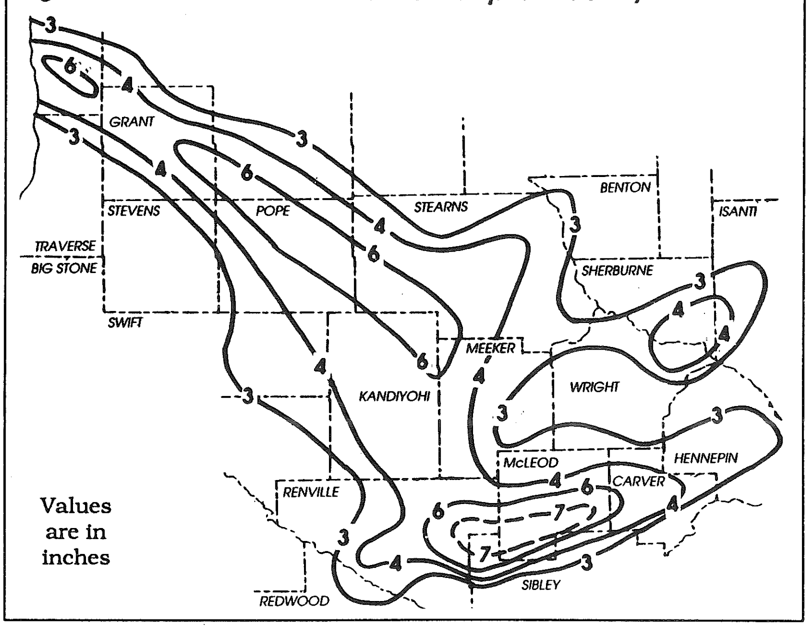


Figure 10. Flash Flood on September 7, 1991



August was the only month of the season with below normal precipitation. This respite was brief as the rains returned in early September. Heavy rains over several days resulted in river flooding in west central and central Minnesota on September 7 (Figure 10).

Autumn 1991 -Water Year Summary

Water Year 1991 is best characterized as wet. With few exceptions, precipitation totals for the 12-month period were well above historical averages. Water Year precipitation totals of 40 inches or more were reported in some areas (Figure 11). A 40 inch total is uncommon for Minnesota, occurring roughly once every 20 years in the south and once every 50 years in the northern two thirds of the state. Positive departures of 12 inches or more were common in southern Minnesota in 1991 (Figure 12). Most hydrologic systems rebounded from the drought of the late 1980's.

Figure 11. ***Water Year Precipitation October 1990-September 1991***

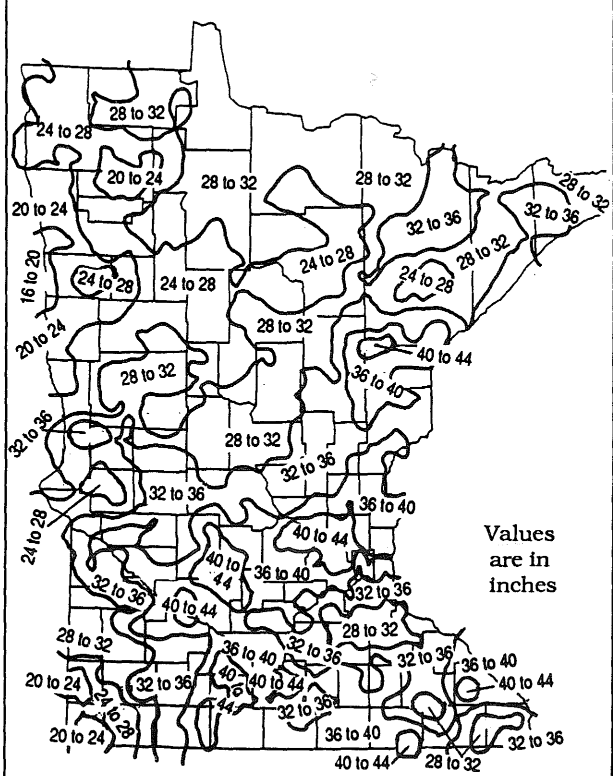
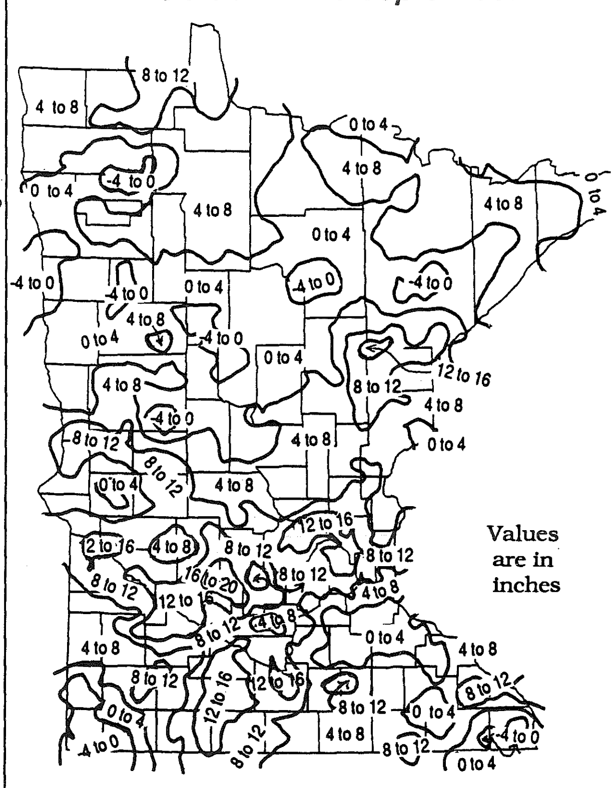


Figure 12. ***Water Year Precipitation Departure from Normal October 1990-September 1991***



Water Year Climate Summary
October 1991 - September 1992

Minnesota began the 1992 Water Year in a generally wet condition. The October, 1991 Palmer Drought Severity Index shows all of Minnesota in the "moist" category at minimum, with four climate regions classified as "very moist" (Figure 13). This condition was enhanced in the following months by the "Great Halloween Snowstorm", an extraordinary three-day event that produced some of the heaviest snowfalls ever recorded in Minnesota. The storm, which began during the late afternoon of October 31, brought freezing rain to southeast Minnesota and 12-36 inches of snowfall to the eastern half of the state (Figure 14). Power outages, travel obstacles, and the depletion of snow removal funds resulted from the record breaking storm.

Figure 13. Palmer Drought Severity Index October, 1991

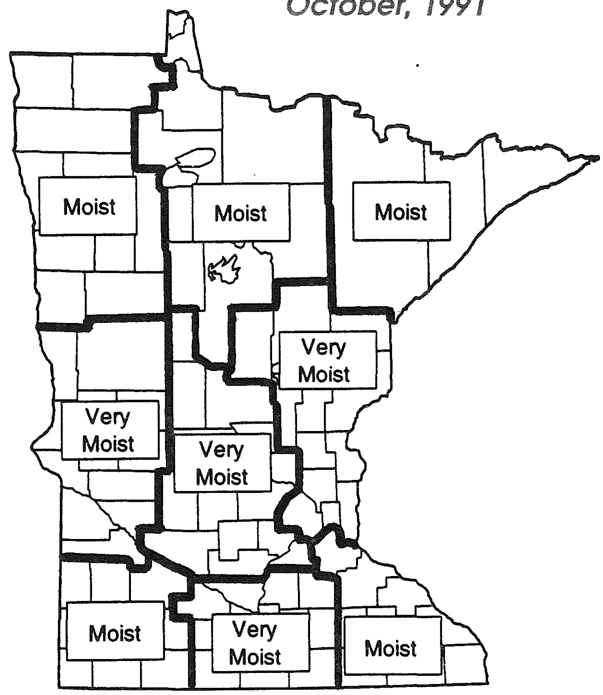
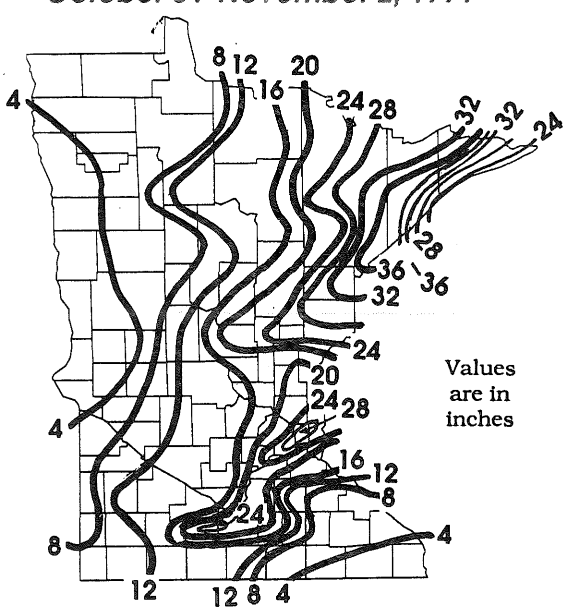


Figure 14. The Great Halloween Snowstorm Snowfall Totals October 31-November 2, 1991



Bitter sub-zero weather followed the storm, breaking several minimum temperature records. In western Minnesota, where snow cover was not as deep, soil temperatures dropped, forcing frost deep into the ground.

After a brief respite, heavy snows fell over southern and eastern Minnesota in late November with totals exceeding 12 inches in east central Minnesota. The Minneapolis/St. Paul total was 46.9 inches, making it the snowiest month ever recorded in the Twin Cities. Many communities in the eastern half of the state reported record November precipitation totals.

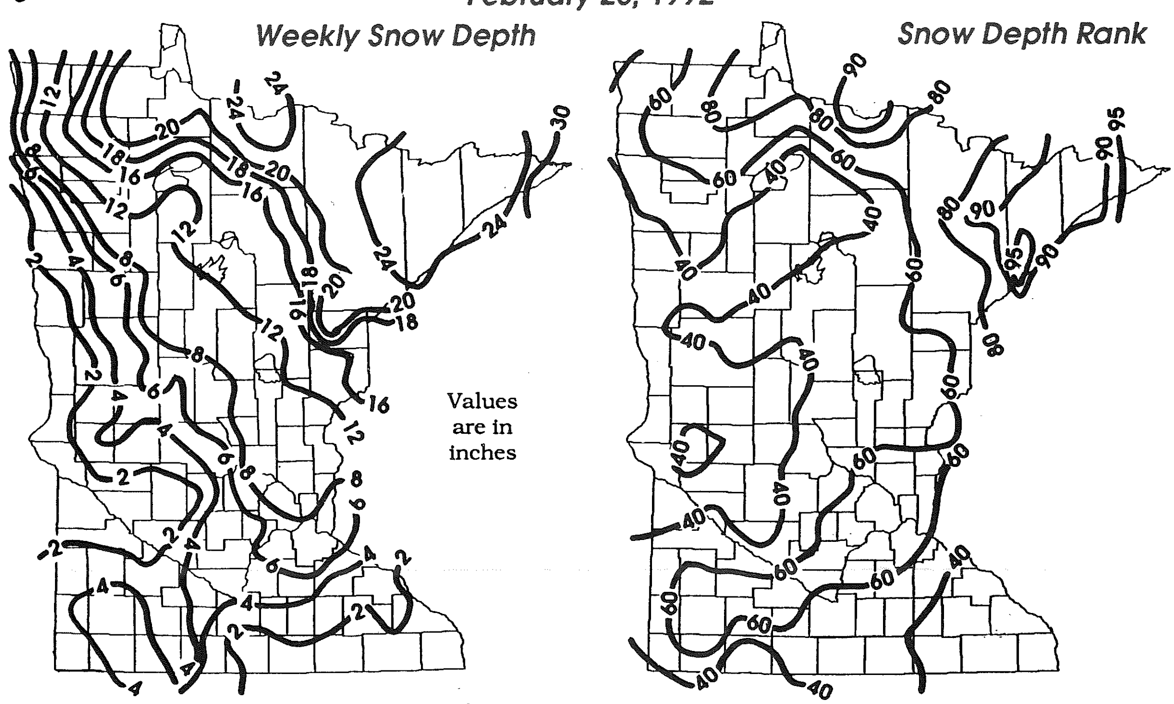
Winter 1991-1992

Extreme cold returned to Minnesota in early December, however, temperatures soon moderated. For most of the remainder of the winter, temperatures across Minnesota were mild with overcast skies and light precipitation. The combined January-February temperatures across Minnesota were among the warmest of the century.

By late February, snow depths across the state were reduced to near median levels (Figure 15). Soil frost, with its early start in November, held steady through the winter instead of continuing to penetrate. Frost depths were near zero in areas with early and heavy snow cover.

Despite early and unusually heavy snow cover in the east, thaws and light precipitation amounts combined to alleviate fears of potential spring flooding. The warm conditions continued into March and led to an early departure of the continuous snow cover and early ice-out dates for many lakes.

Figure 15. February 26, 1992



Snow depths are generally measured on grassy and otherwise protected areas.

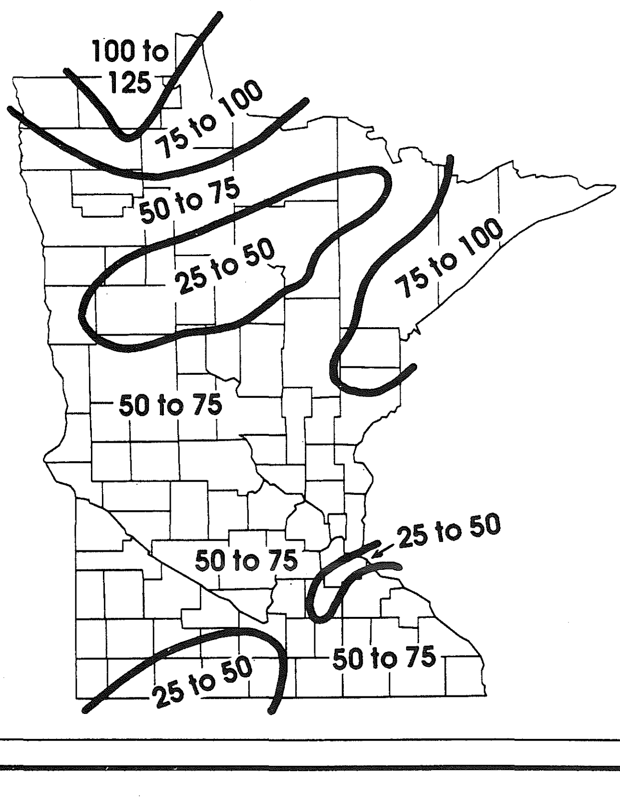
Values are a ranking relative to historical record for this date: 0=lowest, 100=highest.

Spring 1992

The dry pattern continued into April and May. Temperatures turned unseasonably cool in April, however, reducing evaporation rates and leading to wet fields in spite of the light precipitation. Early May brought warm temperatures, high solar radiation values, low relative humidity and rapid drying. The period from late April to mid-May was one of the driest spring periods on record.

This dry spell, following a warm and dry late winter, created concerns for the coming growing season. The warm, sunny weather came to a halt over the Memorial Day weekend with cloudy, cold weather and some snow. However, the overall precipitation deficit continued in spite of the cool and cloudy late May.

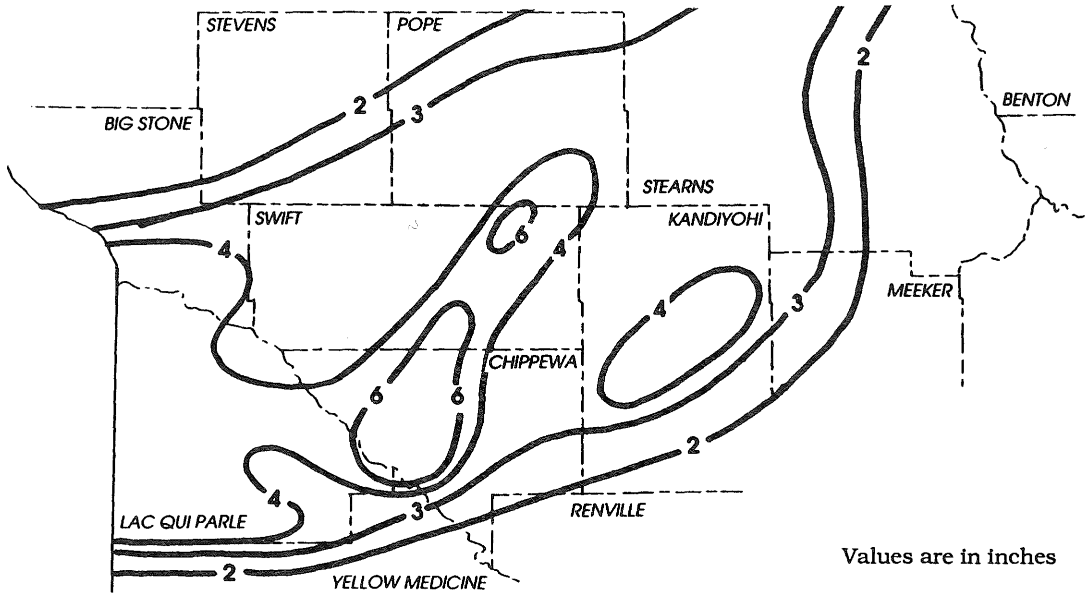
Figure 16. Percent of Normal Precipitation April 1-June 15, 1992



Summer 1992

By June 15, nearly all of Minnesota had received less than 75 percent of its normal growing season precipitation. Many locations reported less than 50 percent of normal precipitation (Figure 16). Some streams experienced low flows due to lack of precipitation.

Figure 17. Heavy Rains Drench West Central MN June 16, 1992



A rapid reversal of precipitation patterns produced two particularly wet spells in mid-late June and early July. Wet summer spells are often accompanied by severe weather. The evening of June 16 produced a sequence of tornadoes, straight line winds, and local flooding in southwest, west, and central Minnesota. The heaviest of the rains exceeded six inches in west central counties (Figure 17). By late July, however, growing season precipitation for most areas of the state ranged from slightly below to slightly above normal (Figure 18).

Figure 18. Percent of Normal Precipitation April 1-July 27, 1992

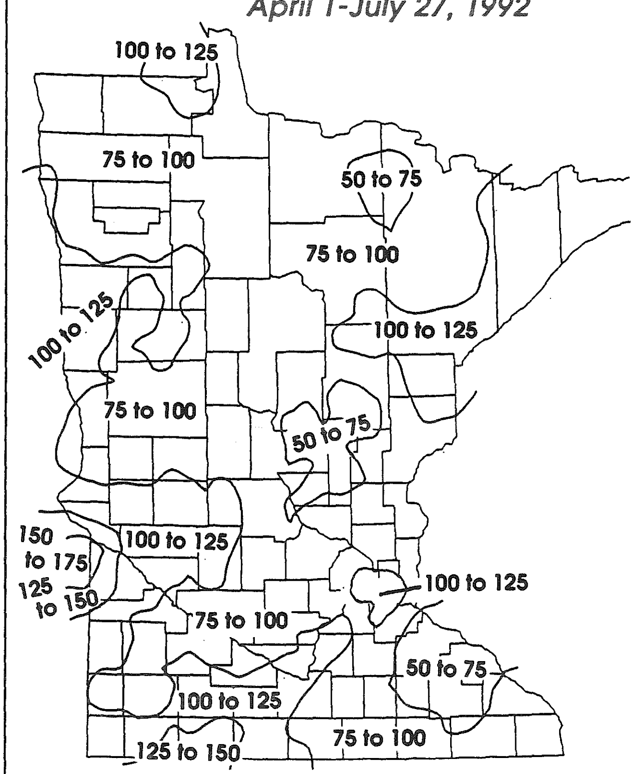
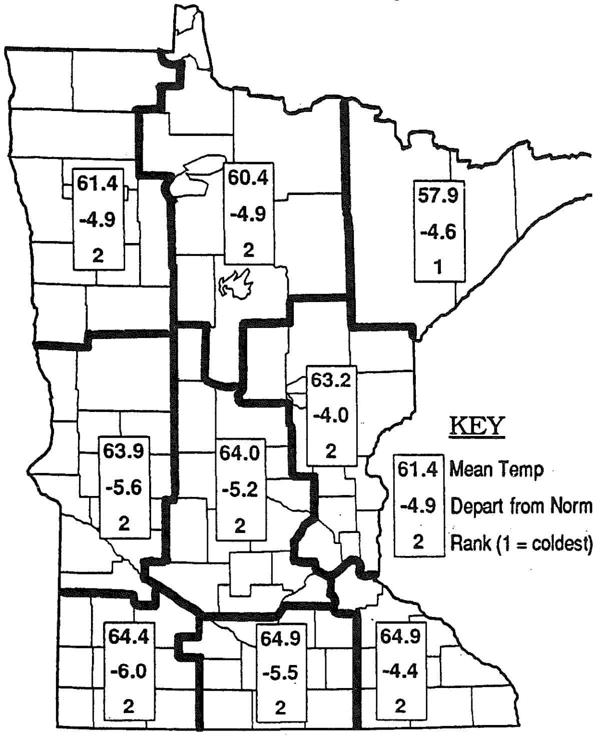


Figure 19. ***Summer Temperatures - 1992 June 1 - August 31***

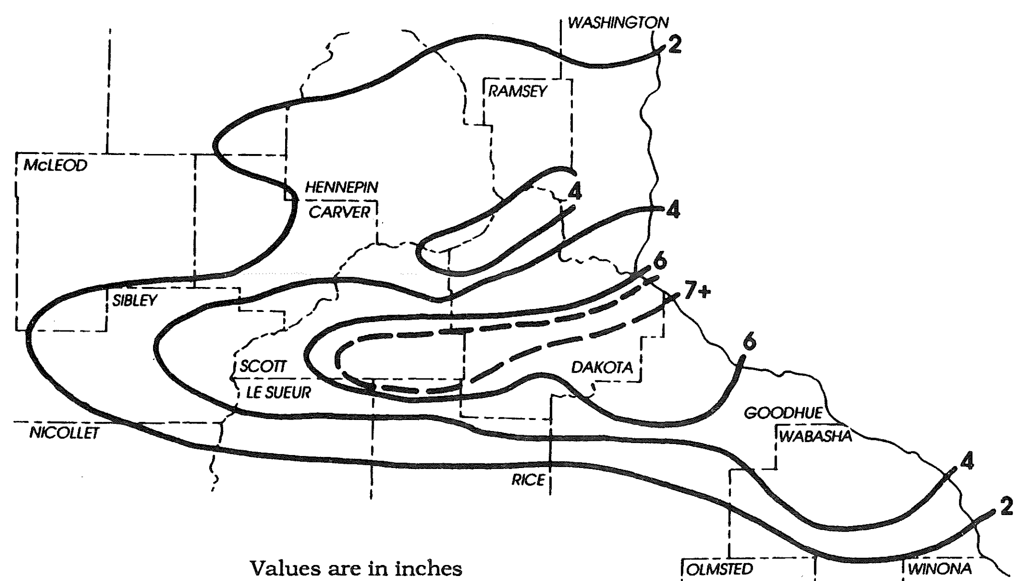


The summer of 1992 (June through August) finished as one of the coolest on record. Temperatures were four to six degrees below the historical average, ranking behind 1915 as the second coolest of the century (Figure 19).

The cool summer temperatures reduced surface evaporation because cooler air has less capacity to hold water vapor than warmer air. Estimates indicate that 1992 summertime evaporation was approximately 15 to 20 percent less than average, and 40 percent less than the summer of 1988. Lakes, wetlands and other land surfaces released two to four inches less water to the atmosphere than an average summer, and as much as eight inches less than the summer of 1988.

The most notable precipitation event of the late summer occurred September 15-16 when seven or more inches of rain fell in a narrow band stretching from Scott County, through Dakota County, and on into Wisconsin (Figure 20). The heavy rains led to road closures, mud slides, and flooding in some small streams and rivers.

Figure 20. ***Flash Flooding in East Central MN September 15-16, 1992***



Autumn 1992 - Water Year Summary

The 1992 Water Year precipitation map indicates a typical pattern of decreasing precipitation from southeast to northwest (Figure 21). Wet spots included extreme southeast and northeast Minnesota and much of Scott County. Drier areas were found in west central and central parts of the state. Reduced summer evaporation and cool temperatures may have created the impression of above normal precipitation. While much of Minnesota received near normal Water Year precipitation, some sections of central Minnesota were well below normal (Figure 22). The precipitation deficit in central Minnesota was counterbalanced by reduced evaporation and no serious hydrologic imbalance occurred as a result.

Figure 21. Water Year Precipitation October 1991-September 1992

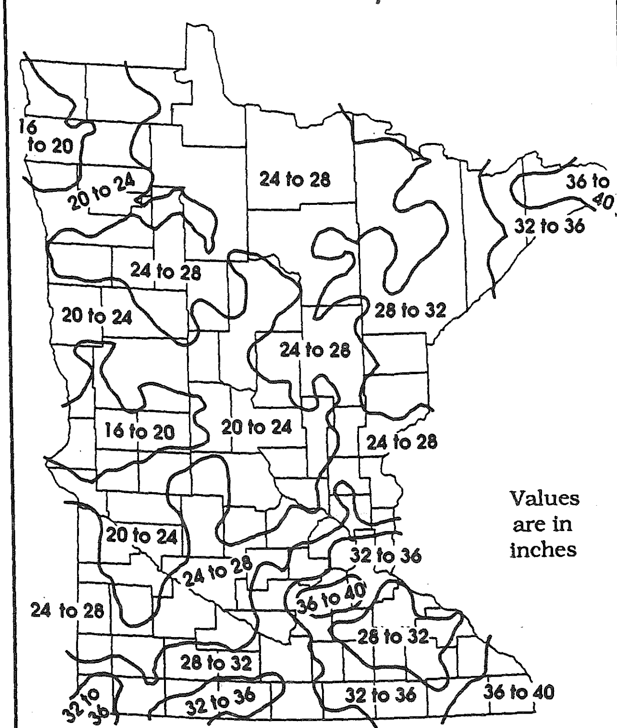
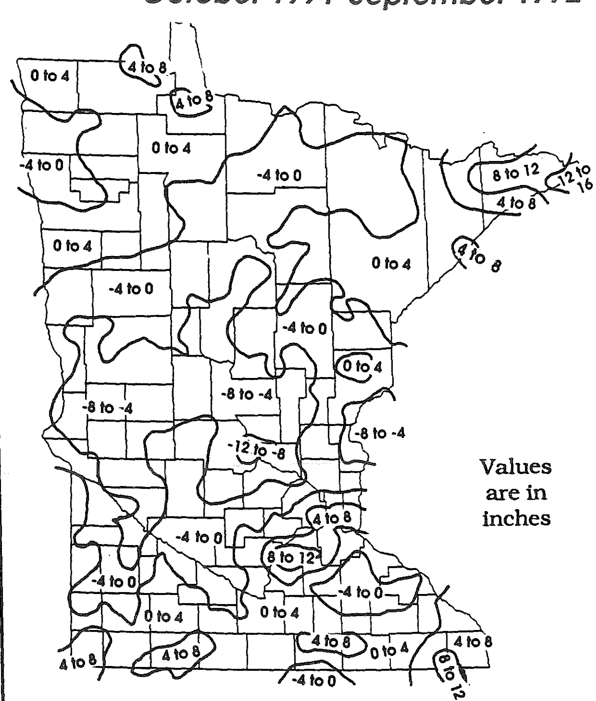
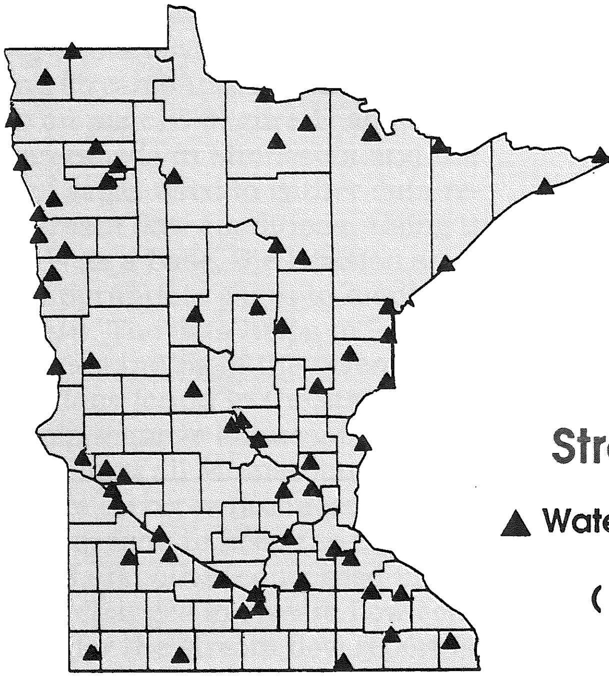


Figure 22. Water Year Precipitation Departure from Normal October 1991-September 1992



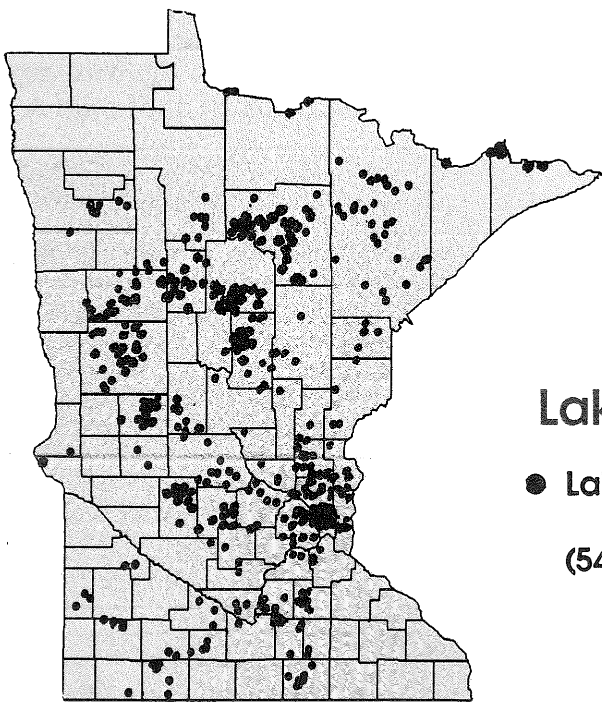
SURFACE WATER

Chapter 2



Stream Flow

▲ Watershed Gaging Station (57 Stations)



Lake Levels

● Lake Gaging Station (545 Stations)

Surface Water - Stream Flow

Introduction

The Stream Flow Unit is responsible for gathering and analyzing data related to the rivers and streams throughout Minnesota. The map on page16 (Figure 1) shows 81 major watersheds in Minnesota and the location of gages used to gather data related to stream flow conditions. Using these watersheds as a base, the Division selects the most appropriate gages to monitor stream flows. The data helps to foster a better understanding of the diverse stream flow conditions found in the state. It is also used to help manage Minnesota's streams for the benefit of all Minnesotans.

A weekly report is produced during the open water season to keep the Division of Waters staff and other concerned interests apprised of changes in stream flow conditions. Data for the stream flow report is from the U.S. Geological Survey's River Gaging Program*, the National Weather Service Flood Forecasting Network and DNR gages through a series of volunteer readers. A map that reflects flow conditions in the 81 major watersheds is included with the weekly stream flow report. The map classifies each major watershed as having either critical, low, normal or high flow conditions, or no report. A low flow report is also prepared when conditions within certain rivers and streams approach critical flow levels (less than the annual 90% exceedence or Q90, see sidebar). When a specific river reaches critical flow, it is closely monitored as long as it remains in that range.

A wide variety of hydrologic flow conditions is found within Minnesota's rivers and streams, so both monthly and annual exceedence values are used. For example, flows below the annual Q90 are most common during the winter months when small streams and tributaries are frozen. However, when flows drop below the Q90 during other periods of the year, the river is considered to be in a critical flow condition. At that time, the Division of Waters may restrict the appropriation of water from the river to maintain adequate water for instream flow needs such as fish and wildlife, and to conserve water for higher priority users such as municipal supplies or for power generation.

An additional statistic calculated for the various rivers but not normally included on the stream flow map is called the flood flow. The purpose of the flood flow is to be an indicator of when a river is reaching a condition that needs to be monitored for possible damage to property. (The stream flow report is typically printed weekly and is not intended to forecast a possible flood event). Flood stages identified by the National Weather Service or another agency are generally used to define the flood flows. In watersheds where a flood stage has not been identified, the highest monthly Q10 is used as an interim estimate of flood flow.

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.)

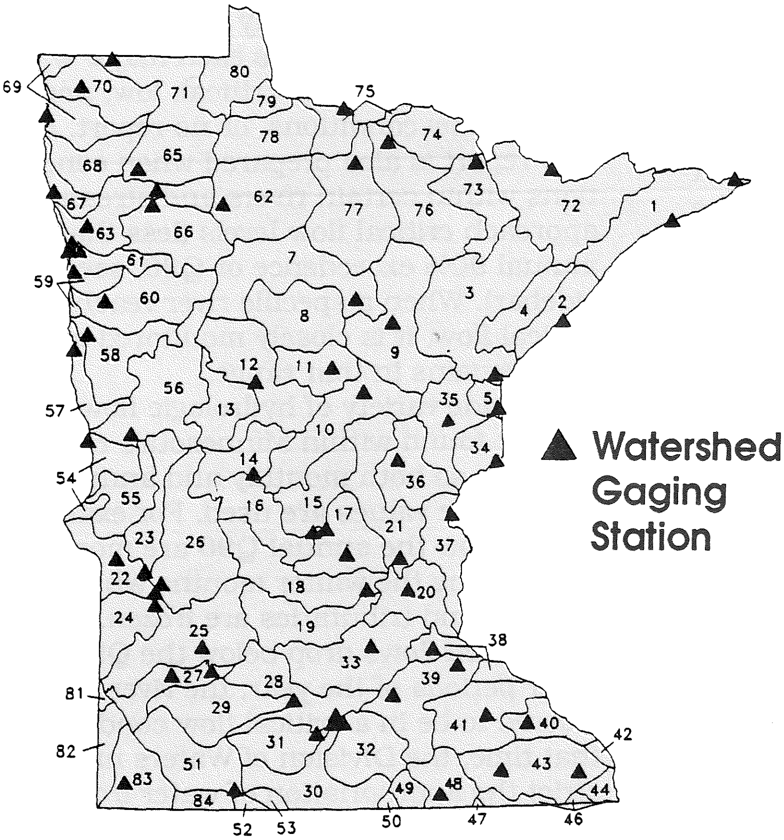
Stream flow reports are based upon the following exceedence values during the open water season.

< annual Q90 - critical
< monthly Q75 - low
monthly Q75 to Q25 - normal
> monthly Q25 - high

* The 1992 data from the USGS gaging program is still provisional and subject to revision at the time of this writing.

Figure 1.

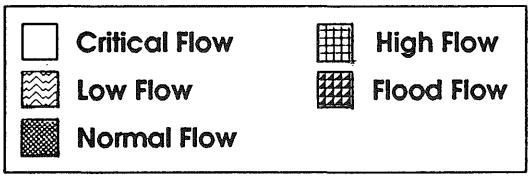
81 Major Watersheds



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

1991 Stream Flow Maps

In the spring of 1991, normal flow conditions were found in most of Minnesota (Figure 2). The exceptions were portions of the southern third of the state which experienced high flows (especially the Minnesota River watersheds) and the northwest which experienced low to critically low flows. The conditions in the northwest were a continuation of drought in that region which began in 1988 (this is also evident in Figure 13).



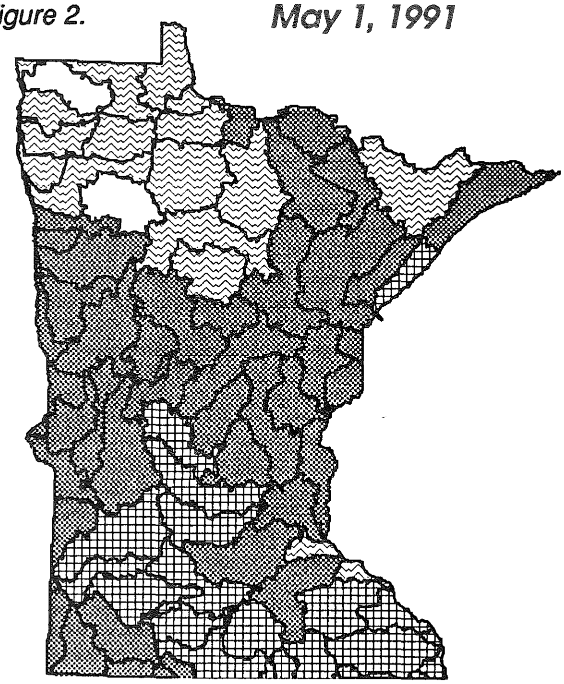


Figure 2.

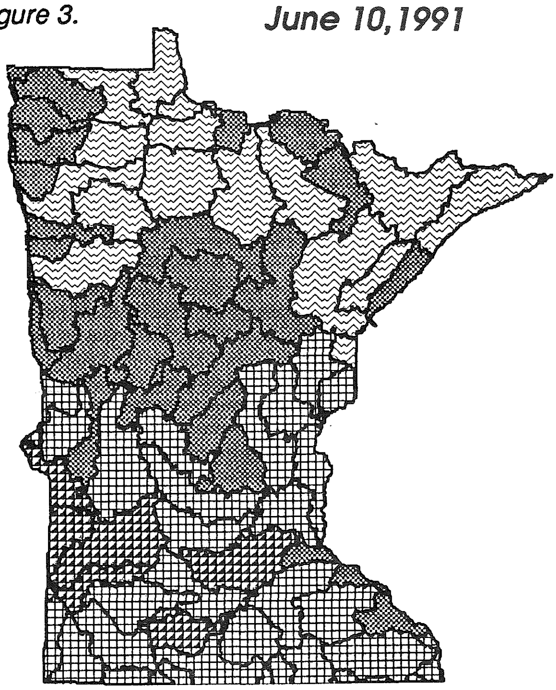


Figure 3.

By June, flows in the northwest had improved slightly, though most rivers remained either in the low flow range or the low side of normal (Figure 3). However, the size of the low flow region expanded from the northwest portion of the state to include much of northeast Minnesota.

In the southern half of the state, flows improved markedly into the high flow range. In mid-June, flood flows could be found in the Minnesota River headwaters, and in the Lac Qui Parle, Redwood, Yellow Bank, Yellow Medicine, Watonwan and Crow River watersheds.

By mid-summer, low flows continued throughout the Mississippi River headwaters while critical flows began appearing downstream of the headwaters (Figure 4). High flows over most of the southern half of the state continued throughout the remainder of the summer.

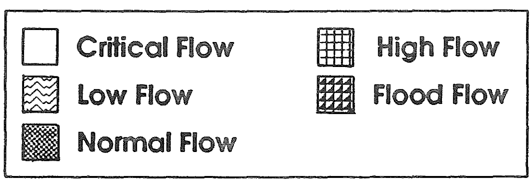


Figure 4. *July 15, 1991*

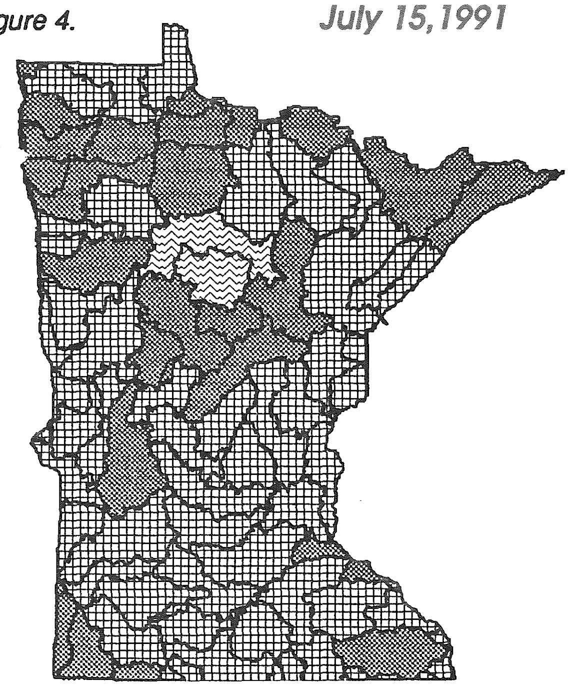
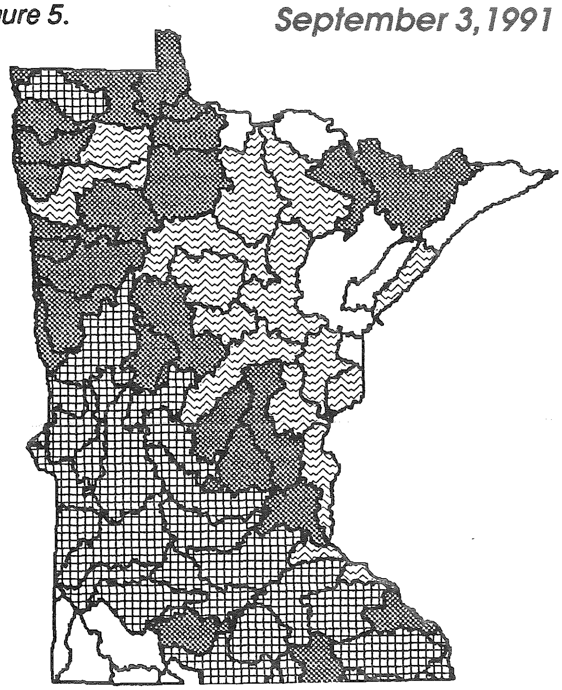


Figure 5. *September 3, 1991*



The Missouri River watersheds in the southwest fell into the low and then critical flow range in July and August (Figure 5). In addition, the Lake Superior and Rainy River watersheds experienced low and critical flows. A sudden wet spell in mid-September, however, improved flows over the northern half of the state.

1992 Stream Flow Maps

Many streams that commonly freeze up remained open during the winter of 1991-1992. Coupled with a gradual spring melt, many streams did not experience a large spring runoff. Precipitation also remained light during this period in the northern two-thirds of the state while it was near normal in the southern third. As a result, much of the flow in the north was either on the low side of normal or in a low flow condition. The Mississippi River Headwaters Region remained in a low flow condition and gradually fell into a critical flow condition by late May and early June (Figure 6). In the southern third of Minnesota, stream flows were on the high side of normal throughout the spring. The exception was in the southeast corner of the state where flows were often in the high flow range.

Figure 6. May 18, 1992

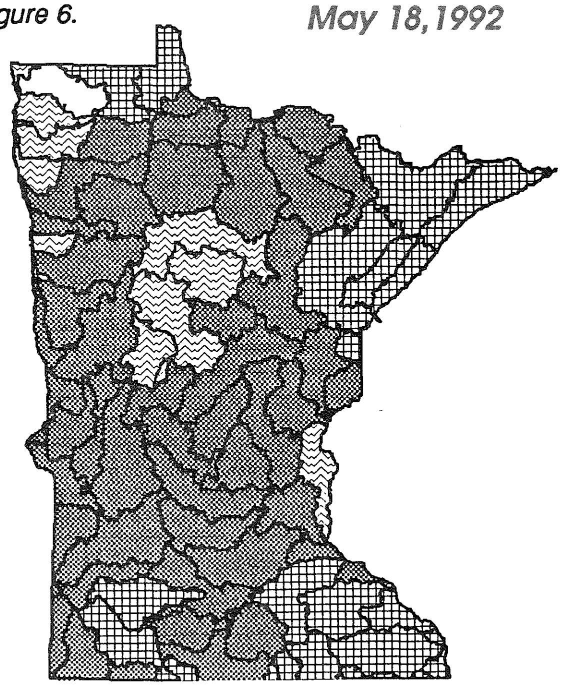
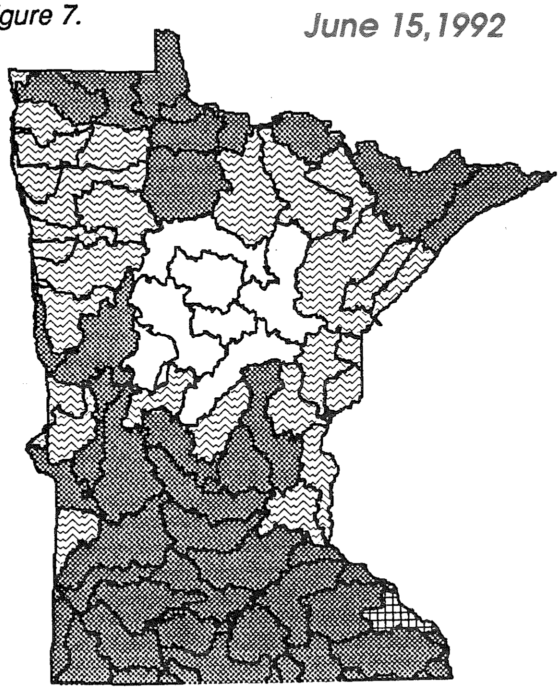
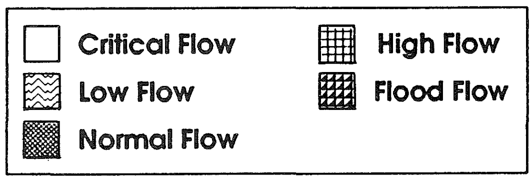


Figure 7. June 15, 1992





By the end of June, stream flow in most of the northern two-thirds of the state had fallen rapidly (Figure 7). As the Division of Waters was preparing to implement its drought plan, however, precipitation patterns suddenly changed.

From mid-June through early July, heavy rains fell throughout much of the southern half of the state, with notable concentrations in the Minnesota River watersheds (Figure 8). These watersheds remained in the high flow range for the remainder of the year.

The Missouri River watersheds, the Minnesota River Headwaters, the Crow River watershed and the Vermillion River watershed all experienced flood flows during the month of July. Flows in the northern half of the state also improved with the change in precipitation patterns. Flows fluctuated between normal and high for most of July.

Figure 8.

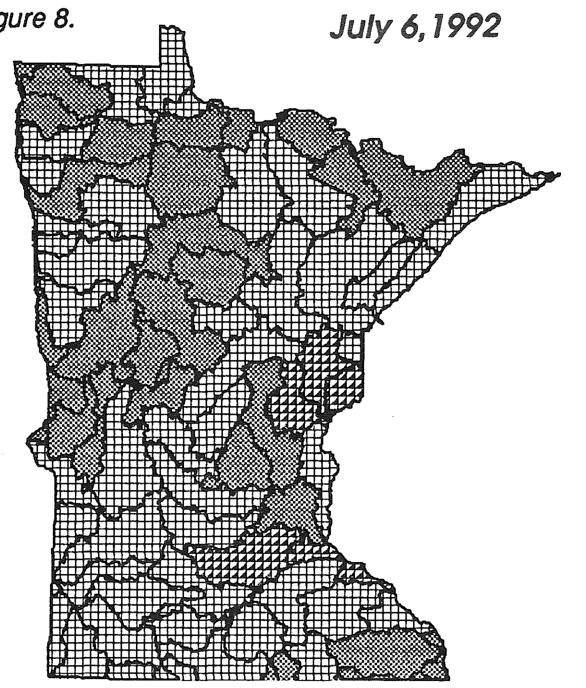
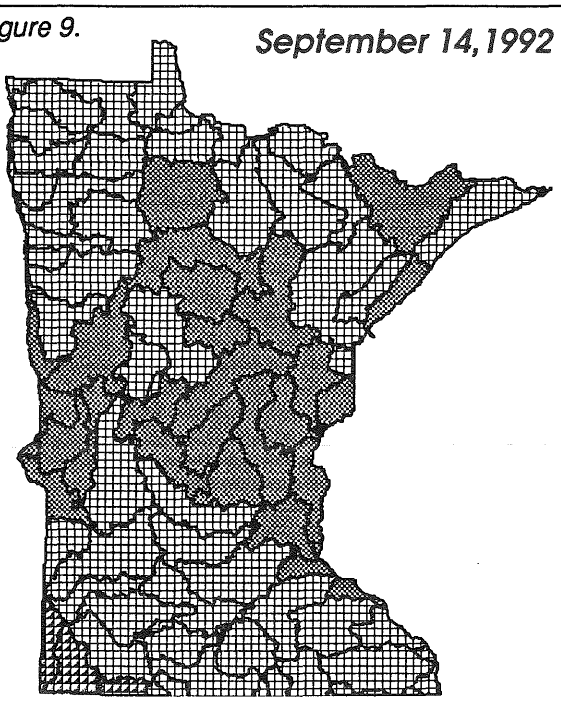
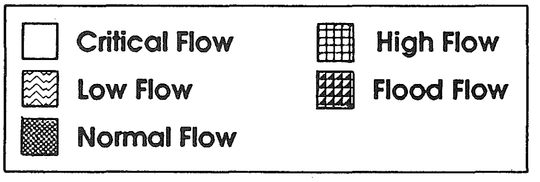


Figure 9.





A brief dry period reappeared in early August, followed by another period of excessive precipitation. By September, flood flows, high flows or flows on the high side of normal existed throughout the state (Figure 9).

Figure 10. **1991 and 1992 Hydrologic Conditions for Five Minnesota Rivers (See Figure 11 for locations)**

RIVER NAME	Pomme de Terre	Red River of the North	Mississippi	St. Louis	South Fork Zumbro
PERIOD OF RECORD	1931-92	1904-92	1931-92	1908-92	1981-92
MEAN ANNUAL (MA) DISCHARGE	111	2565	7904	2338	206
1991 MA DISCHARGE	83	1164	8572	2749	201
1991 % OF NORMAL	75%	45%	108%	118%	98%
1992 MA DISCHARGE*	86	1628	8041	3129	260
1992 % OF NORMAL	77%	63%	102%	134%	126%
1983-92 MA DISCHARGE	136	2871	9583	2712	214
1983-92 % OF NORMAL	123%	112%	121%	116%	104%

* The 1992 data from the USGS gaging program is still provisional and subject to revision at the time of this writing.

Figure 10 is a comparison of certain rivers in Minnesota. These particular rivers were chosen because they represent flow characteristics commonly found in the region. With the exception of the South Fork of the Zumbro River, the rivers chosen have long periods of records so that some basic flow statistics could be calculated. For this report, the mean annual discharge for the period of record is considered "normal flow".

Hydrographs

A hydrograph is a graph showing the volume of water discharged for a specific time period. To gain further insight into flow conditions for 1991 and 1992, 10 hydrographs are attached. These 10 hydrographs show flow characteristics for the same rivers described in Figures 10 and 11. The first hydrograph shows the mean daily discharge for the 1991 and 1992 water years, as well as the monthly Q25 and Q75 flow statistics. The second hydrograph shows the discharge over the last 10 years, the monthly Q50 and, in some cases, the annual Q90. Also included on this hydrograph is a line representing the "mean annual discharge".

Figure 11. ***River Hydrograph Locations***

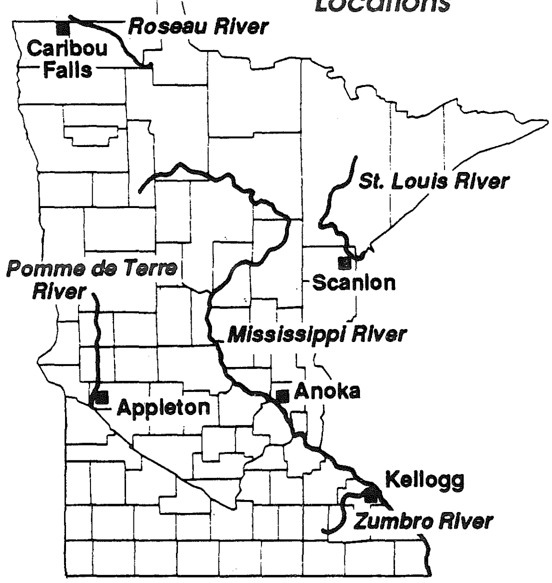


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Figure 8. July 6, 1992

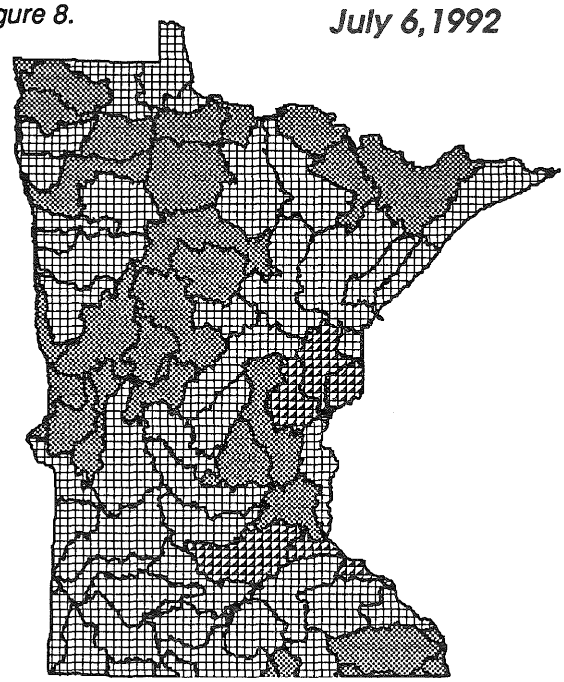
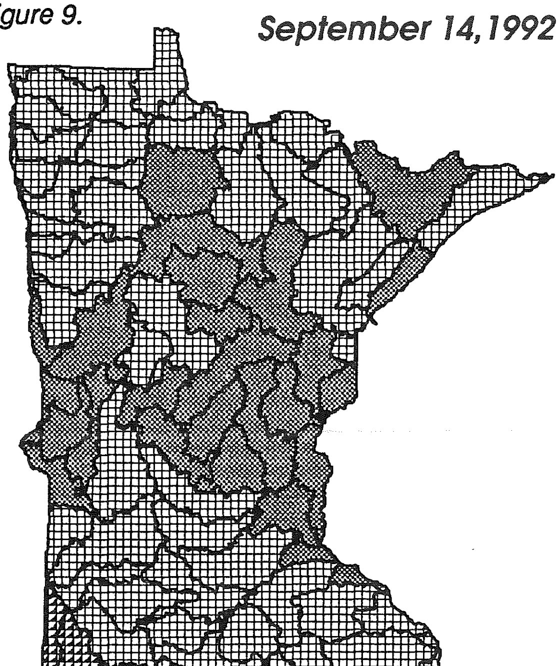
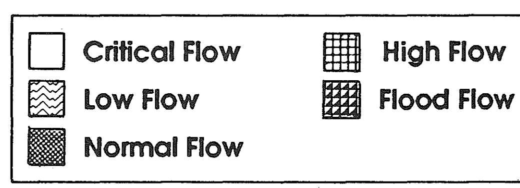


Figure 9. September 14, 1992





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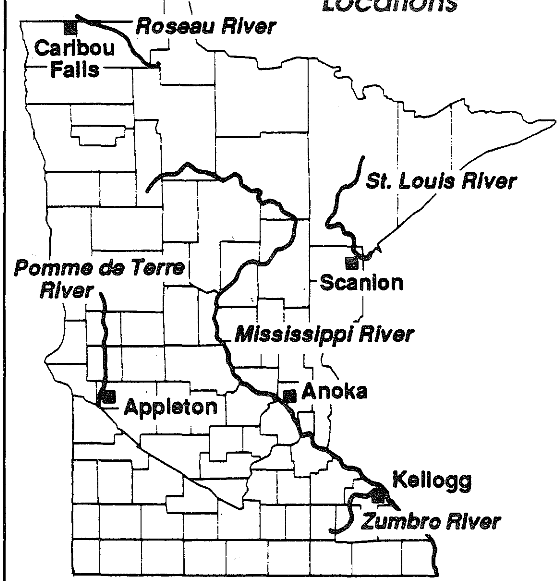
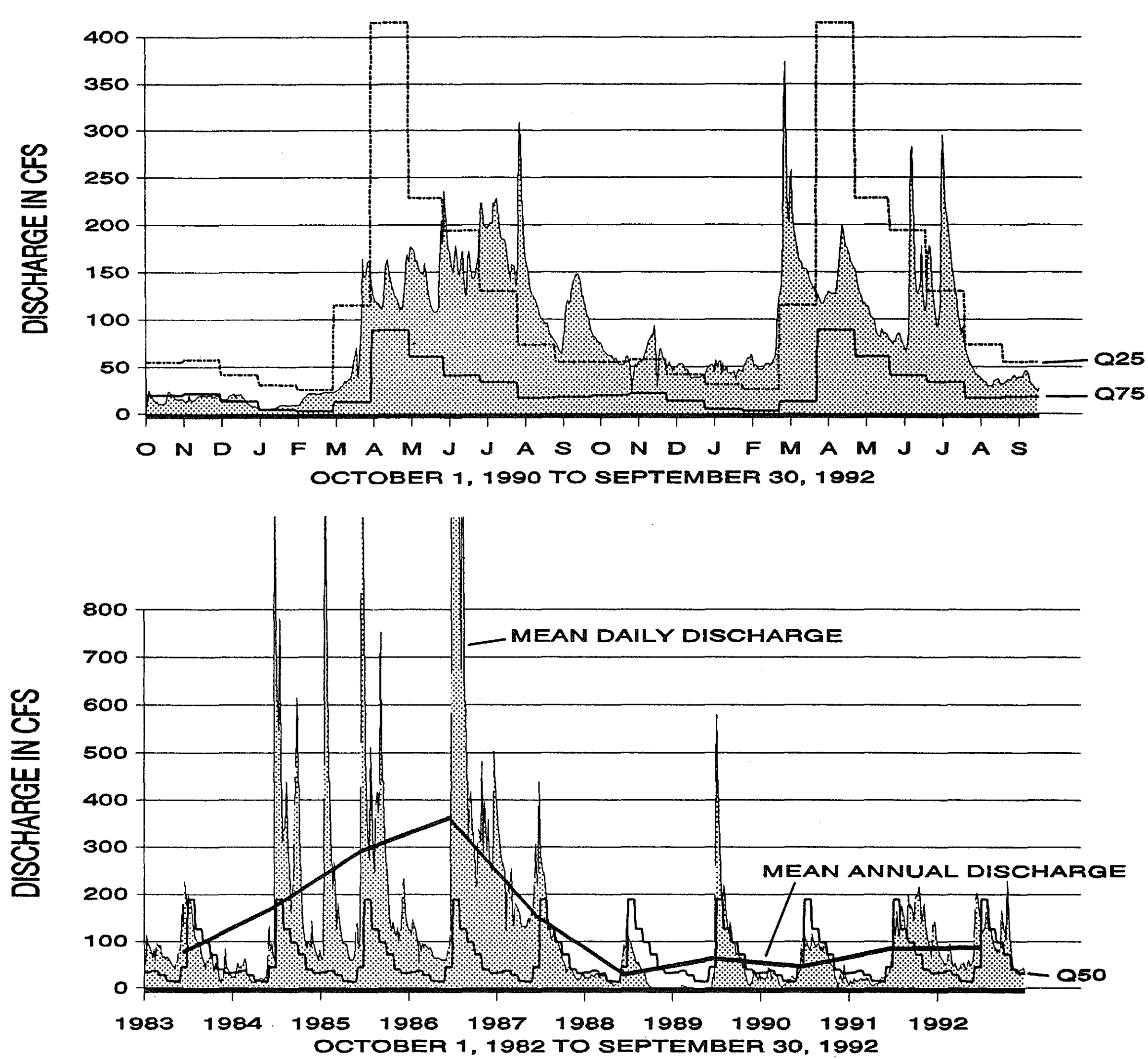


Pomme de Terre River at Appleton

Figure 12.



Flows in the Pomme de Terre River were on the low side of normal for Water Years 1991 and 1992 (Figure 12). The two-year period began with four months of low flows followed by nine months in the high range. Flows averaged in the normal range for the balance of the period.

Flow Comparison

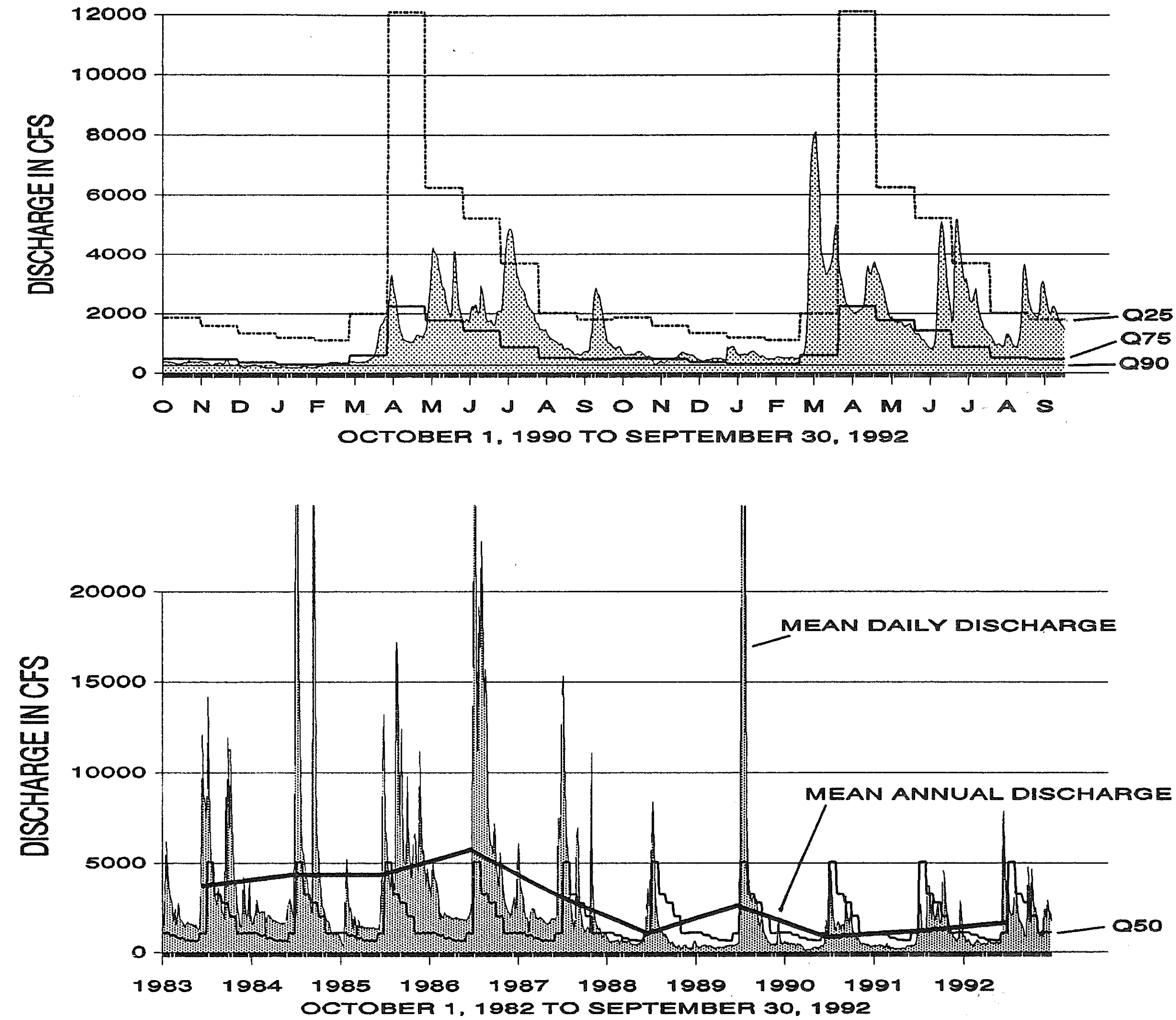
"Normal flow" at the Appleton gage is 111 cfs (mean annual discharge for the period 1931-1992).

Year(s)	Mean Annual Discharge (cfs)	% of Normal
1931-1992	111	100
1983-1992	136	123
1984-1987	211	190
1988-1992	61	55
1986	363*	327
1977	21**	19

*Highest Recorded **Lowest Recorded

Red River of the North at Grand Forks, ND

Figure 13.



Flows in the Red River of the North were often around the monthly Q75 for Water Years 1991 and 1992 (Figure 13). An early warm-up in 1992 moved spring flows up several weeks and into the March Q25 range. (Had the same event occurred during April, the flows would have been considered normal.) This was the first time flows exceeded Q25 for an entire month since April, 1989. Thereafter, flows receded to near the monthly Q75 until July when they improved to the Q50 range. Water Year 1992 ended with flows in the Q25 range.

Year(s)	Mean Annual Discharge (cfs)	% of Normal
1904-1992	2565	100
1983-1992	2871	112
1983-1987	4272	166
1988-1992	1470	57
1950	7580*	295
1934	244**	10

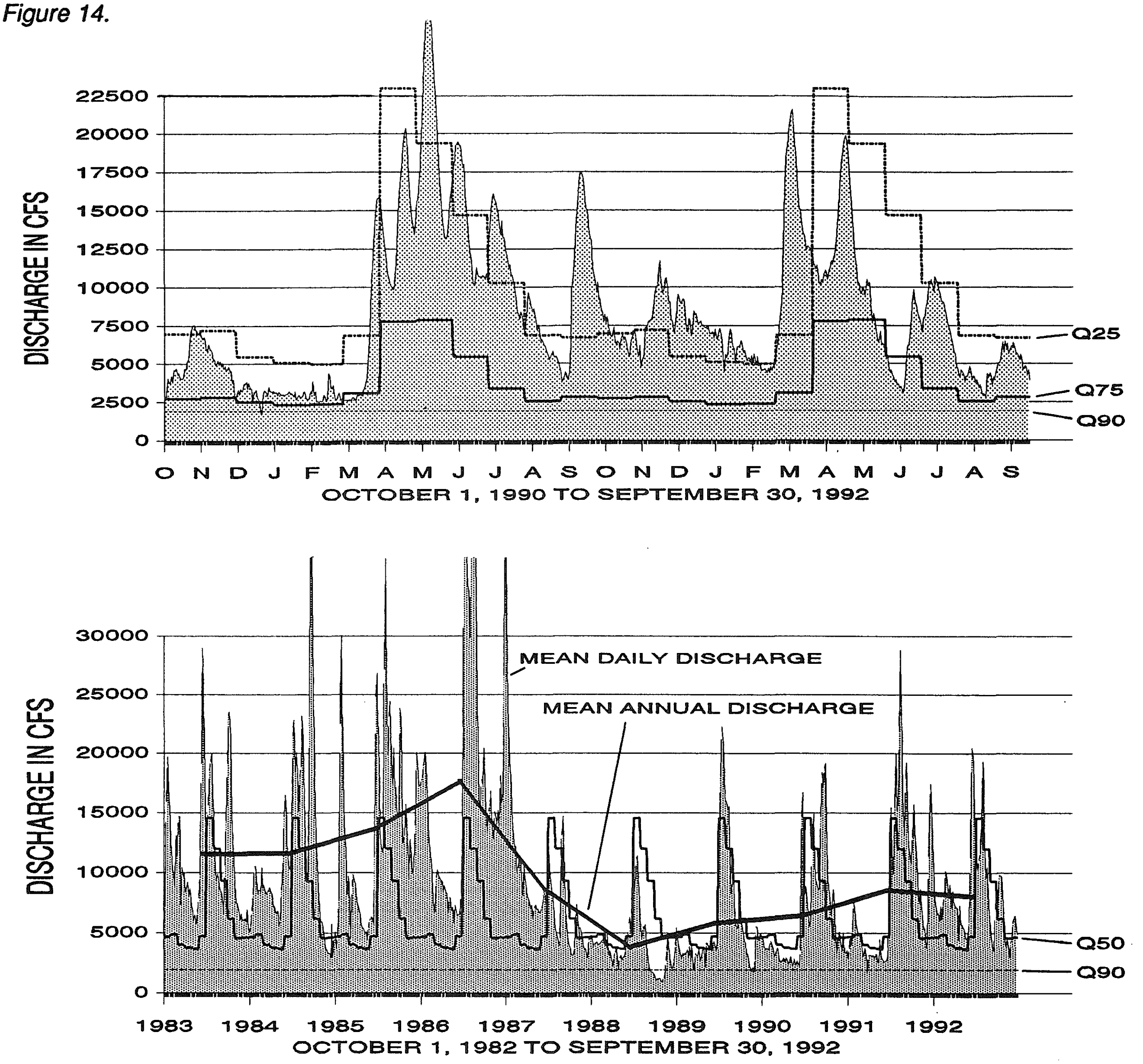
*Highest Recorded **Lowest Recorded

Flow Comparison

"Normal flow" at the Grand Forks, ND gage is 2565 cfs (mean annual discharge for the period 1904-1992).

Mississippi River at Anoka

Figure 14.



Flows in the Mississippi River at Anoka for Water Years 1991 and 1992 were approximately normal (Figure 14). The first 6 months of the 1991 water year had flows near the bottom of the normal range while the last 6 months had flows on the high side of the normal range. The total volume of water discharged in 1991 was 108% of normal. For 1992, flows were in the high range for the first six months of the year and were on the low side of normal for the remainder of the year. The total volume of water discharged in 1992 was 102% of normal.

Year(s)	Mean Annual Discharge (cfs)	% of Normal
1931-1992	7904	100
1983-1992	9583	121
1983-1987	12613	160
1988-1992	6554	83
1986*	17,750	225
1934 **	1603	20

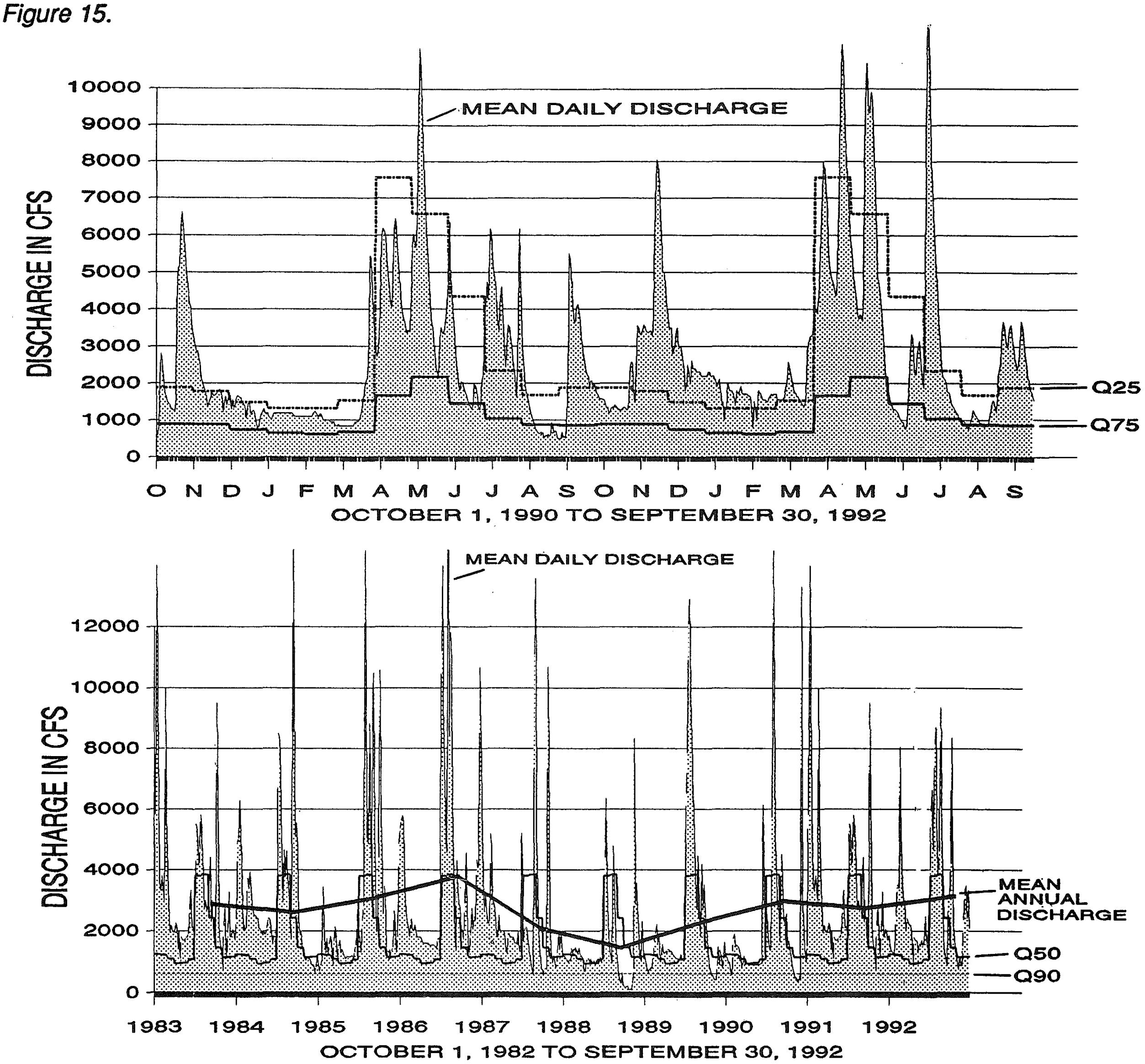
*Highest Recorded **Lowest Recorded

Flow Comparison

"Normal flow" at the Anoka gage is 7904 cfs (mean annual discharge for the period 1931-1992).

St. Louis River at Scanlon

Figure 15.



Flows in the St. Louis River were either high or on the high side of normal during Water Year 1991 (Figure 15). The exception was in late August when flows receded to the low range. Mean annual discharge for the year was 118% of normal. In 1992, flows were in the high range for six months followed by more variable flows which also averaged higher than normal. Mean average discharge for the year was 134% of normal.

Flow Comparison

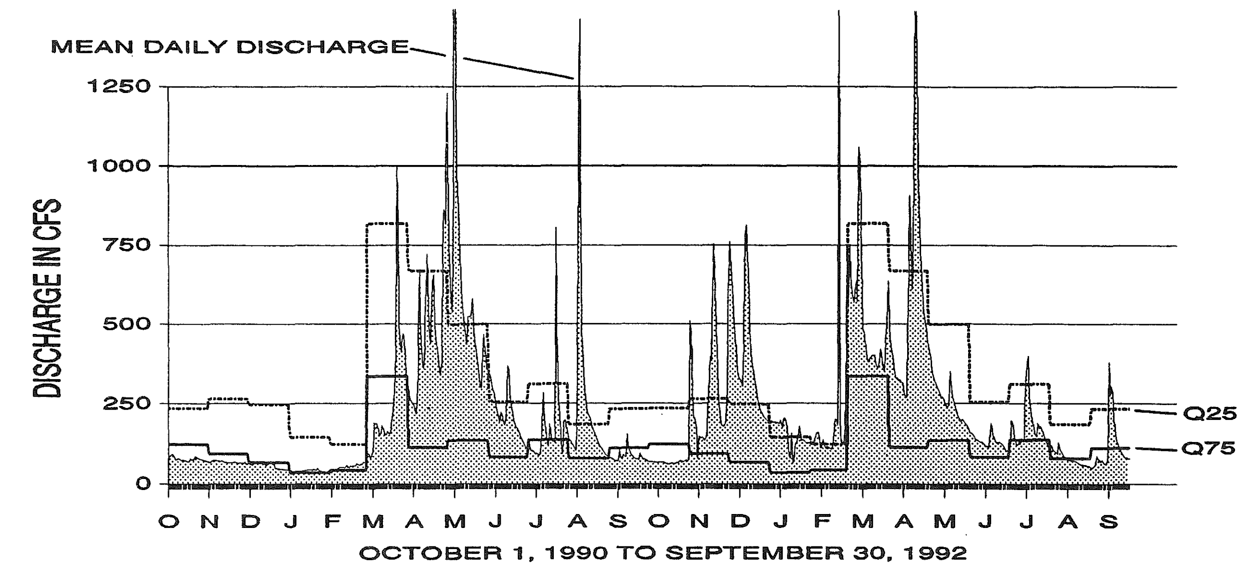
"Normal flow" at the Scanlon gage is 2338 cfs (mean annual discharge for the period 1908-1992).

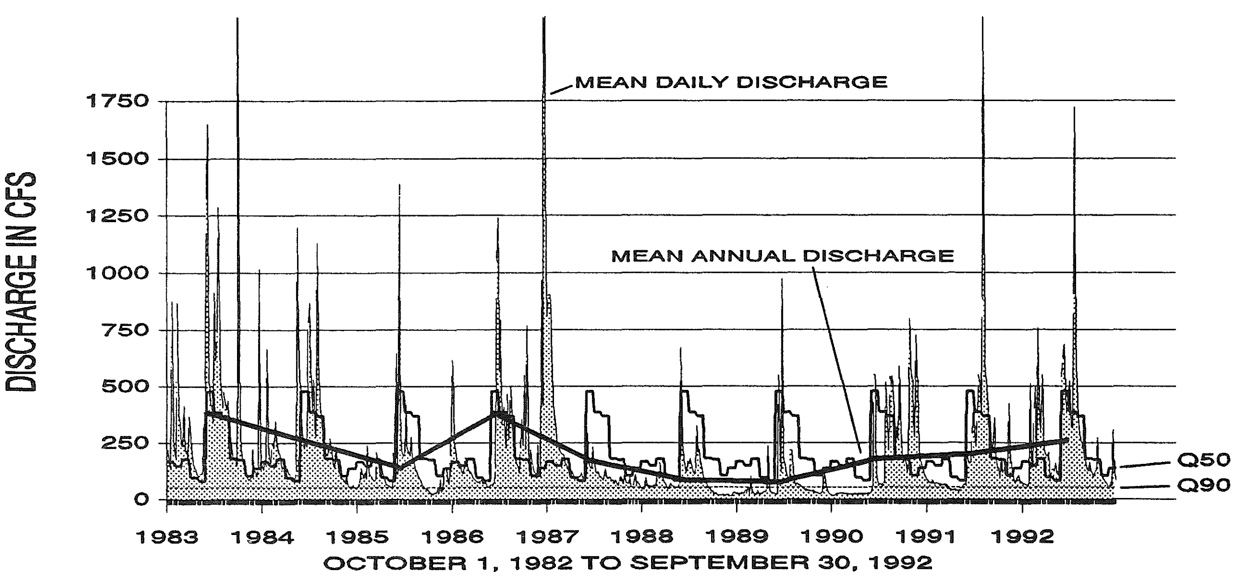
Year(s)	Mean Annual Discharge (cfs)	% of Normal
1908-1992	2338	100
1983-1992	2712	116
1983-1987	2898	124
1988-1992	2526	108
1972*	4276	183
1924**	945	40

*Highest Recorded **Lowest Recorded

South Fork Zumbro River at Rochester

Figure 16.





Flows in the South Fork of the Zumbro River were in the low range during the first half of Water Year 1991 (Figure 16), but improved to the high range by May. Thereafter flows receded to near normal and then into the low range, ending the year at 98% of mean annual discharge. Flows improved to the high range for the first half of 1992, receded to the low side of normal, and finished the year at 126% of normal.

Flow Comparison

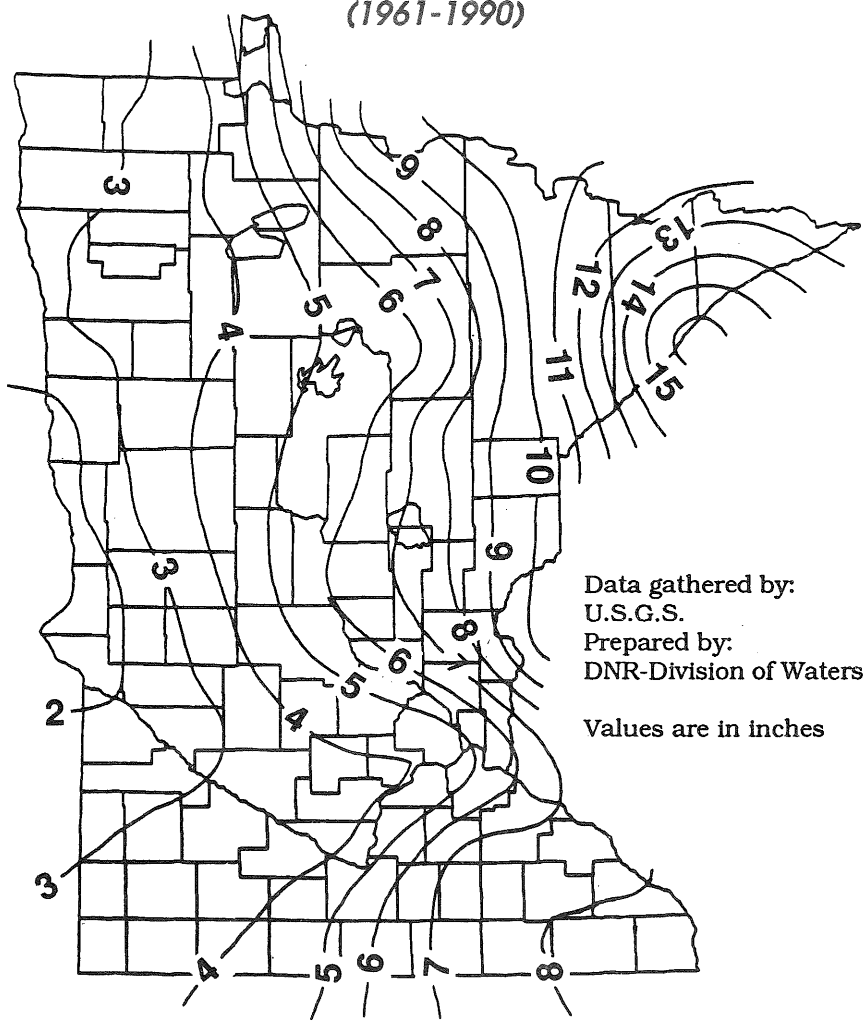
Year(s)	Mean Annual Discharge (cfs)	% of Normal
1981-1992	206	100
1983-1992	214	104
1983-1987	267	130
1988-1992	161	78
1983*	360	175
1989**	87	42

*Highest Recorded **Lowest Recorded

30-Year Average Annual Runoff

Every ten years an average annual runoff map is prepared for the prior 30 years. Figure 17 is the latest map and covers the period 1961 to 1990. It is generally very similar to the previous map with changes often due to the different methods of contouring and different stations used in calculating the data points. The 1961-1990 map reflects a slight increase in runoff for the entire state. The increase is due to a variety of reasons including increased precipitation as well as urbanization, agricultural development and drainage.

Figure 17. *Average Annual Runoff (1961-1990)*



Surface Water - Lake Levels

Introduction

Lake level fluctuations are primarily a response to changes in the quantity of distribution of precipitation (rain and snow). They may also be the result of outlet dam operation or beaver dams. Shoreland development and use can be adversely affected by lake level fluctuations. Knowing the history of these fluctuations can be of assistance in coping with problems such as flooding, drought-related access, vegetation growth or lakeshore erosion. Other uses for lake level data would include:

- calibration of hydrologic and hydraulic simulation models
- flood level estimates
- minimum structure elevations
- local zoning programs
- local water management planning.

Lake Level Monitoring Program

Lake levels are actively monitored at 545 sites in Minnesota. Of these, 310 are monitored by citizen volunteers and 235 by other organizations including:

- Anoka County SWCD
- Becker County Coalition of Lake Associations
- Chisago County
- City of Maple Grove
- Freshwater Foundation
- Isanti County
- Thirty Lakes Watershed District
- Sauk River Watershed District
- Ramsey County
- Polk County SWCD
- Kandiyohi County

The Division of Waters provides the gage and any required survey work. Observers typically read the gages on a weekly basis throughout the open water season, and report their readings to the Division. The success of the program is largely dependent on these volunteers and cooperating organizations.

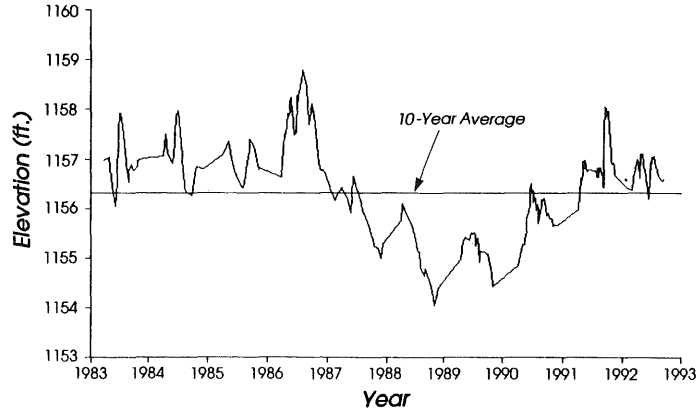
The data that is collected is stored in a data base (Lakes db©), which enables easy access to the information (see pages 29-30 for 10 selected lakes). Lakes db© software has been installed on many cooperators' computers, with staff instructed on basic data storage and retrieval. In four years of operation, approximately 400,000 individual lake level readings have been entered. During Water Years 1991 and 1992, 28,000 water level readings were collected and entered.

Water Levels Trends

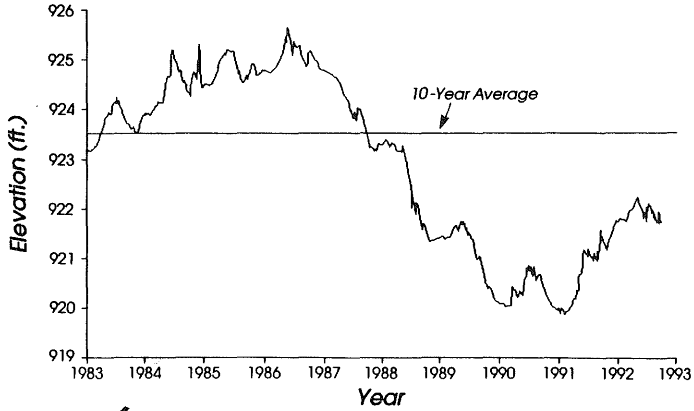
Comparing autumn lake levels during the drought of the late 1980's to autumn levels in 1992 shows that most lakes have recovered to some degree. Generally, the north half of the state experienced increases of up to two feet, while the south half experienced increases ranging from one to seven feet. This was mainly the result of excess precipitation in the south which not only restored lake levels but caused flooding in some cases. However, many landlocked basins remain at lower levels as a lingering effect of the drought, though their decline has substantially subsided.

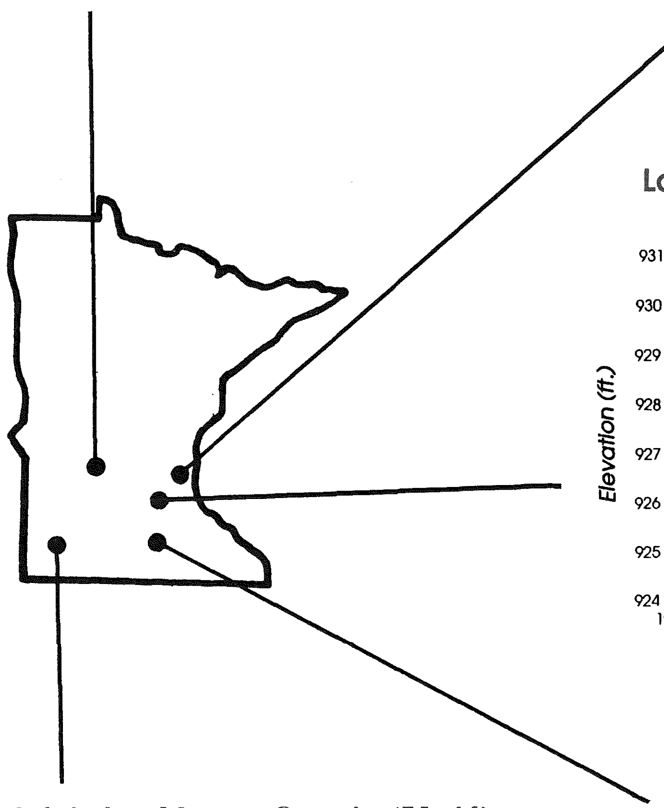
The tables on pages 31-33 show recorded fluctuations for 1991 and 1992 and 10-year average fluctuations for 159 lakes. The tables show that Water Year 1991 fluctuations were generally average as lakes continued to recover from the drought. 1992 fluctuations were somewhat less than average as a result of average precipitation amounts and a cool summer with low evaporation. Most lakes statewide have substantially recovered to near average levels since the late 1980's.

Green Lake Kandiyohi County (34-79)
Recorded Water Levels

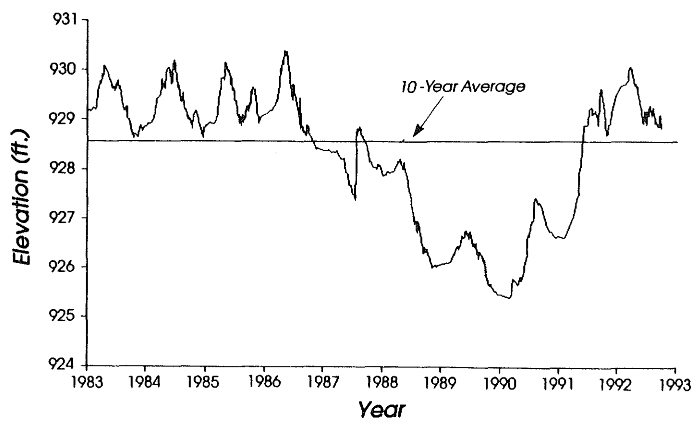


White Bear Lake Washington County (82-167)
Recorded Water Levels

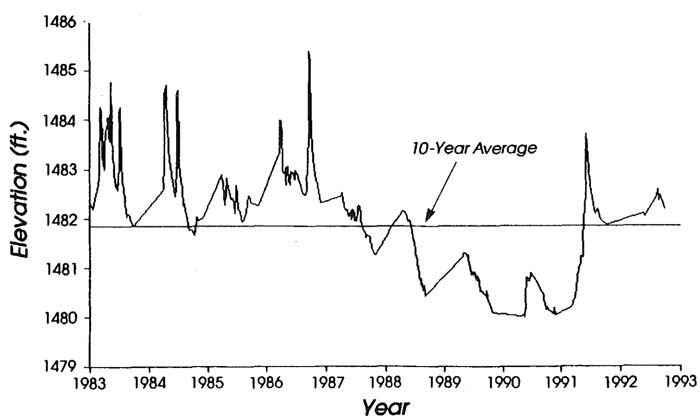




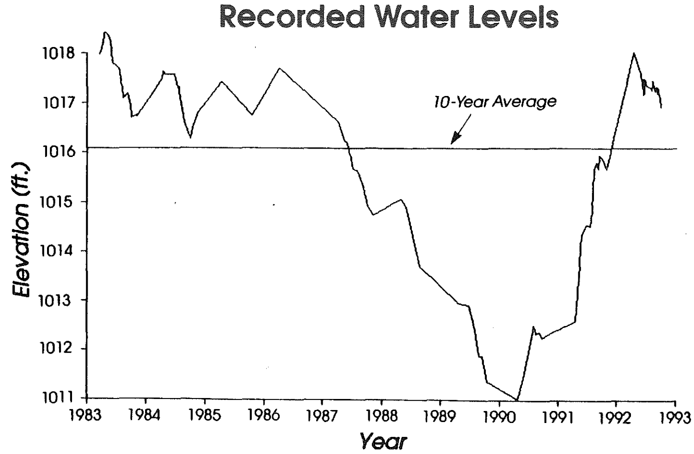
Lake Minnetonka Hennepin County (27-133)
Recorded Water Levels

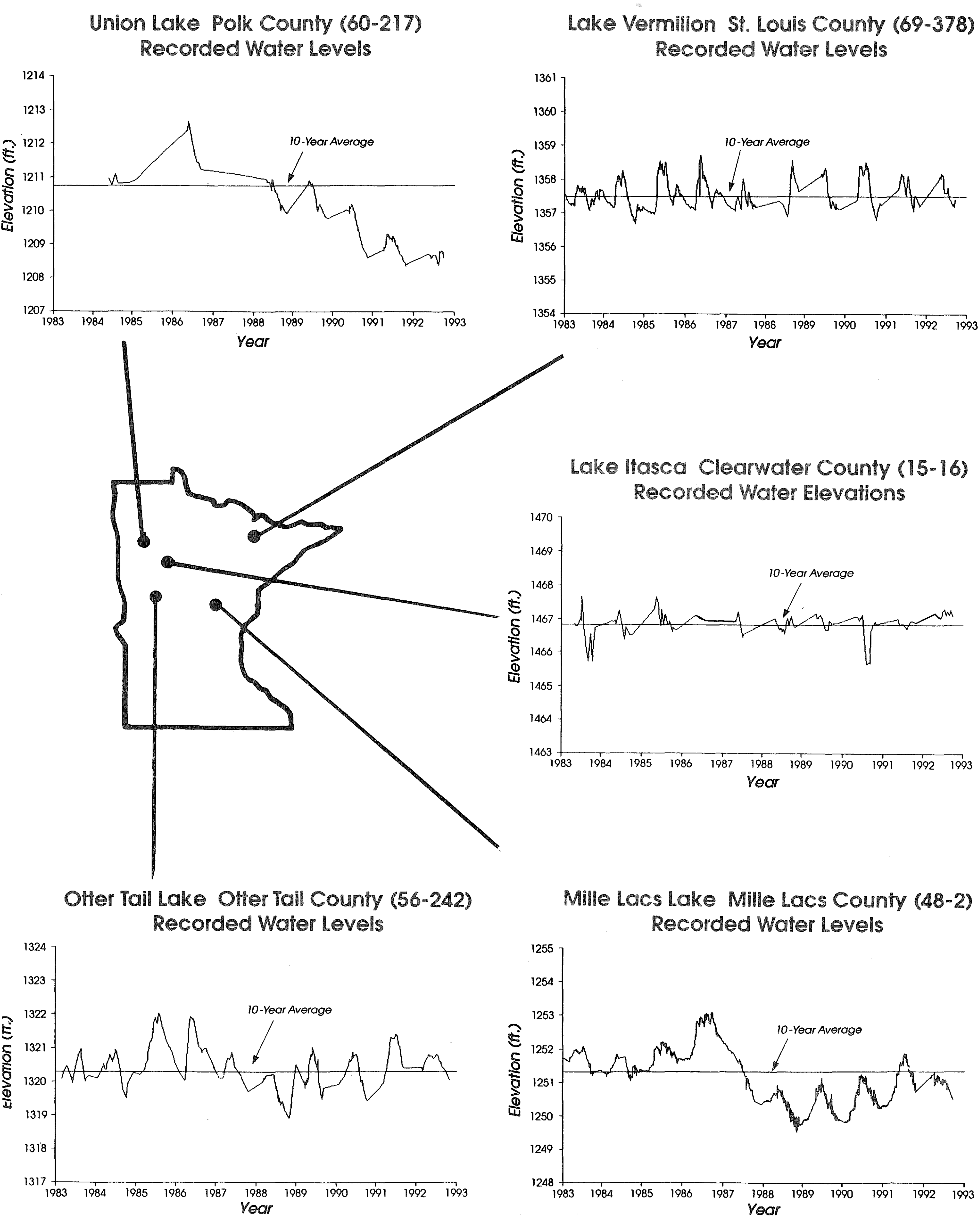


Shetek Lake Murray County (51-46)
Recorded Water Levels



Madison Lake Blue Earth County (7-44)
Recorded Water Levels




Union Lake Polk County (60-217)
Recorded Water Levels
Elevation (ft.)
10-Year Average
Year
Lake Vermilion St. Louis County (69-378)
Recorded Water Levels
Elevation (ft.)
10-Year Average
Year
Lake Itasca Clearwater County (15-16)
Recorded Water Elevations
Elevation (ft.)
10-Year Average
Year
Otter Tail Lake Otter Tail County (56-242)
Recorded Water Levels
Elevation (ft.)
10-Year Average
Year
Mille Lacs Lake Mille Lacs County (48-2)
Recorded Water Levels
Elevation (ft.)
10-Year Average
Year

Annual Lake Level Fluctuation (feet)

LAKE NAME (LAKE ID)	1991	1992	10-YR. AVE.
AITKIN COUNTY			
Farm Island (1-159)	1.02	1.06	0.93
Little Pine (1-176)	1.03	1.06	0.99
ANOKA COUNTY			
Baldwin (2-13)	2.61	2.69	2.60
Coon (2-42)	1.37	1.11	1.00
George (2-91)	0.60	0.45	1.38
Ham (2-53)	1.25	0.80	1.07
Linwood (2-26)	0.48	0.46	0.57
Martin (2-34)	1.12	0.94	1.00
Otter (2-3)	1.86	0.76	1.67
Spring (2-71)	3.27	0.64	1.71
BECKER COUNTY			
Big Cormorant (3-576)	0.51	0.28	1.00
Cotton (3-286)	1.02	0.60	1.32
Height of Land (3-195)	2.08	0.70	1.61
Ida (3-582)	1.08	0.52	1.10
Two Inlets (3-17)	1.00	0.85	1.24
Upper Cormorant (3-588)	0.88	0.58	0.92
BELTRAMI COUNTY			
Gallagher (4-92)	0.42	0.68	0.75
Turtle River (4-111)	2.56	0.92	1.66
BIG STONE COUNTY			
Big Stone (6-152)	1.92	1.77	2.40
BLUE EARTH COUNTY			
Crystal (7-98)	0.54	0.34	0.97
Lilly (7-101)	2.21	0.74	1.66
Madison (7-44)	3.34	1.09	1.94
CARLTON COUNTY			
Chub (9-8)	0.90	0.64	0.90

LAKE NAME (LAKE ID)	1991	1992	10-YR. AVE.
CASS COUNTY			
Big Portage (11-308)	0.34	0.58	0.70
Girl (11-174)	1.11	0.56	0.81
Hand (11-242)	0.82	1.14	0.84
Lower Trelipe (11-129)	0.76	0.82	1.18
Sylvan (11-304)	0.60	1.06	0.88
Ten Mile (11-413)	0.65	0.62	0.82
CHISAGO COUNTY			
Green (13-41)	0.75	1.36	1.12
CLEARWATER COUNTY			
Itasca (15-16)	0.30	0.26	0.78
COOK COUNTY			
Flour (16-147)	0.60	0.40	0.57
Poplar (16-239)	0.82	1.28	0.78
COTTONWOOD COUNTY			
Cottonwood (17-22)	4.22	0.80	2.35
Talcot (17-60)	1.70	1.80	2.88
CROW WING COUNTY			
Edward (18-305)	0.84	0.56	0.74
Hubert (18-375)	0.72	0.58	0.84
North Long (18-372)	0.71	0.67	0.83
Pelican (18-308)	0.80	0.67	0.87
Rabbit (18-93)	0.67	0.55	0.99
South Long (18-136)	1.06	1.22	1.11
DAKOTA COUNTY			
Marion (19-26)	1.82	2.48	1.97
DOUGLAS COUNTY			
Carlos (21-57)	0.76	0.84	1.07
Ida (21-123)	0.87	0.30	1.11
Lobster (21-144)	0.92	0.90	0.92
Miltona (21-83)	0.78	0.58	1.03
Victoria (21-54)	0.78	0.88	1.18

Annual Lake Level Fluctuation (feet)

LAKE NAME (LAKE ID)	1991	1992	10-YR. AVE.
HENNEPIN COUNTY			
Cedar Island (27-119)	1.23	0.84	1.15
Eagle/Pike (27-111)	0.98	0.60	0.89
Fish (27-118)	1.20	0.83	1.12
Independence (27-176)	1.39	1.24	1.38
Medicine (27-104)	1.69	0.85	1.64
Minnetonka (27-133)	3.02	1.48	1.47
Rice (27-116)	0.82	0.62	1.05
Schmidt (27-121)	0.84	0.70	1.07
HUBBARD COUNTY			
Belle Taine (29-146)	1.64	1.33	1.37
Long (29-161)	0.46	0.22	0.49
Plantagenet (29-156)	1.55	1.10	1.44
Potato (29-243)	0.28	0.48	0.69
ISANTI COUNTY			
Green (30-136)	1.24	0.45	1.51
Skogman (30-22)	1.14	1.10	1.22
ITASCA COUNTY			
Dora (31-882)	2.22	2.27	1.70
Loon (31-571)	0.57	0.62	1.17
Siseebakwet (31-554)	0.41	0.60	0.74
Split Hand (31-353)	0.78	1.02	1.60
JACKSON COUNTY			
North Heron (32-57-5)	4.52	3.16	3.06
South Heron (32-57-7)	5.03	3.44	3.41
North Marsh (32-57-1)	5.82	4.38	3.74
Loon (32-20)	1.99	1.44	1.19
KANDIYOHI COUNTY			
Andrew (34-206)	5.18	1.54	1.49
Eagle (34-171)	1.10	1.22	1.69
Green (34-79)	2.07	0.91	1.41
Mud (34-158)	2.00	1.30	1.39
Skataas (34-196)	0.74	1.04	1.40
LE SUEUR COUNTY			
Jefferson (40-92)	1.31	0.62	1.33
Washington (40-117)	1.08	1.02	1.50
West Jefferson (40-92-2)	3.28	0.77	1.44

LAKE NAME (LAKE ID)	1991	1992	10-YR. AVE.
LINCOLN COUNTY			
Benton (41-43)	1.08	1.10	1.52
MARTIN COUNTY			
Okamanpeedan (46-51)	2.95	1.90	1.50
MILLE LACS COUNTY			
Mille Lacs (48-2)	1.56	0.79	1.34
Shakopee (48-12)	2.10	0.58	1.19
MORRISON COUNTY			
Alexander (49-79)	0.73	0.72	0.88
Sullivan (49-16)	0.64	1.00	1.29
MURRAY COUNTY			
Shetek (51-46)	3.51	0.54	2.10
NOBLES COUNTY			
Ocheda (53-24)	2.17	2.22	1.62
OTTER TAIL COUNTY			
Big Pine (56-130)	1.30	0.70	1.63
Little Pine (56-142)	0.84	0.51	1.02
Lizzie (56-760)	1.16	0.46	1.16
Long (56-388)	0.22	0.80	0.81
Otter Tail (56-242)	1.60	0.76	1.48
Pickerel (56-475)	0.54	0.45	0.64
Rush (56-141)	1.68	1.30	1.58
Star (56-385)	1.04	0.64	0.85
West Battle (56-239)	0.71	0.60	1.05
PINE COUNTY			
Grindstone (58-123)	1.92	0.82	1.15
Island (58-62)	1.23	0.89	1.47
POLK COUNTY			
Badger (60-214)	0.66	1.00	1.36
Maple (60-305)	1.50	1.20	1.13
Union (60-217)	0.96	0.44	1.09
POPE COUNTY			
Minnewaska (61-130)	0.84	1.20	1.15

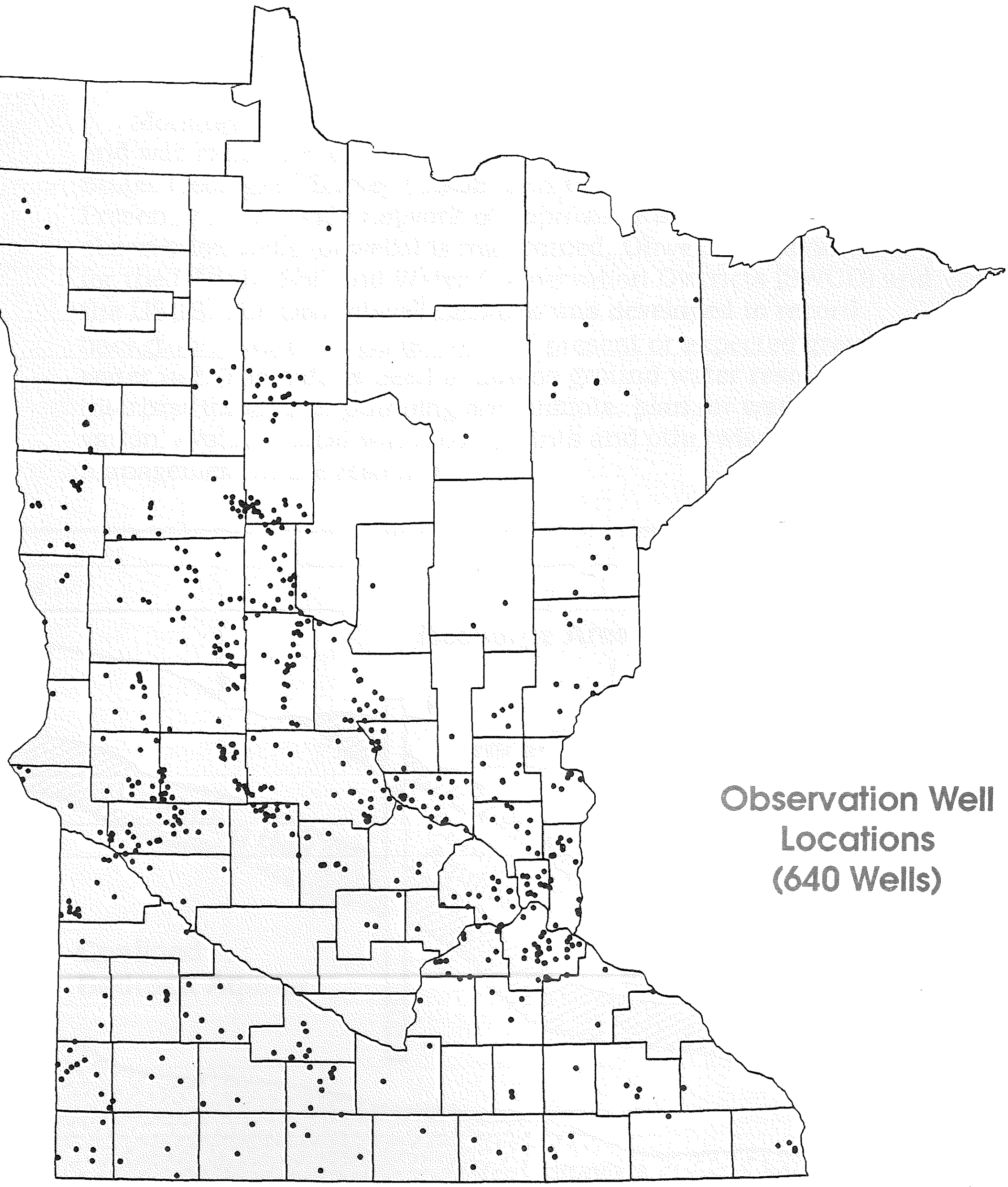
Annual Lake Level Fluctuation (feet)

LAKE NAME (LAKE ID)	1991	1992	10-YR. AVE.
RAMSEY COUNTY			
Bald Eagle (62-2)	1.07	0.51	1.27
Beaver (62-16)	1.25	1.07	2.05
Birch (62-24)	2.61	1.60	1.37
Como (62-55)	1.79	1.80	1.76
East Silver (62-1)	1.67	1.42	1.69
Gervais (62-7)	2.30	1.24	2.26
Island (62-75)	1.87	0.64	1.43
Johanna (62-78)	2.46	1.36	2.17
Josephine (62-57)	1.03	0.91	1.27
Long (62-67)	2.46	1.70	1.69
McCarron (62-54)	1.07	0.88	1.19
Owasso (62-56)	1.05	0.55	1.22
Phalen (62-13)	5.84	2.20	3.81
Pike (62-69)	1.59	1.45	1.32
Round (62-9)	2.05	1.31	2.20
Snail (62-73)	3.79	1.23	1.66
Turtle (62-61)	1.37	0.49	1.04
Valentine (62-71)	1.86	1.74	1.79
Wabasso (62-82)	1.81	0.96	1.51
Wakefield (62-11)	3.09	1.90	2.58
West Silver (62-83)	1.41	1.17	1.72
RICE COUNTY			
Circle (66-27)	1.92	1.42	1.67
Roberds (66-18)	1.29	0.93	1.42
ST. LOUIS COUNTY			
Dark (69-790)	1.24	1.25	1.63
Ely (69-660)	0.30	0.36	0.89
Esquagama (69-565)	1.50	0.84	2.56
Pelican (69-841)	0.58	0.66	1.22
Pequaywan (69-11)	0.44	0.83	0.67
St. Mary's (69-651)	0.86	0.32	1.25
Sturgeon (69-939)	1.56	0.87	1.23
Vermilion (69-378)	1.11	1.07	1.64
Wynne (69-434)	4.12	3.04	3.01
SCOTT COUNTY			
Upper Prior (70-72)	2.81	3.10	2.72
STEARNS COUNTY			
Big Fish (73-106)	0.96	0.63	0.84
Grand (73-55)	0.64	0.74	1.08
Koronis (73-200)	2.98	1.52	1.76
Rice (73-196)	4.20	2.93	2.84
Two Rivers (73-138)	2.55	3.20	2.77
TODD COUNTY			
Big Birch (77-84)	1.28	1.10	1.07
Osakis (77-215)	1.05	1.70	1.44
WASECA COUNTY			
Elysian (81-95)	1.33	0.76	1.81
WASHINGTON COUNTY			
Demontreville (82-101)	3.59	0.59	1.81
Downs (82-110)	1.21	1.64	2.67
Eagle Point (82-109)	1.71	1.11	2.32
Elmo (82-106)	0.91	0.59	1.34
Forest (82-159)	0.38	0.50	0.62
Horseshoe (82-74)	2.06	0.61	1.96
Jane (82-104)	1.23	0.36	1.77
Long (82-118)	4.88	1.17	3.50
Sunfish (82-107)	0.75	1.14	2.00
White Bear (82-167)	1.87	0.59	1.20
WATONWAN COUNTY			
St. James (83-43)	1.78	0.60	1.70
WRIGHT COUNTY			
Indian (86-223)	1.96	0.98	1.57
Maple (86-134)	2.64	0.90	1.56
Pulaski (86-53)	2.23	0.64	1.57
Sylvia (86-289)	0.66	1.04	0.84
AVERAGES:	**1.58**	**1.05**	**1.46**

GROUND WATER

Chapter 3

Number of Active Observation Wells in Water Year 1992

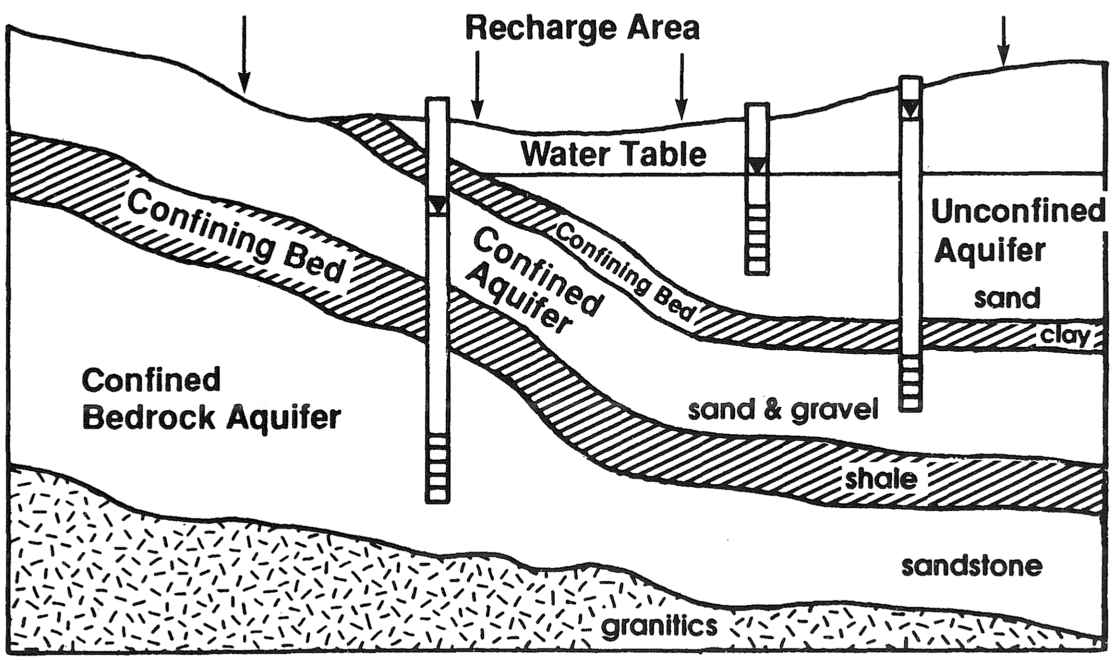


Ground Water

Introduction

Monitoring of ground water levels in Minnesota began in 1942 and was expanded by a cooperative program between the United States Geological Survey (USGS) and the DNR starting in 1947. Presently a statewide network of approximately 640 water level observation wells (obwells) is maintained. Obwells are monitored for the DNR by Soil and Water Conservation Districts (SWCD) and the USGS. The DNR obwell network was developed to record background water levels in areas of present or expected ground water use. The data is used to assess ground water resources, interpret impacts of pumping and climate, plan for water conservation, evaluate local water complaints and otherwise provide for management of the resource.

Figure 1.



AQUIFERS

An aquifer is a geologic formation which is saturated and sufficiently permeable to transmit economic quantities of water to wells and springs. Aquifers may exist under either 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 unsaturated geologic materials. Unconfined aquifers may also be called water table aquifers.

CONFINED AQUIFERS - When the aquifer is separated from the ground surface and atmosphere by a low permeability material, the aquifer is confined. When a well is installed into a confined aquifer, the water level in the well casing rises above the top of the aquifer because the water is under pressure. Confined aquifers may be either buried artesian (buried sand and gravel) or bedrock.

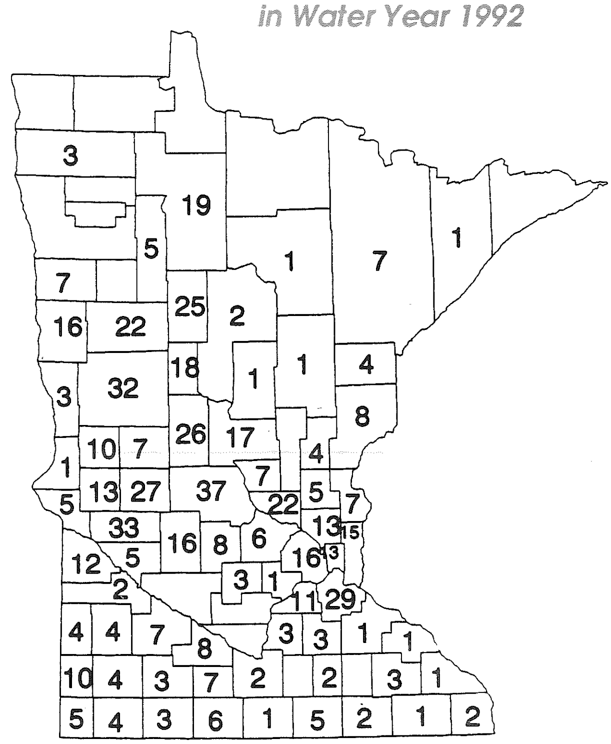
An unconfined aquifer generally responds more quickly to seasonal climatic changes than a confined aquifer since the water table is in more direct contact with the surface. However, the magnitude of change in water levels over time is usually more pronounced in a confined aquifer.

Statewide Summary

This section discusses the ground water levels in unconfined aquifers and confined aquifers during WY92 and compares them with WY90 levels and average levels. Index obwells were selected based on length of record and the best geographical representation for a region. Water level measurements for the index obwells were averaged for each water year and then compared to the average for the period of record for the obwell.

Figure 2 illustrates the number of obwells in each county. Figures 3, 4, and 5 illustrate the location of the obwells in each of the three groups discussed in this section, unconfined aquifers, buried artesian aquifers and bedrock aquifers.

Figure 2. Number of Active Obwells in Water Year 1992



Unconfined Aquifers

Unconfined aquifers are monitored throughout the state (Figure 3)*. Statewide, water tables in the index obwells for unconfined aquifers are generally higher when compared to Water Year 1990. Most index water table obwells fall within average levels. The exception is the northwest which continues to experience some water tables below average and slightly below WY90 levels. Hydrographs for selected unconfined aquifers are shown in Figure 8.

*Approximately half of the index obwells in unconfined aquifers contained in this report have periods of record in excess of 20 years each.

Figure 3. Water Table Aquifer Obwells

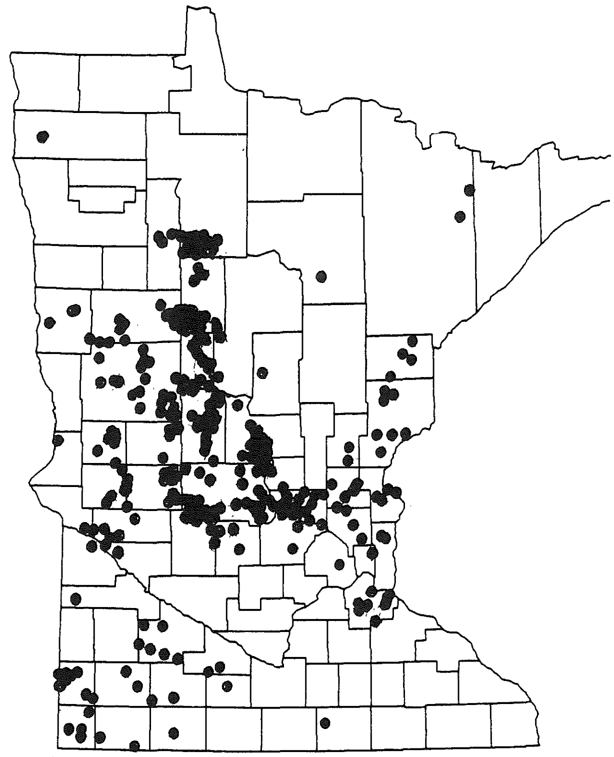
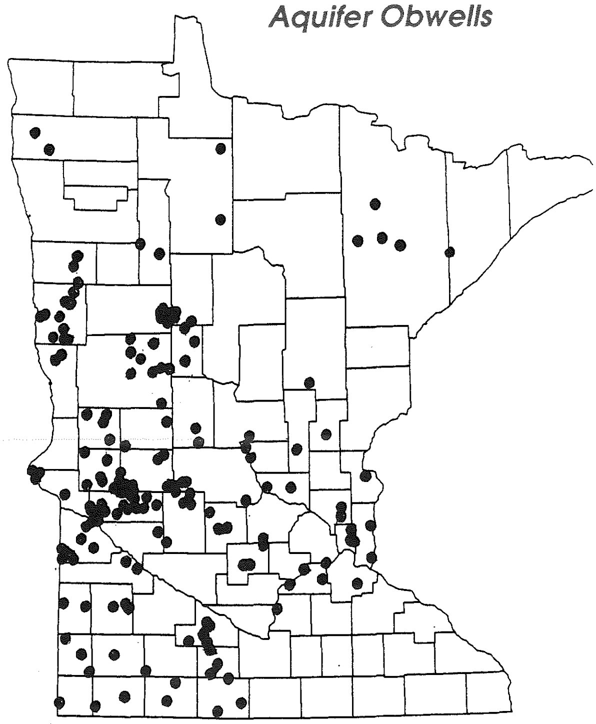


Figure 4. Buried Artesian Aquifer Obwells



Confined Aquifers - Buried Artesian

Figure 4 shows the distribution of buried artesian aquifers in unconsolidated deposits in the state. Hydrographs for selected confined aquifers are shown in Figure 9.

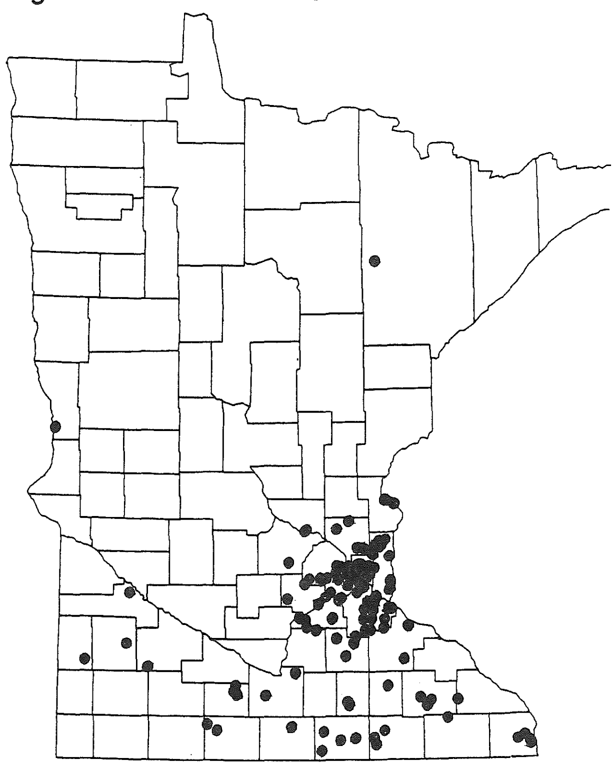
Index obwells in the buried artesian aquifers are generally within average levels and are generally higher when compared to WY90. The exception is the northwest, which generally experienced water levels below average (as much as 6 feet) and below WY90 levels (1-3 feet in some cases).

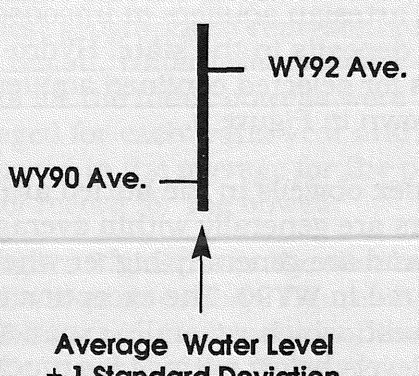
Bedrock Aquifers

Bedrock aquifers are monitored only in the central, south and southeast portions of the state where they are the aquifers most often used for water supply (Figure 5).

Most of the bedrock aquifers monitored by obwells are confined although bedrock aquifers may be either confined or unconfined. Figure 10 shows hydrographs for bedrock obwells (continued on page 44).

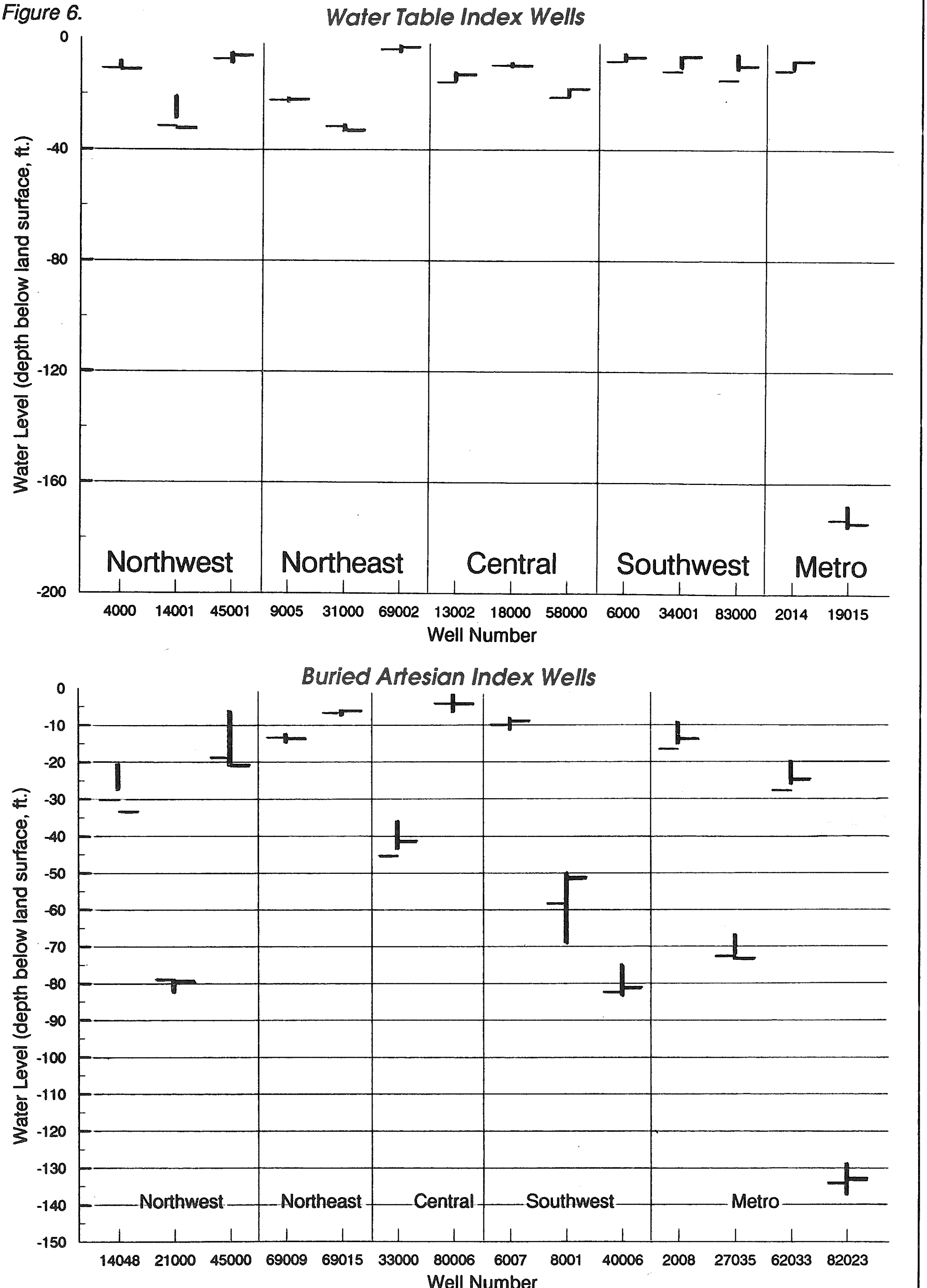
Figure 5. **Bedrock Aquifer Obwells**





Figures 6 and 7 are graphical comparisons of WY90 and WY92 with the average water level ± standard deviation for each index obwell, separated by aquifer. The representation of ± 1 standard deviation encompasses 66% of all water level measurements made on that obwell for its period of record. This gives a statistical representation of the water levels taken at that obwell. No analysis has been done on the possible effects on obwells from nearby pumping wells.

Figure 6.


Water Table Index Wells
Water Level (depth below land surface, ft.)
0
-40
-80
-120
-160
-200
Northwest
Northeast
Central
Southwest
Metro
4000 14001 45001 9005 31000 69002 13002 18000 58000 6000 34001 83000 2014 19015
Well Number
Buried Artesian Index Wells
Water Level (depth below land surface, ft.)
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
-110
-120
-130
-140
-150
Northwest
Northeast
Central
Southwest
Metro
14048 21000 45000 69009 69015 33000 80006 6007 8001 40006 2008 27035 62033 82023
Well Number

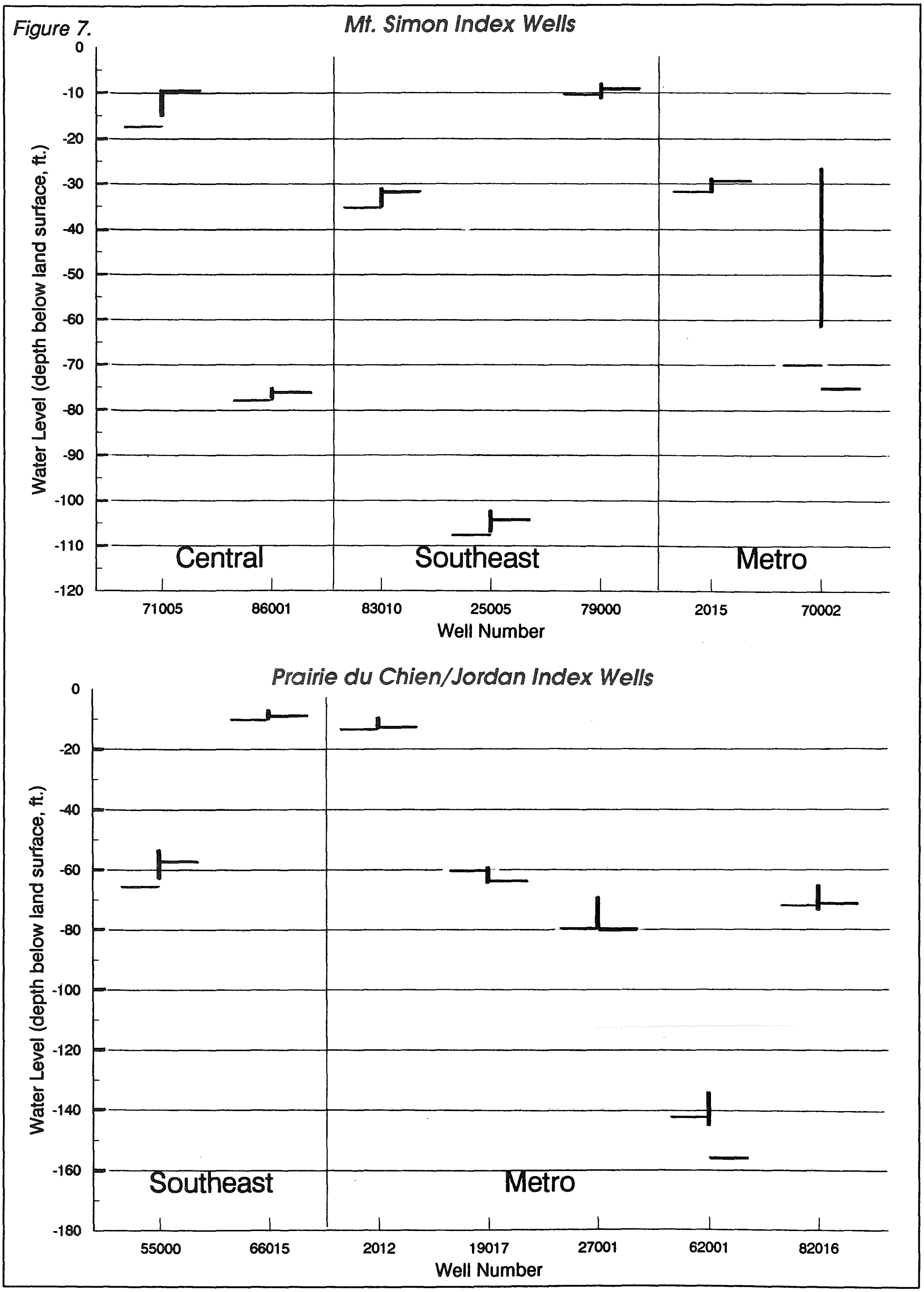


Figure 7.
Mt. Simon Index Wells
Water Level (depth below land surface, ft.)
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
-110
-120
Central
Southeast
Metro
71005
86001
83010
25005
79000
2015
70002
Well Number
Prairie du Chien/Jordan Index Wells
Water Level (depth below land surface, ft.)
0
-20
-40
-60
-80
-100
-120
-140
-160
-180
Southeast
Metro
55000
66015
2012
19017
27001
62001
82016
Well Number

Figure 8. **Historical Water Tables in Unconfined Aquifers**

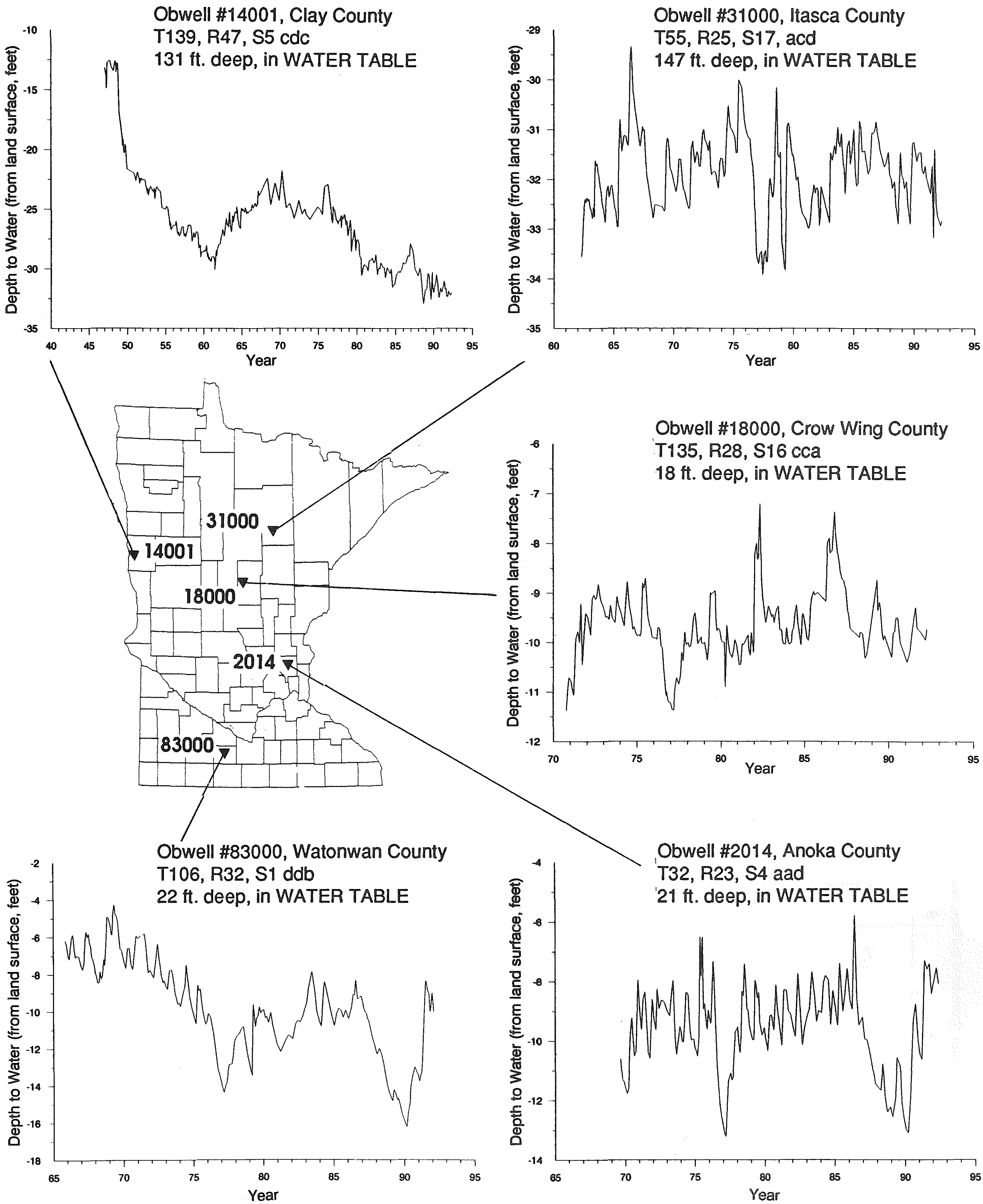


Figure 9. **Historical Water Levels in Buried Artesian Aquifers**

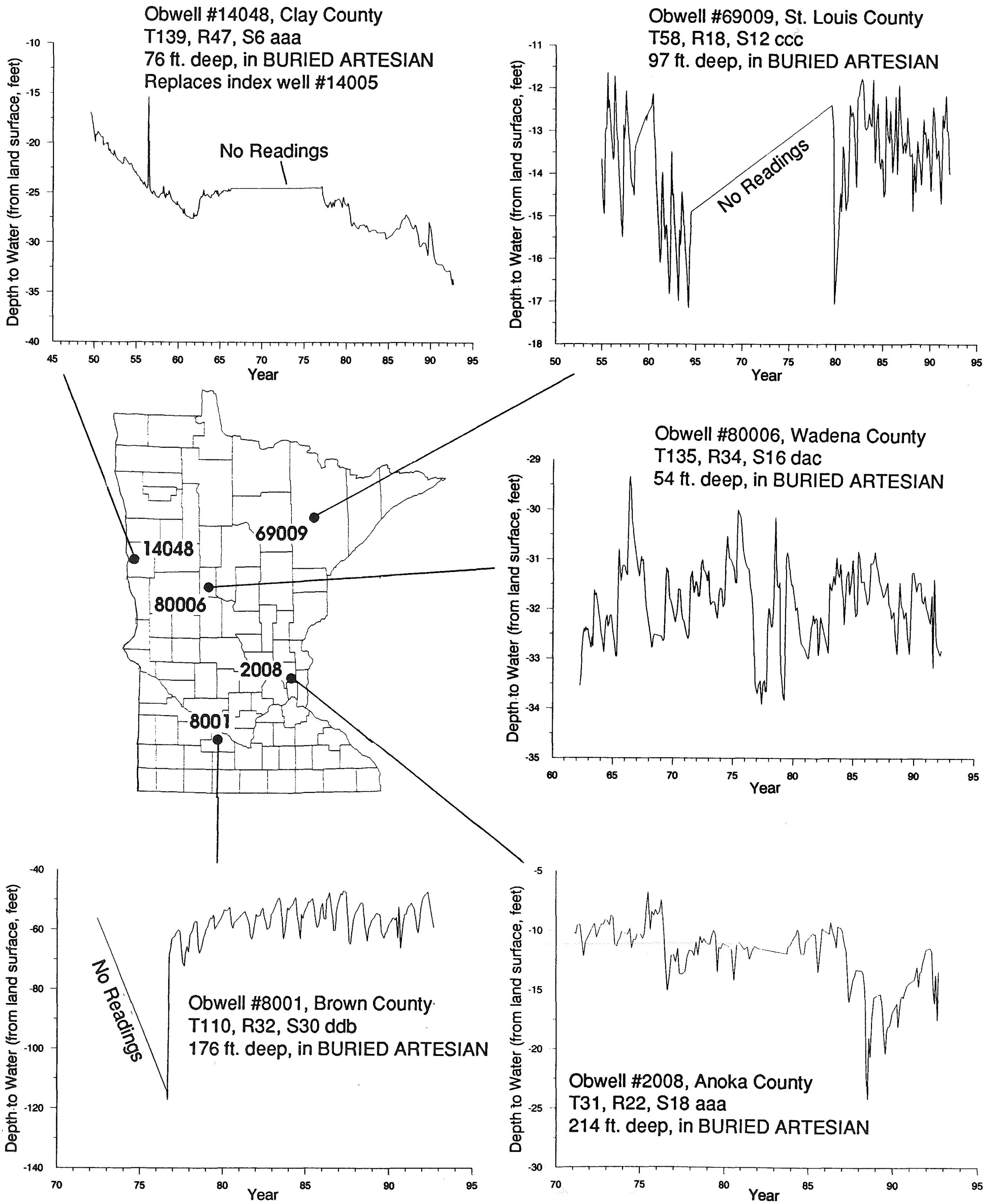
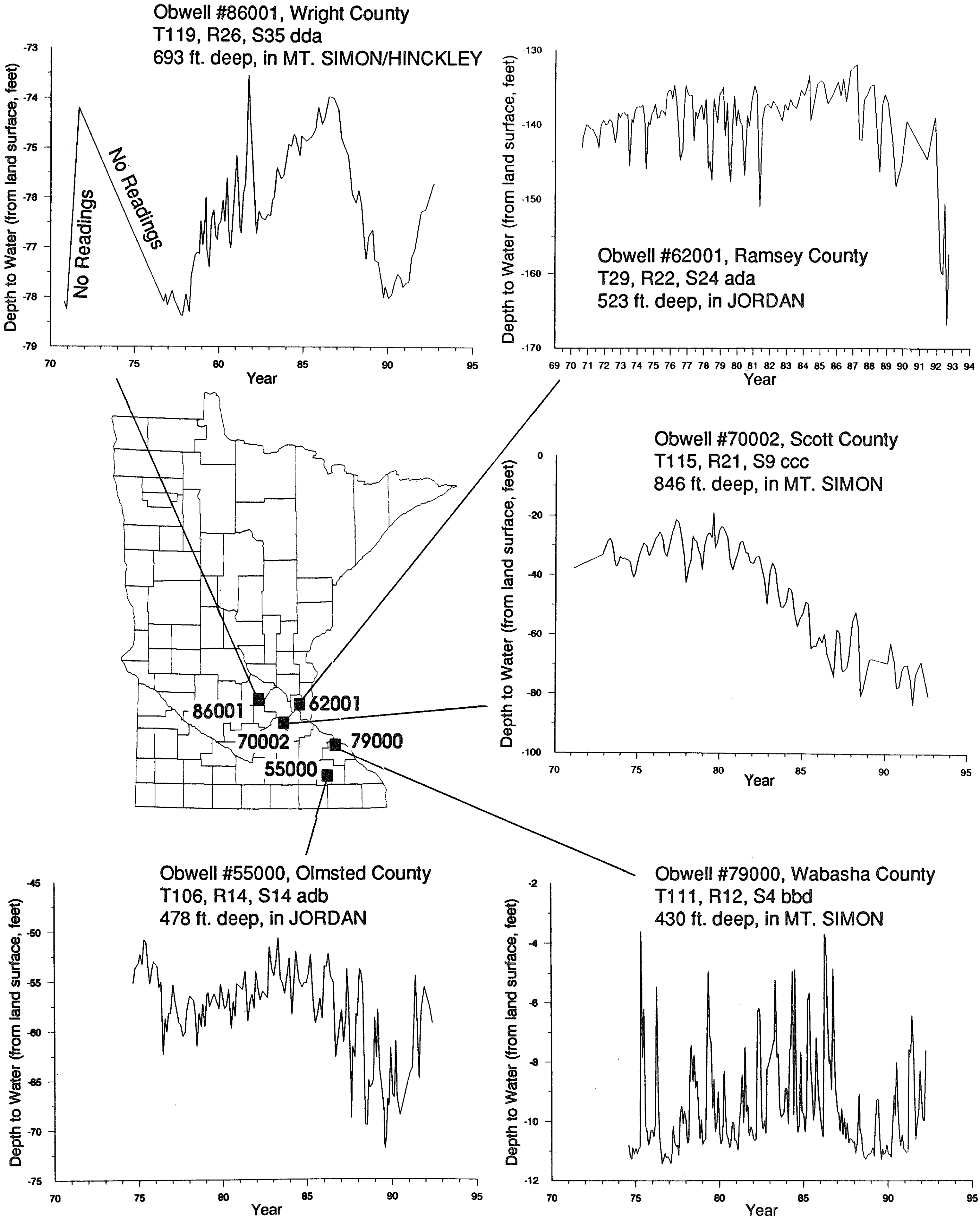


Figure 10. **Historical Water Levels in Bedrock Aquifers**



The Mt. Simon aquifer in central Minnesota is monitored by a series of obwells stretching from McLeod to Chisago Counties. These obwells have been monitored for periods ranging from 15 to 25 years. The water levels of the Mt. Simon index obwells were all generally higher when compared to WY90 and are within average. However, one index obwell in Scott County (70002), monitored for 22 years, showed a water level approximately 5 feet below the WY90 level and 31 feet below the average water level. This particular obwell may be affected by nearby pumping.

The Praire du Chien/Jordan aquifer is monitored on a limited basis in the Twin Cities Metro Area and a few counties southeast of the Twin Cities. In the southeast, index levels were above WY90 levels and within the average level. In the Twin Cities Metro Area, index levels ranged from slightly above to considerably below WY90 levels and average levels. Since there are relatively few obwells monitored, care should be taken in using these data.

In the Twin Cities Metro Area, water levels in bedrock aquifers are strongly influenced by seasonal pumping for air conditioning and irrigation. Levels in obwells decline sharply at the start of the pumping season (May), continue to decline until the end of the pumping season (late August) and then generally recover to pre-pumping levels by mid-autumn. Short-term fluctuations in climate are usually not evident in the water levels of these obwells. The fluctuations are masked by extensive pumping and by the length of time between a change in aquifer recharge and the expression of that change in confined water levels. The lowest levels occur in late summer at the end of the air conditioning season. This is in contrast to unconfined aquifers where drought or precipitation excess can be evident in the same year.

Water levels in the Prairie du Chien/ Jordan aquifer in the downtown pumping centers of the Twin Cities Metro Area were within average in both St. Paul and Minneapolis. On the outer edges of the Twin Cities Basin, levels in this aquifer were generally within average, although these wells experienced larger fluctuations over the period of monitoring. Water levels in obwells in both areas are higher than WY90 averages.

In the Mt. Simon-Hinckley aquifer (the Twin Cities' second principal aquifer), levels were within average in St. Paul and Minneapolis. Levels in wells outside the pumping centers were also generally within average. However, wells within the St. Paul and Minneapolis pumping center have exhibited much larger water level fluctuations over the period of monitoring. Water levels in obwells in both areas are higher than WY90 averages.

The Sioux Quartzite, the Cedar Valley Limestone, the Galena Formation, the Biwabik Iron Formation and other bedrock aquifers are monitored on a limited basis. Data from these wells may be obtained from the Observation Well Data Summary available at DNR/Waters offices and county Soil and Water Conservation District (SWCD) offices.

Obwell Network Expansion

Network expansion funding is partly from the 1989 Ground Water Act. The network includes almost all the aquifers in common use and is constantly expanding. Nineteen obwells were added to the network during the last two years. Of these obwells, 10 were existing wells and 9 were newly drilled obwells. Future network expansion is targeted at the bedrock aquifers statewide and the buried artesian aquifers in the west and southwest. Additional obwell sites are actively pursued.

Summary

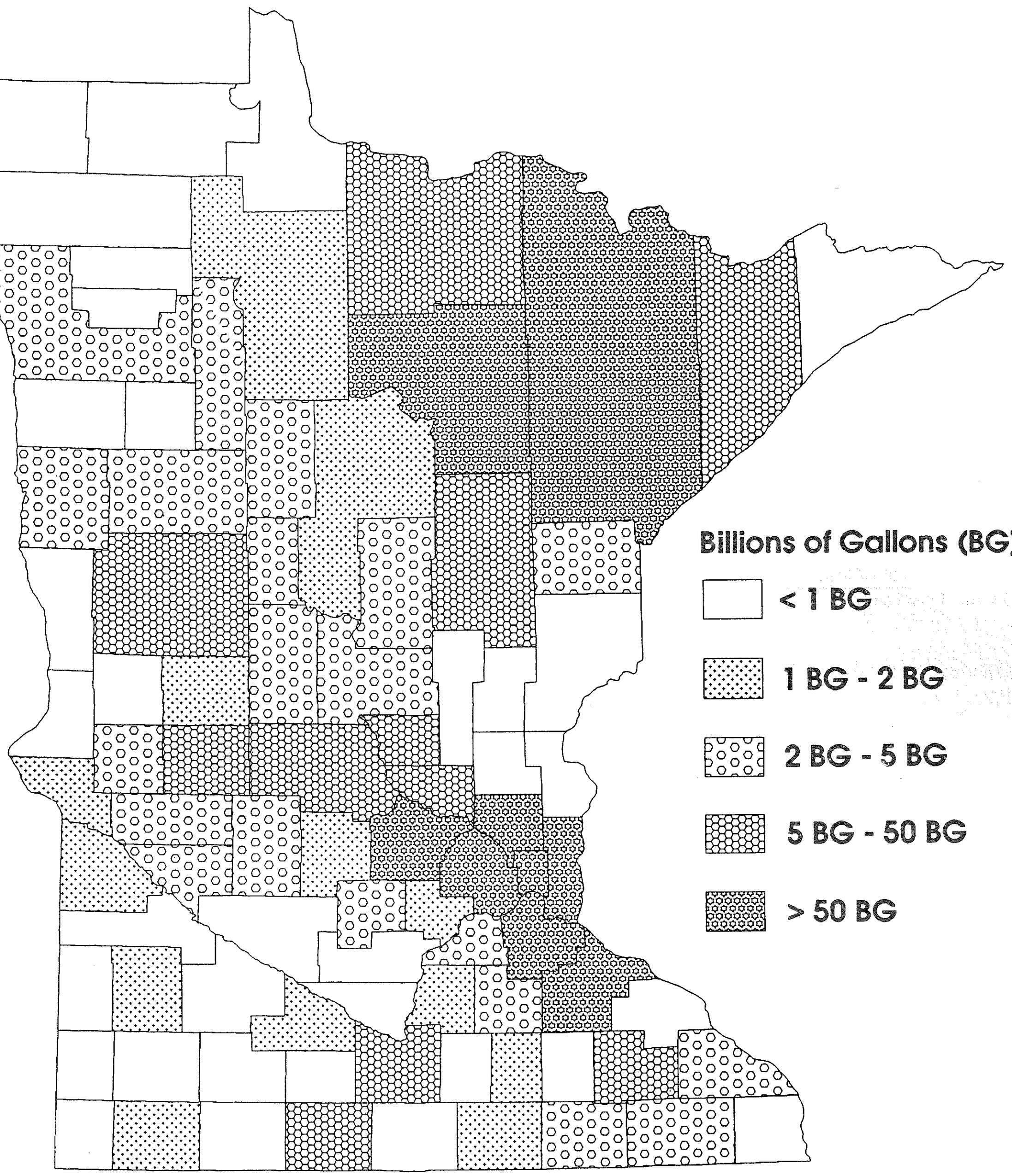
Unconfined, buried artesian and bedrock aquifers are generally within average levels statewide. WY92 levels are generally higher than WY91 levels with most aquifers fully recovered from the drought of the late 1980's.

The exception is northwest Minnesota which continues to experience below average water levels in both unconfined aquifers and buried artesian aquifers in spite of average precipitation. This is especially true along the Red River of the North where unconfined aquifers and buried artesian aquifers are used more frequently for water supply.

WATER USE

Chapter 4

Reported Water Withdrawals by County - 1990*



* Water use by county was similar in 1991.

Water Use

Introduction

This chapter will explore water use in Minnesota as reported to the DNR through its water appropriation permit program. DNR water appropriation permits are required for all users withdrawing more than 10,000 gallons per day or one million gallons per year. As a condition of each permit, the holder must report the volume of water withdrawn the previous year within 10% accuracy. 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.

Water use data is reported on a calendar year basis and is presented here in the same manner for Calendar Year (CY) 1990 and 1991 (CY 1992 data is not yet available). This report does not include water withdrawn in rural areas for domestic use that is estimated every five years by the United States Geological Survey.

Statewide Water Use - CY 1990

Total reported water use in Minnesota during 1990 was 1088 billion gallons (BG), a decrease of 1.5% (17 BG) from 1988. 81% (879 BG) of the water came from surface water sources, primarily rivers, while ground water sources accounted for 19% (209 BG) of the total (Figure 1).

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. Less than 1% of all appropriation permits are represented by this category. 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 to domestic, commercial, smaller industrial and public users. This category relies on both surface water and ground water sources. Consumptive use varies by season.

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.

See pages 53 to 57 for a detailed breakdown of reported water use for CY 1990-1991. The data are separated into the same five categories described above. Subtotals as well as surface water and ground water components are shown in each category. Overall totals of reported water use are specified at the end.

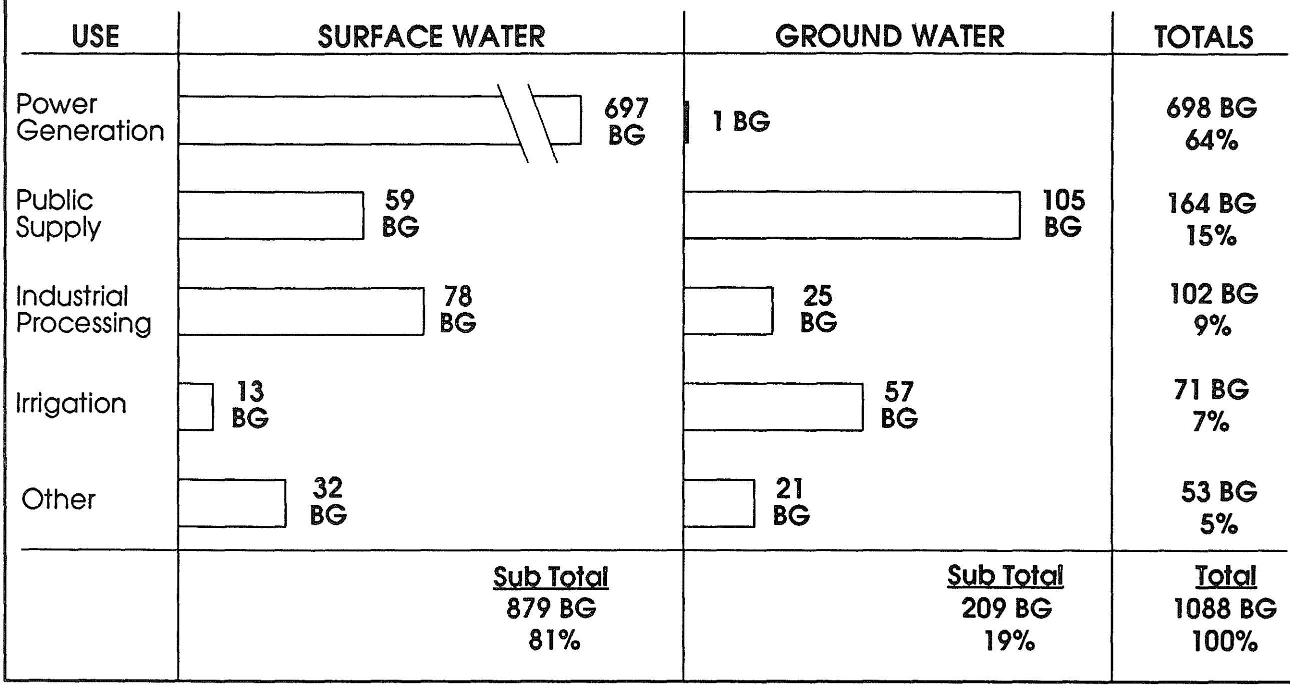


Figure 1. 1990 Reported Water Use Billions of Gallons (BG)

Statewide Water Use CY 1991

Minnesota water use remained approximately the same from 1990 to 1991. Overall appropriation in 1991 was 1092 BG, a slight increase over 1990. Although the total amount was similar, there were shifts in water sources and uses. Figure 2 is a comparison of water use between 1990 and 1991.

Surface water use increased slightly from 1990 to 1991. The largest single-use volume reported was for nuclear power plant cooling. Water withdrawn for thermoelectric power generation use increased 90%, while irrigation use from this source was the lowest in five years, with sod irrigation experiencing a decrease of 92%.

Reported ground water use decreased by 2% in 1991. Sod irrigation, pulp and paper processing, and temporary construction dewatering each decreased by 37% from this source. Ground water used for air conditioning (heating and cooling) increased slightly from 1990 to 1991.

Figure 2. Water Use Comparison: 1990-1991
Billions of Gallons (BG)

Use Category	1990 BG/% of total		1991 BG/% of total		Gain or loss in 1991 (BG)
Power Generation	698	64	694	64	-4
Public Supply	164	15	170	16	+6
Industrial Processing	102	9	115	10	+13
Irrigation	71	7	60	5	-11
Other	53	5	52	5	-1
	1088	100	1091	100	3

Public Supply

Minnesota has experienced tremendous growth in public supply since the 1950's, however, that growth appears to be leveling off in recent years. In 1989 public supply was 174 BG; in 1990 it was 164 BG and in 1991, 170 BG.

The ground water component of public supply was only 34% in 1950. It increased to 47% by 1970 and to 65% in 1990 (Figure 3). This increase is largely attributed to the fact that ground water is a more reliable source of water and it is a more cost effective source in areas of population growth.

Figure 3.
Public Water Supply 1970-1990

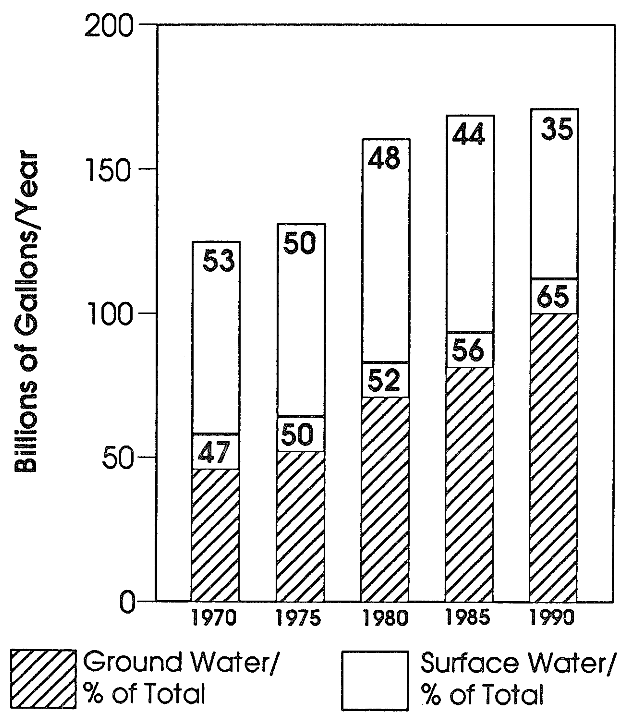
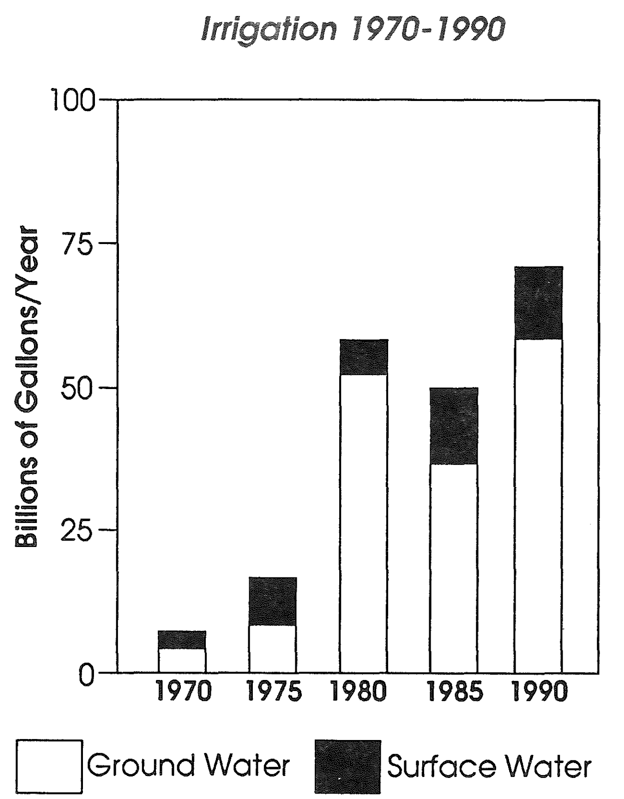


Figure 4.



Withdrawals for irrigation have decreased since the drought of the late 1980's in response to more normal precipitation. Irrigation use dropped 43%, from a high of 103 million gallons in 1988 to 60 million gallons in 1991, 65% of the latter from ground water sources.

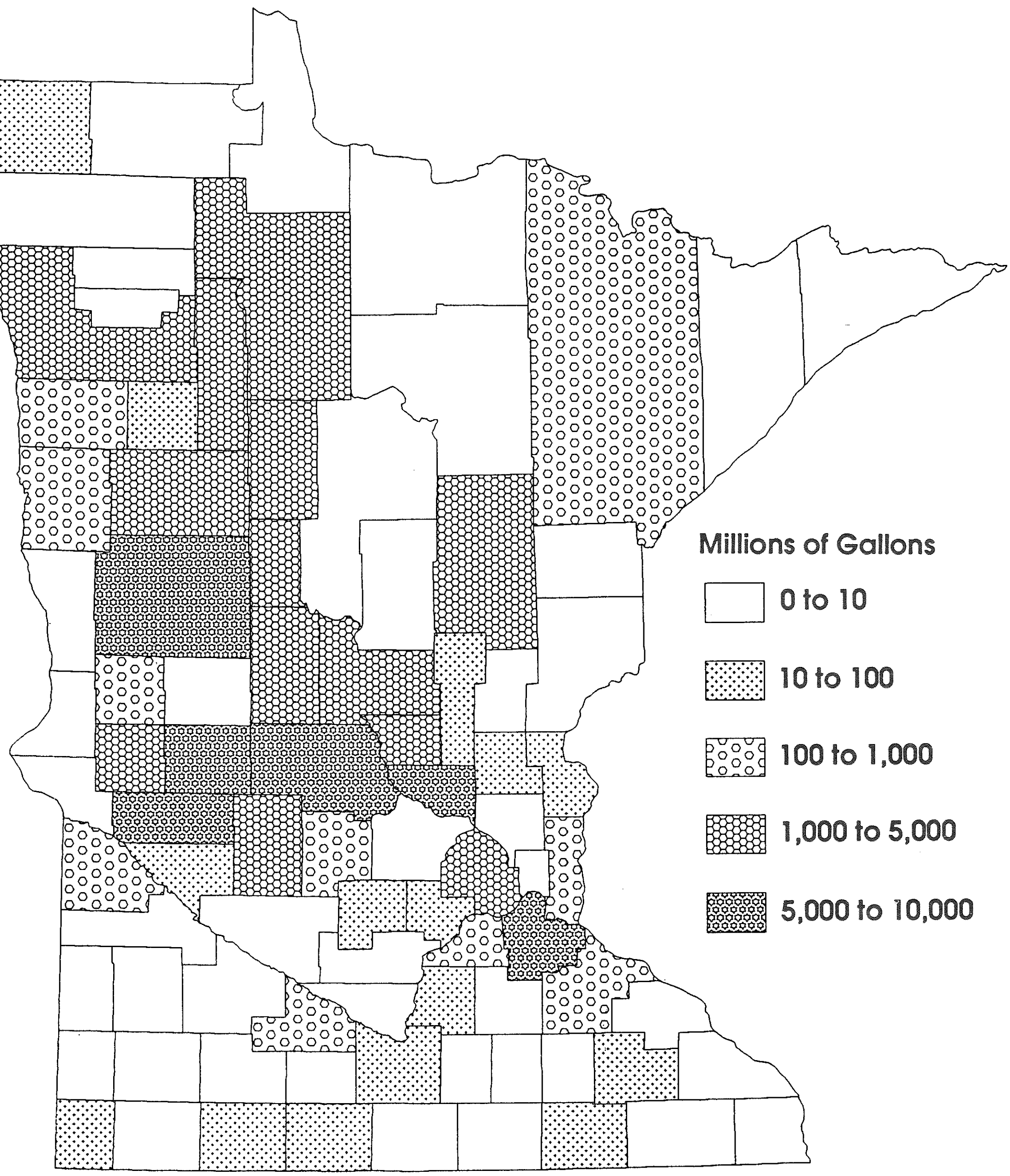
Although irrigation comprises about 5% of total water use, the withdrawals are important because irrigation is a major consumptive use of water. Irrigation withdrawals are nearly all consumptive use, either through absorption by plants or through evaporation. Very little is returned to the source of origin. In 1990, 80% of withdrawals for irrigation were from ground water sources (Figure 4).

In 1991, irrigation was reported in all counties except Kanabec, Mahnomen and Roseau. Otter Tail County reported the highest irrigation use that year (7 BG-51,000 acres), followed by Sherburne County (6.2 BG-37,000 acres) and Dakota County (6.1 BG-50,000 acres). These counties reported the largest irrigation appropriations from ground water sources. Clearwater, Polk and Aitkin Counties accounted for the largest irrigation appropriations from surface water sources at more than 2 BG in 1991.

Major crop irrigation (corn, beans, potatoes, etc.) accounted for most irrigation use, with 92% of withdrawals coming from ground water sources. Wild rice production, which is almost entirely surface water, accounted for 72% of irrigation from surface water sources in 1991, and 16% of total irrigation. Golf course watering has decreased by 16% since 1988, accounting for 6% of irrigation use statewide.

Figure 5.

Reported Irrigation - 1990



Includes crop and noncrop irrigation from surface and ground water sources.

Water Use by County - CY 1990

Water appropriation varies by county in the source of the withdrawals, amounts of withdrawals and intended uses. In CY 1990, ten counties accounted for 81% (884 billion gallons) of all reported water use (Figure 6).

Figure 6.

CY 1990
Water Appropriation by County
Billions of Gallons (BG)

County	Surface	Ground	Total	Primary Use
1) Goodhue	178	2	180	
2) Wright	129	2	131	
3) Washington	107	10	117	
4) Hennepin	58	36	94	Power
5) St. Louis	84	2	86	
6) Itasca	74	1	75	Generation
7) Dakota	47	20	67	
8) Ramsey	33	19	52	
9) Sherburne	29	7	36	
10) Anoka	38	8	46	Waterworks
			884 BG 81% of total use	

Summary

Reported water use decreased slightly from 1988 to 1990 and appears to have substantially stabilized. The majority of use, over 80%, continues to be from surface water sources. The primary changes in reported water use since 1988 were in the categories of public supply (-19%), irrigation (-31%) and industrial processing (+9%).

Reported Water Use
1990 - 1991 (Millions of Gallons)

Power Generation	1990	1991
HYDROPOWER GENERATION *	120.0	0.0
Surface Water:	120.0	0.0
Ground Water:	0.0	0.0
STEAM POWER COOLING - ONCE THROUGH	278615.0	261537.6
Surface Water:	278615.0	261537.6
Ground Water:	0.0	0.0
STEAM POWER COOLING - WET TOWER	8557.5	10386.3
Surface Water:	8356.1	10169.5
Ground Water:	201.4	216.8
STEAM POWER - OTHER THAN COOLING	103402.1	98705.4
Surface Water:	102990.1	98287.1
Ground Water:	412.1	418.3
NUCLEAR POWER PLANT COOLING	291961.0	295199.0
Surface Water:	291961.0	295199.0
Ground Water:	0.0	0.0
THERMO ELECTRIC POWER GENERATION	15043.4	28235.8
Surface Water:	14640.6	27748.7
Ground Water:	402.8	487.1
SUBTOTALS	697699.0	694064.1
Surface Water:	696682.7	692941.9
Ground Water:	1016.3	1122.2
Public Supply		
MUNICIPAL WATERWORKS	160282.5	165982.4
Surface Water:	58931.9	60231.4
Ground Water:	101350.6	105751.0
PRIVATE WATERWORKS	866.0	1423.4
Surface Water:	3.5	2.0
Ground Water:	862.5	1421.4
COMMERCIAL & INSTITUTIONAL	2692.9	2779.4
Surface Water:	0.0	0.0
Ground Water:	2692.9	2779.4

*St. Anthony Falls Hydraulics Laboratory only

Public Supply, cont.	1990	1991
COOPERATIVE WATERWORKS	133.5	137.5
Surface Water:	0.0	0.0
Ground Water:	133.5	137.5
FIRE PROTECTION	23.9	29.8
Surface Water:	0.0	0.0
Ground Water:	23.9	29.8
STATE PARKS, WAYSIDES, REST AREAS	33.2	27.4
Surface Water:	0.0	0.0
Ground Water:	33.2	27.4
SUBTOTALS	164032.0	170379.9
Surface Water:	58935.4	60233.4
Ground Water:	105096.6	110146.5

Irrigation

GOLF COURSE IRRIGATION	3556.4	3588.6
Surface Water:	837.4	771.7
Ground Water:	2719.0	2816.9
CEMETERY IRRIGATION	31.3	38.6
Surface Water:	0.0	0.0
Ground Water:	31.3	38.6
LANDSCAPING IRRIGATION	291.4	273.0
Surface Water:	43.5	25.0
Ground Water:	247.9	248.0
SOD IRRIGATION	86.6	39.4
Surface Water:	27.4	2.1
Ground Water:	59.2	37.3
NURSERY IRRIGATION	311.3	285.9
Surface Water:	14.1	17.2
Ground Water:	297.2	268.7
ORCHARD IRRIGATION	4.9	1.4
Surface Water:	4.7	1.4
Ground Water:	.2	0.0
NON CROP IRRIGATION	38.3	39.1
Surface Water:	17.6	16.9
Ground Water:	20.7	22.2
MAJOR CROP IRRIGATION	56870.4	45784.0
SurfaceWater:	3159.5	2775.2
Ground Water:	53710.9	43008.9

Irrigation, cont.	1990	1991
WILD RICE IRRIGATION	9552.0	9369.8
Surface Water:	9552.0	9360.6
Ground Water:	0.0	9.2
SUBTOTALS	70742.6	59419.8
Surface Water:	13656.2	12970.1
Ground Water:	57086.4	46449.7

Industrial Processing

	1990	1991
AGRICULTURAL PROCESSING	11651.4	13164.9
Surface Water:	545.8	567.7
Ground Water:	11105.6	12597.2
PULP AND PAPER PROCESSING	28684.8	24916.4
Surface Water:	27282.2	24029.1
Ground Water:	1402.6	887.3
MINE PROCESSING	43877.1	57901.9
Surface Water:	43874.9	57899.6
Ground Water:	2.2	2.3
SAND AND GRAVEL WASHING	2126.5	2821.8
Surface Water:	1482.1	2157.0
Ground Water:	644.4	664.0
SEWAGE TREATMENT	1025.2	1225.0
Surface Water:	1.7	14.3
Ground Water:	1023.5	1210.7
PETROLEUM OR CHEMICAL PROCESSING	3422.9	3053.9
Surface Water:	0.0	0.0
Ground Water:	3422.9	3053.9
METAL PROCESSING	1618.8	1575.1
Surface Water:	0.0	0.0
Ground Water:	1618.8	1575.1
NON-METALLIC PROCESSING	830.0	813.7
Surface Water:	1.7	1.0
Ground Water:	828.3	812.7
OTHER INDUSTRIAL PROCESSING	9318.0	9556.0
Surface Water:	4513.4	4639.5
Ground Water:	4804.6	4916.5
SUBTOTALS	102554.7	115028.7
Surface Water:	77701.8	89308.2
Ground Water:	24852.9	25720.5

Other	1990	1991
COMMERCIAL BUILDING AIRCONDITIONING (A/C)	225.9	385.3
Surface Water:	0.0	0.0
Ground Water:	225.9	385.3
INSTITUTIONS - SCHOOLS, HOSPITALS A/C	6.0	8.6
Surface Water:	0.0	0.0
Ground Water:	6.0	8.6
HEAT PUMPS	9.5	6.4
Surface Water:	9.5	6.4
Ground Water:	0.0	0.0
COOLANT PUMPS	495.6	481.7
Surface Water:	435.9	404.1
Ground Water:	59.7	77.6
DISTRICT HEATING	52.2	53.2
Surface Water:	0.0	0.0
Ground Water:	52.2	53.2
ONCE-THROUGH HEATING OR A/C	7619.2	7594.3
Surface Water:	0.0	0.0
Ground Water:	7619.2	7594.3
OTHER AIR CONDITIONING	260.1	279.3
Surface Water:	228.0	212.9
Ground Water:	32.1	66.4
TEMPORARY CONSTRUCTION NON-DEWATERING	12.1	15.0
Surface Water:	12.1	15.0
Ground Water:	0.0	0.0
TEMPORARY CONSTRUCTION DEWATERING	3780.3	2592.4
Surface Water:	80.7	261.4
Ground Water:	3699.6	2331.0
TEMPORARY CONSTRUCTION AND TANK TESTING	37.0	40.5
Surface Water:	6.1	23.8
Ground Water:	30.9	16.7
OTHER TEMPORARY	81.6	10.3
Surface Water:	81.6	10.3
Ground Water:	0.0	0.0
BASIN (LAKE) LEVEL MAINTENANCE	1842.7	1532.1
Surface Water:	1394.2	1166.1
Ground Water:	448.5	366.0
MINE DEWATERING	13692.9	16362.4
Surface Water:	13692.9	16362.4
Ground Water:	0.0	0.0

Other, cont.	1990	1991
QUARRY DEWATERING	8613.6	9851.0
Surface Water:	8613.6	9851.0
Ground Water:	0.0	0.0
SAND/GRAVEL PIT DEWATERING	62.0	124.4
Surface Water:	62.0	124.4
Ground Water:	0.0	0.0
TILE DRAINAGE AND PUMPED SUMPS	140.4	186.4
Surface Water:	139.8	186.4
Ground Water:	0.6	0.0
OTHER WATER LEVEL MAINTENANCE	5490.3	31.9
Surface Water:	5435.5	9.3
Ground Water:	54.8	22.6
POLLUTION CONFINEMENT	4238.6	5240.0
Surface Water:	0.7	0.1
Ground Water:	4237.9	5239.9
HATCHERIES AND FISHERIES	5493.4	6428.8
Surface Water:	903.8	1111.7
Ground Water:	4589.6	5317.1
SNOW MAKING	373.0	354.3
Surface Water:	98.5	84.1
Ground Water:	274.5	270.2
PEAT FIRE CONTROL	.2	.7
Surface Water:	.1	0.0
Ground Water:	.1	.7
OTHER SPECIAL CATEGORIES	585.8	623.4
Surface Water:	585.8	623.4
Ground Water:	0.0	0.0
SUBTOTALS	53052.4	52202.4
Surface Water:	31780.8	30452.8
Ground Water:	21271.6	21749.6

GRAND TOTALS OF REPORTED WATER USE 1990-1991 (Millions of Gallons)

	1990	1991
TOTALS	1088080.7	1091094.4
Surface Water:	878756.9	885906.4
Ground Water:	209323.8	205188.0

Reported Water Use by County 1990 - 1991 (Millions of Gallons)

REPORTED PUMPAGE

COUNTY		1990 SURFACE	1990 GROUND	1990 TOTAL	1991 SURFACE	1991 GROUND	1991 TOTAL	PRIMARY USE(S) 1991
1	AITKIN	2069.1	147.2	2216.3	2164.6	166.3	2330.9	Irrigation 93%, Waterworks 4%
2	ANOKA	38209.5	8090.5	46300.0	36225.6	7717.0	43942.6	Waterworks 98%
3	BECKER	72.9	2192.2	2265.1	56.0	2299.5	2355.5	Irrigation 62% Waterworks 35%
4	BELTRAMI	1220.6	627.5	1848.1	1358.4	692.0	2050.4	Irrigation 69% Waterworks 25%
5	BENTON	3831.1	2336.3	6167.4	3960.2	2165.0	6125.2	Ind. process 63% Irrigation 29%
6	BIG STONE	895.9	531.7	1427.6	61.1	278.6	339.7	Waterworks 57% Irrigation 25%
7	BLUE EARTH	4016.1	5521.4	9537.5	4338.2	5486.7	9824.9	Power gen. 44% Ind. process 27%
8	BROWN	158.9	1441.4	1600.3	141.3	1531.3	1672.6	Waterworks 64% Irrigation 23%
9	CARLTON	2889.6	498.1	3387.7	3003.2	509.5	3512.7	Ind. process 72% Waterworks 14%
10	CARVER	16.5	1891.4	1874.9	8.7	1906.3	1915.0	Waterworks 78% Ind. process 14%
11	CASS	116.5	1074.0	1190.5	152.5	1061.6	1214.1	Irrigation 45% Special cat. 29%
12	CHIPPEWA	2835.1	335.2	3170.3	2754.2	308.2	3062.4	Power gen. 87%
13	CHISAGO	4.5	584.6	589.1	8.6	609.9	618.5	Waterworks 82%
14	CLAY	1361.9	1633.3	2995.2	1185.4	1283.8	2469.2	Waterworks 74% Irrigation 20%
15	CLEARWATER	3988.3	149.3	4137.6	2993.0	145.2	3138.2	Irrigation 94%
16	COOK	85.8	3.8	89.6	13783.9	4.2	13788.1	Power gen. 99%
17	COTTONWOOD	73.9	694.8	768.7	42.0	803.2	845.2	Waterworks 55%
18	CROW WING	1574.4	1638.3	3212.7	1397.5	1780.1	3177.6	Ind. process 39% Waterworks 32%
19	DAKOTA	46892.9	20222.3	67115.2	43500.0	20125.2	63625.2	Power gen. 65% Waterworks 16%
20	DODGE	14.2	327.7	341.9	11.6	339.2	350.8	Waterworks 97%
21	DOUGLAS	16.3	1144.5	1160.8	17.9	784.5	802.4	Waterworks 66% Irrigation 28%
22	FARIBAULT	31.0	758.2	789.2	1.1	755.7	756.8	Waterworks 75%
23	FILLMORE	11.7	4407.5	4419.2	4.5	3925.6	3930.1	Special cat. 86%
24	FREEBORN	58.9	1532.9	1591.8	14.0	2453.4	2467.4	Waterworks 55% Ind. process 37%
25	GOODHUE	177741.2	2472.6	180213.8	198210.6	2842.9	201053.5	Power gen. 98%
26	GRANT	0.0	784.5	784.5	0.2	615.1	615.3	Irrigation 79%
27	HENNEPIN	57774.2	36232.2	94006.4	54820.0	35994.3	90814.3	Power gen. 59% Waterworks 27%
28	HOUSTON	0.0	541.3	541.3	253.0	461.8	714.8	Waterworks 54% Special cat. 43%
29	HUBBARD	89.6	3709.4	3799.0	33.1	4115.2	4148.3	Irrigation 86%
30	ISANTI	0.0	565.2	565.2	0.0	571.4	571.4	Waterworks 71%
31	ITASCA	74187.8	807.1	74994.9	56035.9	806.9	56842.8	Power gen. 83% Ind. process 13%
32	JACKSON	12.0	255.2	267.2	51.3	258.2	309.5	Waterworks 80%
33	KANABEC	10.8	140.7	151.5	4.0	155.7	159.7	Waterworks 97%
34	KANDIYOHI	566.3	2615.3	3181.6	475.7	1903.6	2379.3	Waterworks 59%
35	KITTSON	241.5	228.8	470.3	185.6	182.7	368.3	Waterworks 49% Ind. process 49%
36	KOOCHICHING	16202.9	46.5	16249.4	15368.5	40.6	15409.1	Ind. process 98%
37	LAC QUI PARLE	57.4	1288.5	1345.9	15.7	943.1	958.8	Ind. process 61%
38	LAKE	33861.2	.1	33861.3	46055.4	.1	46055.5	Ind. process 98%

REPORTED PUMPAGE

COUNTY		1990 SURFACE	1990 GROUND	1990 TOTAL	1991 SURFACE	1991 GROUND	1991 TOTAL	PRIMARY USE(S) 1991
39	LAKE OF THE WOODS	138.5	80.4	218.9	161.5	82.8	244.3	Irrigation 66%
40	LESUEUR	921.4	990.5	1911.9	2584.6	1092.7	3677.3	Waterworks 44% Ind. process 32%
41	LINCOLN	2.1	597.3	599.4	6.0	546.7	552.7	Waterworks 79%
42	LYON	66.6	1232.6	1299.2	102.9	1272.8	1375.7	Waterworks 92%
43	MCLEOD	220.0	2015.9	2235.9	163.6	1977.0	2140.6	Waterworks 51% Ind. process 40%
44	MAHNOMEN	0.0	103.0	103.0	0.0	77.2	77.2	Waterworks 100%
45	MARSHALL	49.4	177.2	226.6	62.0	184.7	246.7	Waterworks 93%
46	MARTIN	13579.7	467.1	14046.8	15374.1	383.0	15757.1	Power gen. 94%
47	MEEKER	45.8	1153.7	1199.5	38.9	857.3	896.2	Waterworks 56% Irrigation 27%
48	MILLE LACS	40.7	417.5	458.2	56.1	409.6	465.7	Waterworks 76%
49	MORRISON	698.4	3039.5	3737.9	99.9	3485.9	3585.8	Irrigation 77%
50	MOWER	0.0	2006.8	2006.8	0.0	2202.0	2202.0	Waterworks 60% Ind. process 35%
51	MURRAY	13.8	251.2	265.0	3.4	273.9	277.3	Waterworks 99%
52	NICOLLET	42.2	941.8	984.0	56.6	966.6	1023.2	Waterworks 90%
53	NOBLES	16.7	1053.9	1070.6	74.7	1082.0	1156.7	Waterworks 92%
54	NORMAN	26.6	234.3	260.9	13.1	150.0	163.1	Waterworks 92%
55	OLMSTED	70.3	5194.8	5265.1	72.9	5407.2	5480.1	Waterworks 82%
56	OTTERTAIL	10407.0	8589.7	18996.7	10386.6	8461.6	18848.2	Power gen. 49% Irrigation 41%
57	PENNINGTON	658.4	19.9	678.3	793.3	25.0	818.3	Irrigation 54% Waterworks 45%
58	PINE	79.6	305.7	385.3	2.8	320.1	322.9	Waterworks 80%
59	PIPESTONE	27.8	455.2	483.0	71.3	671.3	742.5	Irrigation 54%
60	POLK	4508.4	823.2	5331.6	4514.3	783.0	5297.3	Irrigation 53% Waterworks 46%
61	POPE	66.7	5992.1	6058.8	26.6	2566.7	2593.3	Irrigation 90%
62	RAMSEY	33530.4	18713.0	52243.4	36474.2	18194.1	54668.3	Power gen. 58% Waterworks 23%
63	RED LAKE	11.6	71.2	82.8	49.4	75.2	124.6	Waterworks 57% Water level main 32%
64	REDWOOD	30.2	424.9	455.1	34.7	446.4	481.1	Waterworks 91%
65	RENVILLE	47.8	431.7	479.5	20.9	447.5	468.4	Waterworks 84%
66	RICE	94.1	2049.1	2143.2	90.6	2164.3	2254.9	Waterworks 83%
67	ROCK	44.6	740.7	785.3	40.6	784.6	825.2	Waterworks 90%
68	ROSEAU	0.0	351.0	351.0	0.0	301.5	301.5	Waterworks 90%
69	ST LOUIS	84609.0	1656.9	86265.9	82106.5	2316.7	84423.2	Power gen. 51% Waterworks 18%
70	SCOTT	1708.0	2978.9	4687.5	1929.9	2771.9	4701.8	Waterworks 43% Water level main 41%
71	SHERBURNE	29231.3	6689.6	35920.9	23121.0	7040.5	30161.5	Power gen. 77%
72	SIBLEY	5.0	432.7	437.7	6.1	429.8	435.9	Waterworks 82%
73	STEARNS	2781.1	7613.7	10394.8	2883.9	5525.5	8409.4	Waterworks 51% Irrigation 37%
74	STEELE	244.7	1573.6	1818.3	296.7	1586.0	1882.7	Waterworks 78%
75	STEVENS	23.7	2290.4	2314.1	78.2	911.7	989.9	Irrigation 55% Waterworks 37%
76	SWIFT	32.7	4631.8	4664.5	4.9	1235.9	1240.8	Irrigation 78%
77	TODD	262.6	2389.5	2652.1	184.5	2124.4	2308.9	Irrigation 78%
78	TRAVERSE	3.4	164.3	167.7	2.2	155.6	157.8	Waterworks 99%
79	WABASHA	6.4	869.4	875.8	7.8	891.7	899.5	Waterworks 75%
80	WADENA	564.9	1707.3	2272.2	593.4	1841.2	2434.6	Irrigation 87%
81	WASECA	49.6	788.9	838.5	41.1	874.1	915.2	Waterworks 93%
82	WASHINGTON	107435.0	9837.1	117272.1	103472.0	9884.5	113356.5	Power gen. 87%
83	WATONWAN	9.3	766.9	776.2	9.2	780.8	790.0	Waterworks 87%
84	WILKIN	173.7	454.3	628.0	113.8	331.8	445.6	Irrigation 58%
85	WINONA	9.5	3671.0	3680.5	6.6	3714.3	3720.9	Waterworks 52%
86	WRIGHT	129577.6	1640.9	131218.5	111876.4	1477.2	113353.6	Power gen. 98%
87	YELLOW MEDICINE	91.0	293.3	384.3	98.3	221.2	319.5	Waterworks 64%
TOTALS		**878756.9**	**209623.6**	**1088380.5**	**885962.3**	**205514.4**	**1091476.7**	