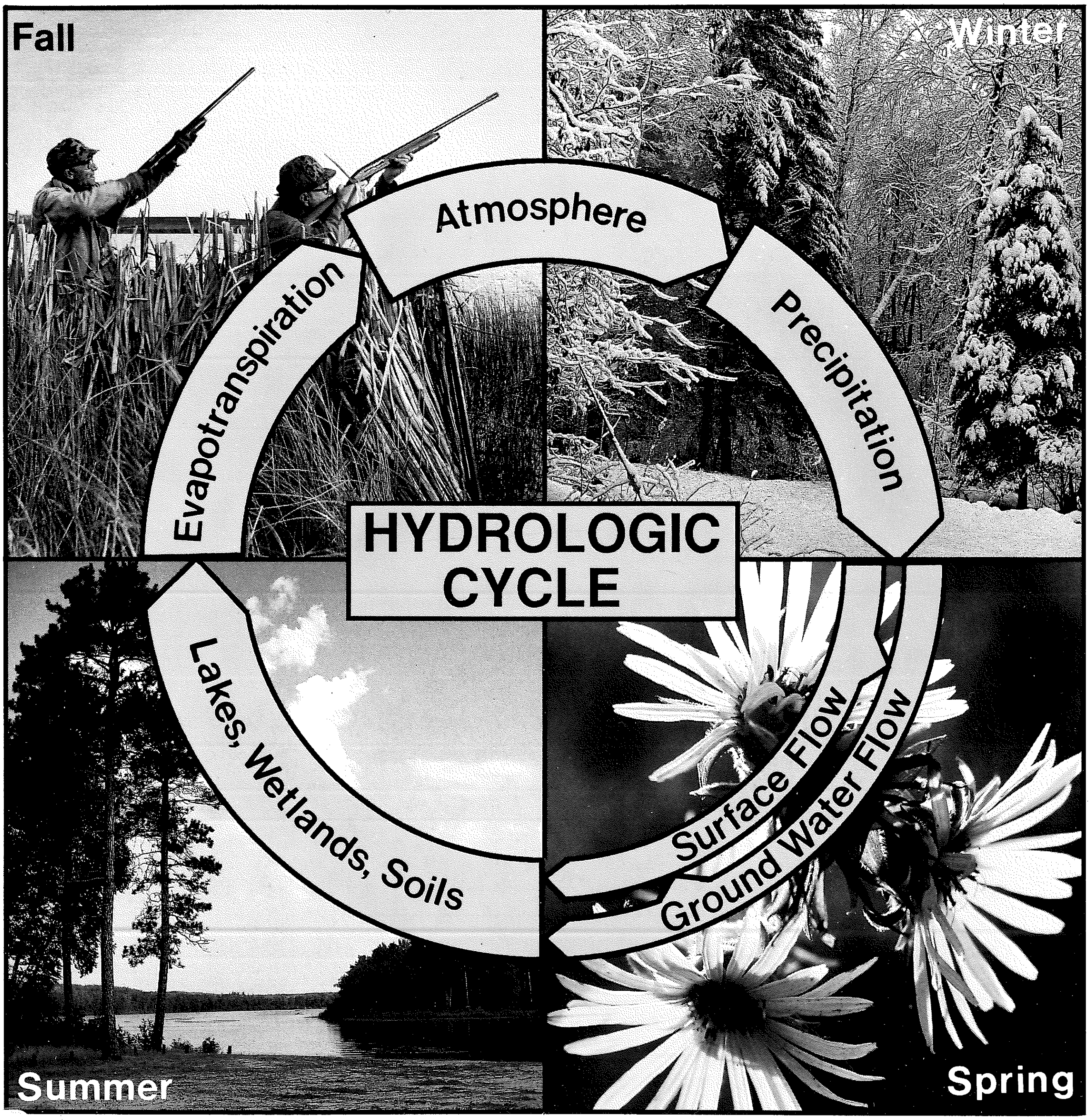
Water Year Data Summary

1989 and 1990



Minnesota
Department of Natural Resources
Division of Waters

May 1991

Water Year Data Summary

1989 and 1990

October 1, 1988 - September 30, 1990
by the Division of Waters Staff

St. Paul, MN
May 1991

Minnesota
Department of Natural Resources
Division of Waters

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Acknowledgements

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

Sandra Fecht - editing
Gene Hollenstein - introduction
Felicia White - word processing
Jim Zicopula - graphic arts
Colleen Mlecoch and Jim Solstad

Glen Yakel
Editor

Introduction

This document provides a review, summary and analysis of basic hydrologic data collected under DNR-Division of Waters programs. It succeeds a Division publication titled "Drought of 1988" which was substantially based on hydrologic data from Water Years 1987 and 1988 (Oct. 1, 1986 to Sept. 30, 1988) with obvious emphasis on the dramatic events of 1988. The focus of this report is on data and is a specific attempt to resume and expand upon Water Year reports published by the Division of Waters in 1979 and 1980.

Basic data are essential to water resource programs and related efforts such as:

- shoreland management
- floodplain management
- watershed management
- ground water management
- drought management
- public and private water supply
- agricultural crop management
- pollution control
- transportation system management
- comprehensive water resources planning

The four major areas of data collection (climatology, surface water, ground water and water use) follow the hydrologic cycle and provide essential facts on the distribution and availability of Minnesota's water resources. The extent of our knowledge depends greatly on the quality and quantity of this basic hydrologic data. With expanding technologies, new and emerging methodologies and computer advancements, there is a need for even more data of higher quality. Analysis and use of data is vital to understanding complex hydrologic relationships.

WATER YEAR

The climatology, surface water and ground water data presented are for Water Years 1989 and 1990:

WY 1989 - October 1, 1988—September 30, 1989
WY 1990 - October 1, 1989—September 30, 1990

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 response of hydrologic systems after October 1 are practically all a reflection of precipitation (snow and rain) occurring within that water year.

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

Gene H. Hollenstein
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Division of Waters

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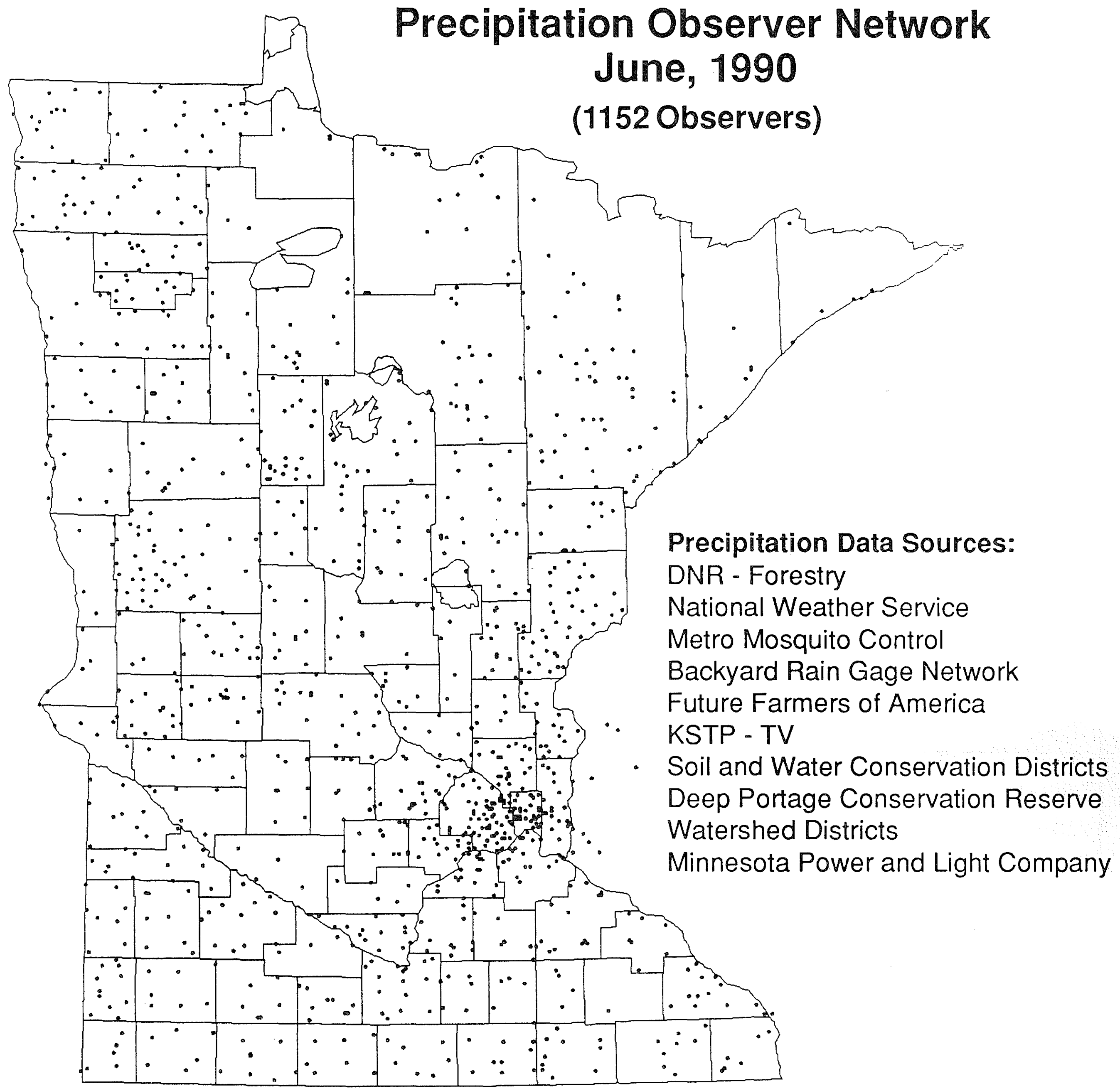
Chapter 1: CLIMATOLOGY



The State Climatology Office attempts to integrate information from a multitude of sources. The organizations listed above as precipitation data sources regularly contribute data from multiple sites. Many of those networks include contributions from other local, state, and federal agencies, private concerns, and individual volunteers. In addition, special climatic information is routinely supplied by the University of Minnesota Agricultural and Forestry Experiment Stations and the Extension Service Climatologist.

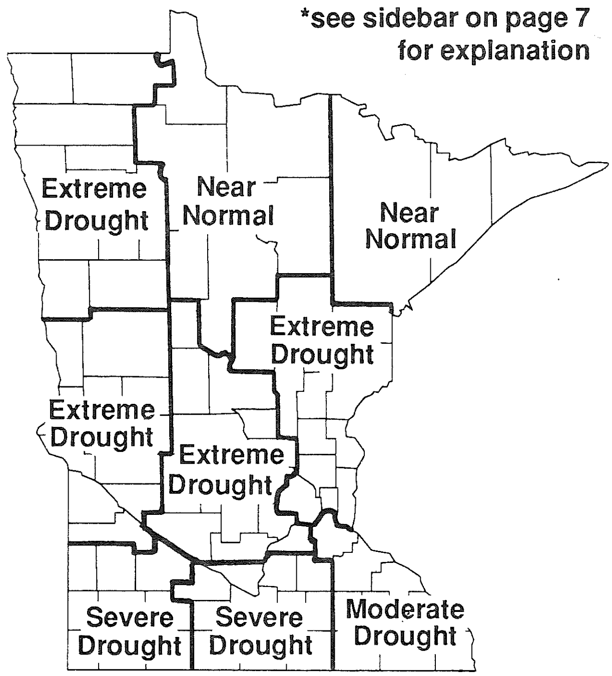
All references to "normal precipitation" in the Climatology chapter are based upon a 30-year average for the period 1951-1980.

Water Year Climate Summary
October 1988 - September 1989

Minnesota entered the 1988 -1989 Water Year reeling from a drought that began in the late fall of 1986, expanded in 1987, and reached maximum intensity in the summer of 1988.

Figure 1. **Palmer Drought Severity Index***
October 22, 1988

***see sidebar on page 7 for explanation**

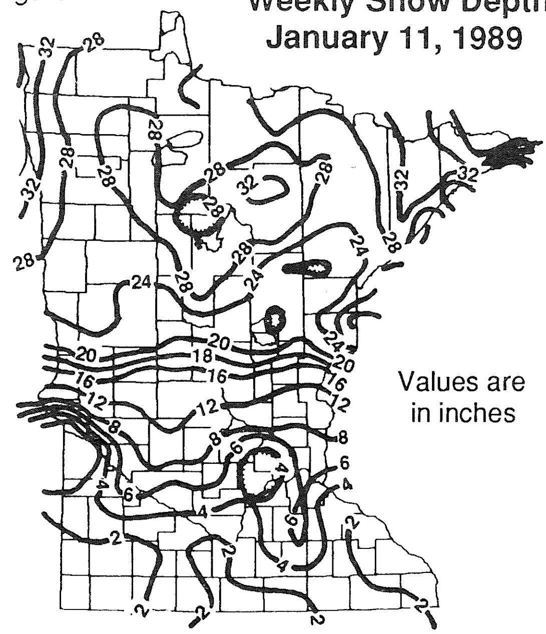


By October of 1988 the state found itself in extreme drought in many areas (Figure 1). Buoyed by near normal fall rains in 1988, soil moisture reserves (water available to plants in the top five feet of soil) had improved to a point where some optimism could be directed toward the coming 1989 growing season. However, other components of the hydrologic cycle (lake and river levels, shallow aquifers, etc.) were still lacking in replenishment.

Winter of 1988 - 1989

The winter of 1988 - 1989 was highlighted by a series of early January snows that blanketed northwestern Minnesota (Figure 2). The heavy snow fell on deeply frozen soil creating an ironic situation where great quantities of water sat above the surface but could not enter the soil. These conditions led to spring flooding of the Red River in the midst of a drought! Winter temperatures were unique in their remarkable transition from a mild January to an unusually cold February.

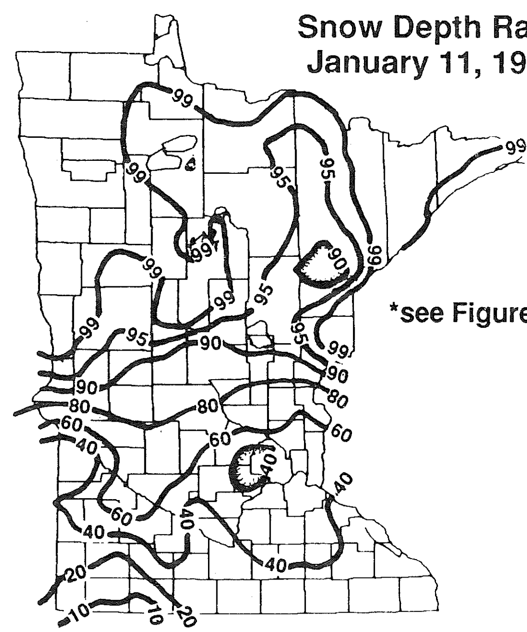
Figure 2. **Weekly Snow Depth**
January 11, 1989



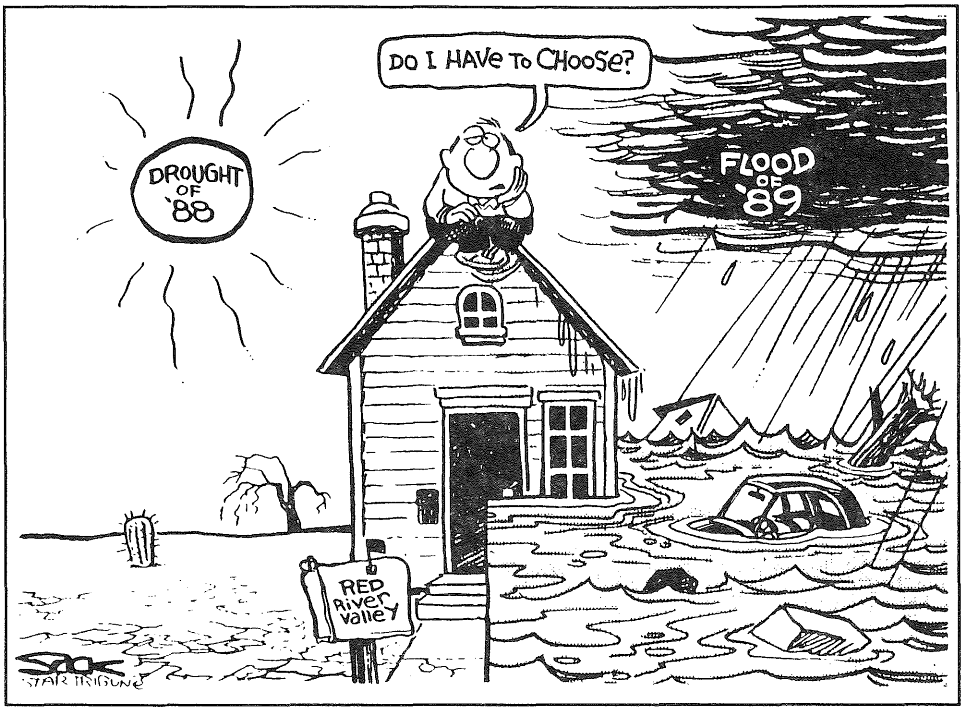
Values are in inches

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

Snow Depth Rank*
January 11, 1989



***see Figure 3**



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In late winter-early spring, a prolonged heavy snow cover (Figure 3) in the northern half of Minnesota with a high water content (three to five inches) led to flooding in the northwest. The snow cover also delayed ice-out on lakes by 3 to 5 days.

Entering the growing season, soil moisture was considered adequate in the top foot of soil with residual dryness remaining deeper in the rooting zone. Surface water systems in the north initially benefited from snow melt while southern surface waters received a far smaller contribution.

Figure 3.

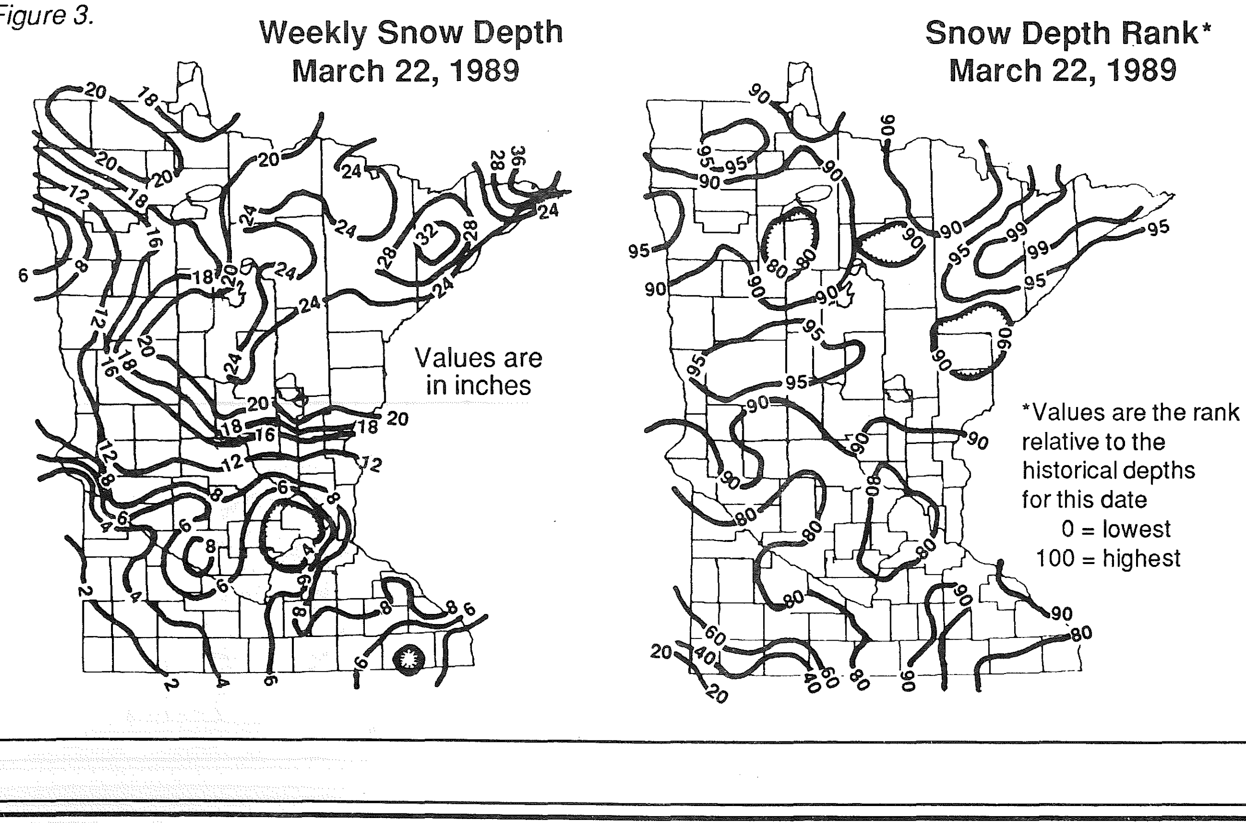
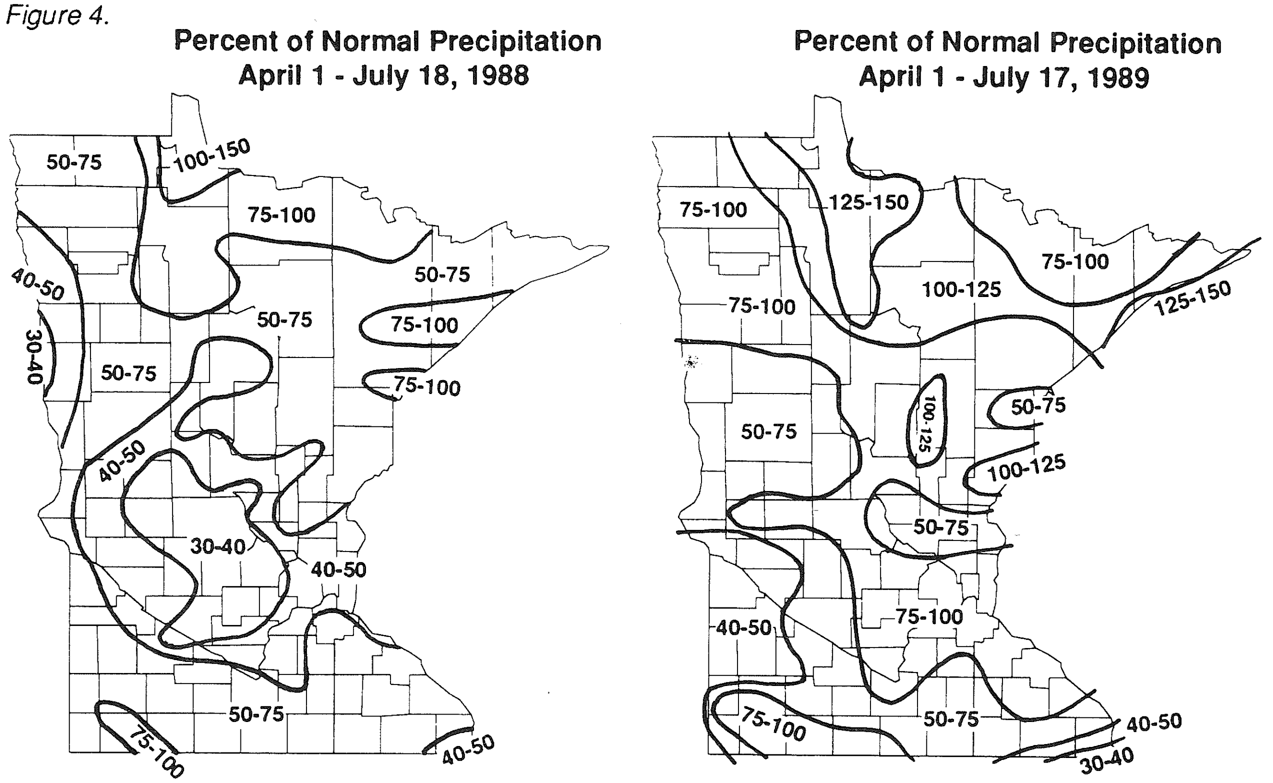


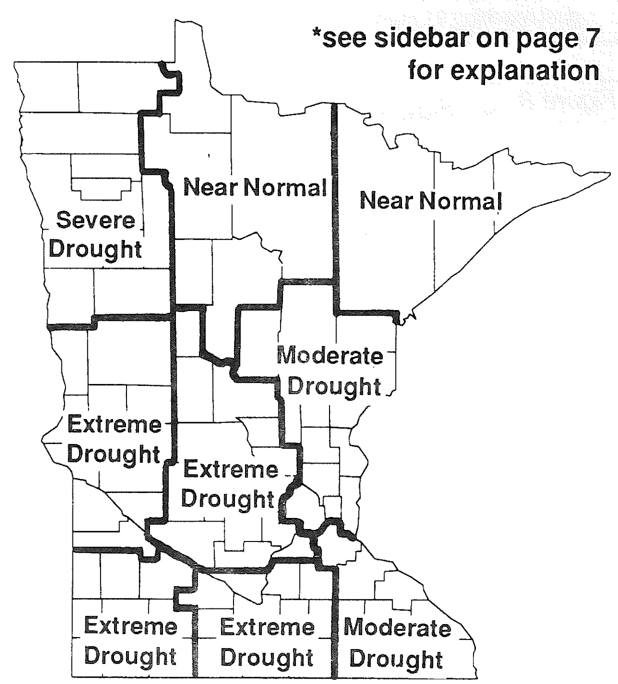
Figure 4.



Spring and Summer of 1989

Spring and summer of 1989 were a lesson in "making the most of what you've got." The ongoing drought, as it approached its third year, neither eased greatly nor did it intensify. Similar to 1988, precipitation continued at below normal levels (figure 4). However, rainfall events were well timed and air temperatures were moderate with only one-fourth as many days over 90 degrees as in 1988. Generally, lawns stayed green and agricultural productivity was surprisingly high. Despite the green tint to the landscape, the underlying condition of much of Minnesota's hydrology was bleak (Figure 5). Rainfall was consumed by plants shortly after falling with little water left to replenish lakes, rivers, wetlands and aquifers. Only the north central and northeastern sections of the state were drought free.

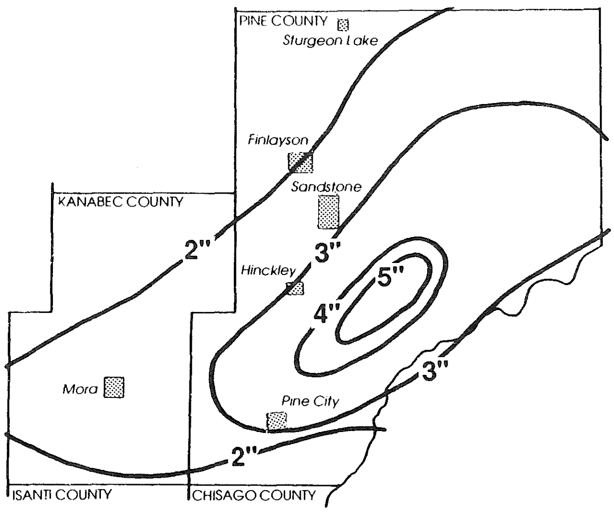
Figure 5. **Palmer Drought Severity Index***
July 15, 1989



Notable Rainfall Events - 1989

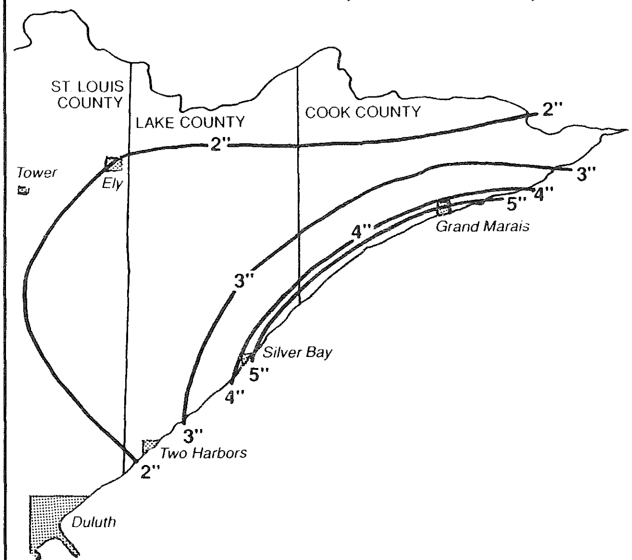
Heavy rainfall events in the spring and summer of 1989 were infrequent. Only one storm (Figure 9) was a "100-year" event, which produced over six inches of precipitation.

Figure 6. **Pine County, May 24, 1989**



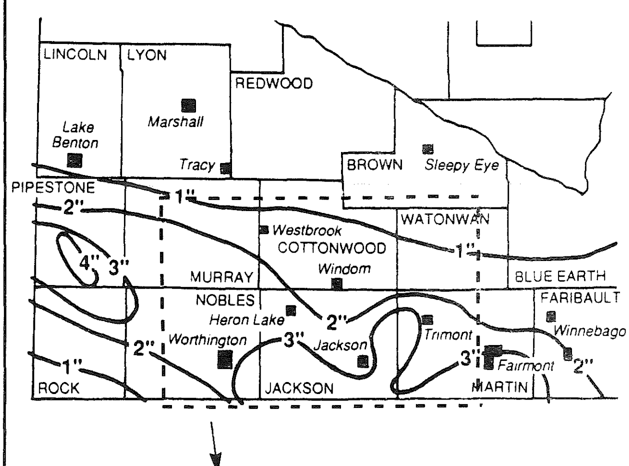
Heavy rains fell upon Pine County during the afternoon and evening hours of Wednesday, May 24, causing washouts of county and township roads. The greatest rainfall amount reported was 6.03 inches in Arlone township, east of Hinckley. The heaviest downpour occurred between 3:30 and 4:30pm. The Arlone township site received five inches between noon and 5:00pm. High winds accompanied the most severe of the thunderstorms. Sustained winds of 60 mph were observed by WCMP Radio in Pine City, with a single gust reaching 91 mph.

Figure 7. **North Shore, June 12-14, 1989**



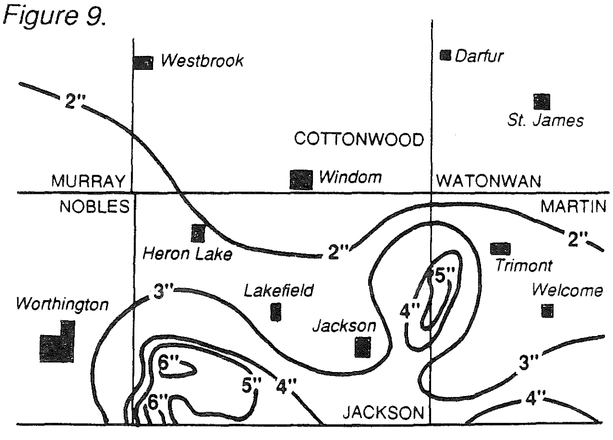
For a 48-hour period ending Wednesday morning, June 14th, torrential rains drenched a 60 mile stretch of Cook and Lake Counties immediately adjacent to Lake Superior. Precipitation totals exceeded five inches in many lakeshore communities. The heavy rains resulted in flooded basements, leaking roofs and washed out roads. The rainfall pattern indicated that the precipitation was enhanced significantly along the shore due to the influence of the lake (cold and moist easterly gales) and the topography of the region.

Figure 8. **Southwestern Minnesota, July 10-11, 1989**



See Figure 9 for detail

Figure 9.



On July 10-11, portions of southwestern Minnesota received much-needed rainfall. The rains began in the early evening hours of the 10th, and fell steadily until the mid-morning hours of the 11th. The gentle rate of rainfall made for very efficient soil moisture recharge. Round Lake township of Jackson County reported the heaviest rainfall with 6.7 inches.

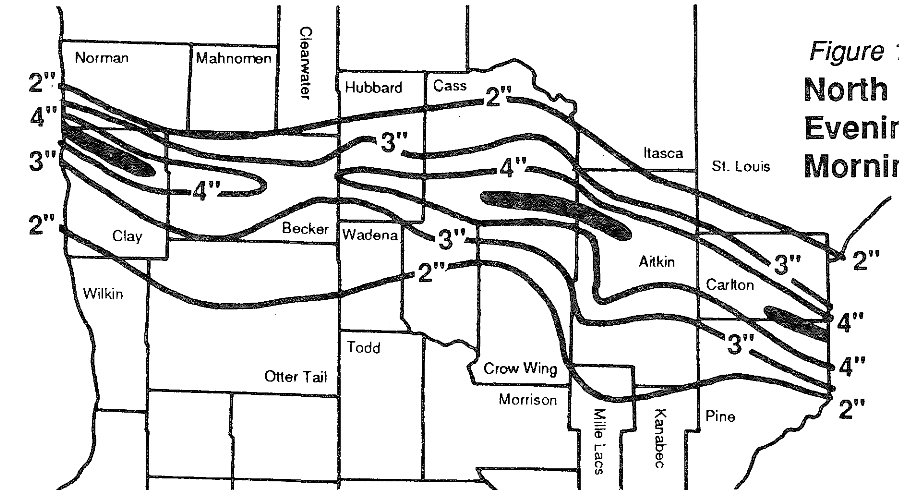


Figure 10.
North Central Minnesota, Evening August 30- Morning August 31,1989

Autumn of 1989 - Water Year Summary

The growing season (and the Water Year) finished strong in August and September with normal to above normal precipitation. Nonetheless, precipitation totals were below normal for the Water Year (Figures 11 and 12). Areas of southern, central, and northwestern Minnesota received from 4 to 8 inches less than normal. While this represents a negative departure from the normal of 25 percent or more, this deficit was still less than the 30 to 40 percent shortfall common in central Minnesota in the 1988 Water Year. Only in north central and northeastern Minnesota did precipitation substantially exceed normal, causing some high water problems.

Figure 11. **Water Year Precipitation October 1988 - September 1989**

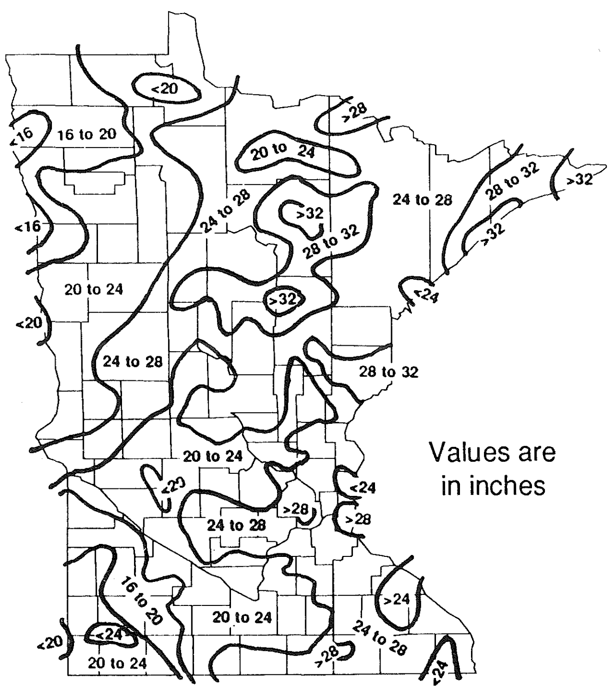
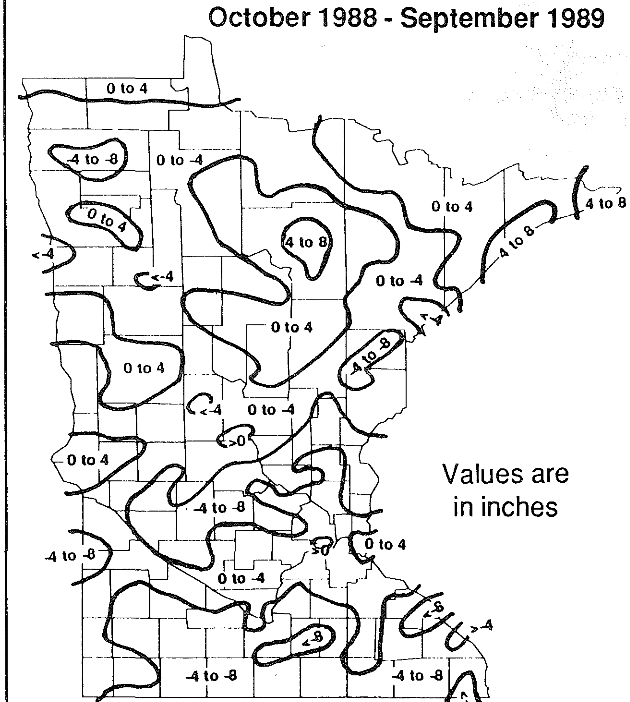


Figure 12. **Water Year Precipitation Departure from Normal October 1988 - September 1989**



Water Year Climate Summary
October 1989 - September 1990

Despite the above average agricultural productivity observed in the 1989 growing season, the overall water picture at the onset of the 1990 Water Year was grim. The relatively meager (yet timely) rain that fell during the growing season of 1989 was immediately absorbed by vegetation. Very little surplus water was available to recharge lakes, rivers, wetlands, and shallow aquifers. Minnesota's drought was three years old (Figure 13) and little improvement was in sight.

To aggravate matters, the fall of 1989 provided less than normal precipitation during a very critical recharge period (Figure 14).

Figure 13. **1987 - 1989 Cumulative Precipitation Departure**

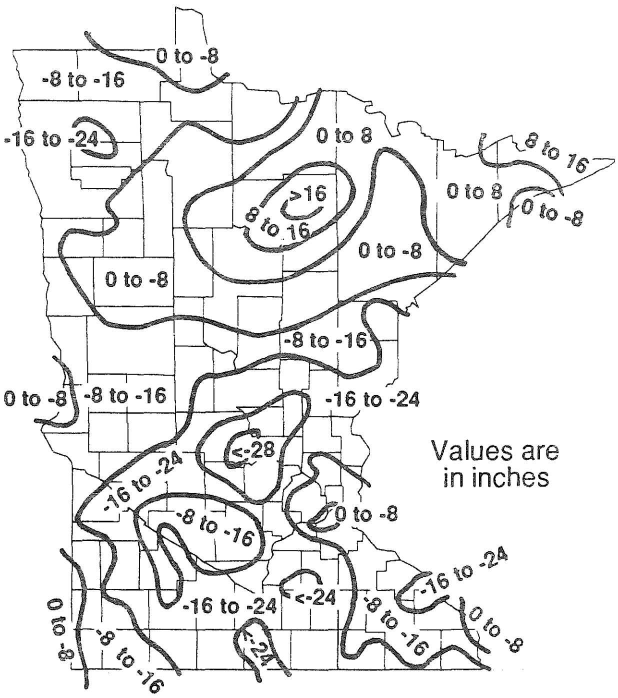
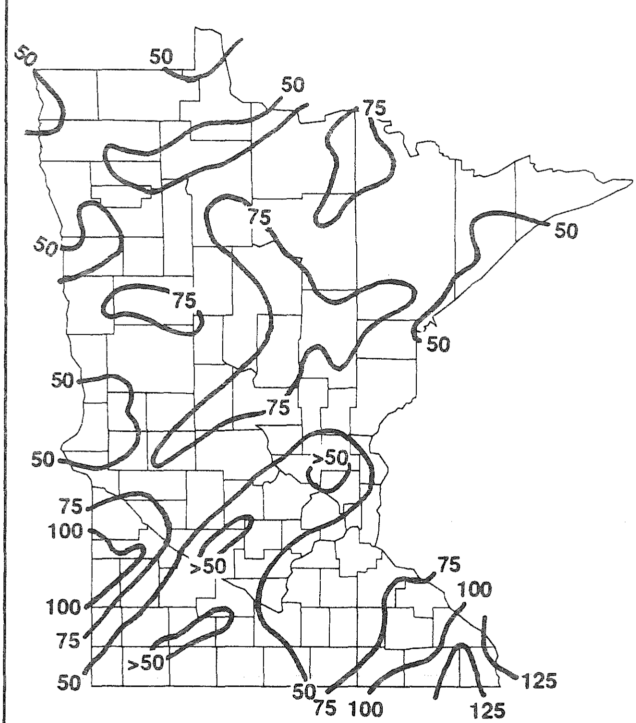
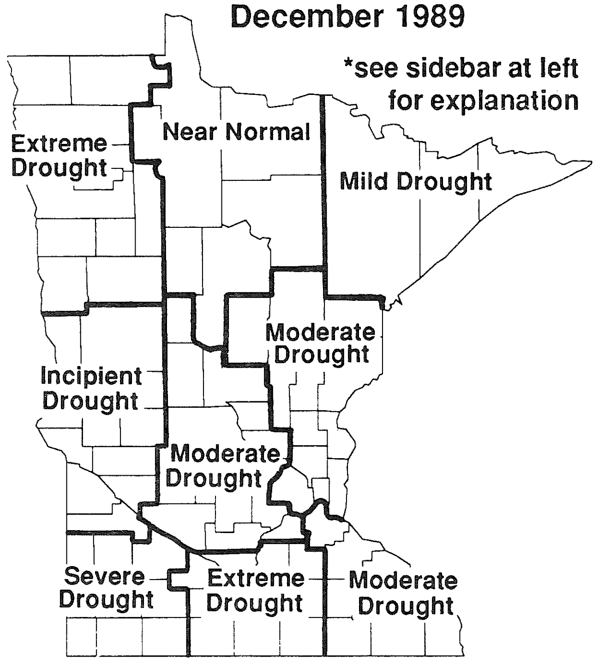


Figure 14. **Percent of Normal Precipitation October - November 1989**



Not only were lakes and wetlands in a deficient state (Figure 15), but soil moisture in the rooting zone was two to five inches below historical averages in many places (Figure 16). True recovery for most hydrologic systems can occur only after moisture in the soil (roughly the top five feet) is replenished.

Figure 15. Palmer Drought Severity Index* December 1989



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

Figure 16. Available Soil Moisture in Top Five Feet of Soil and Field Capacity November 1, 1989

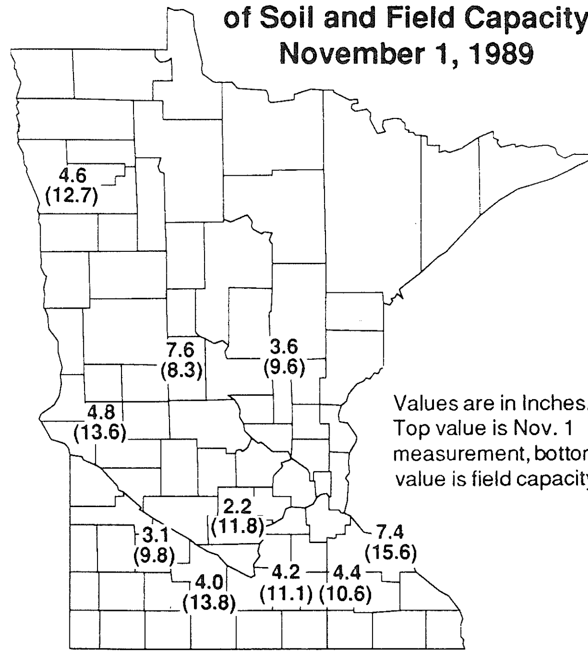
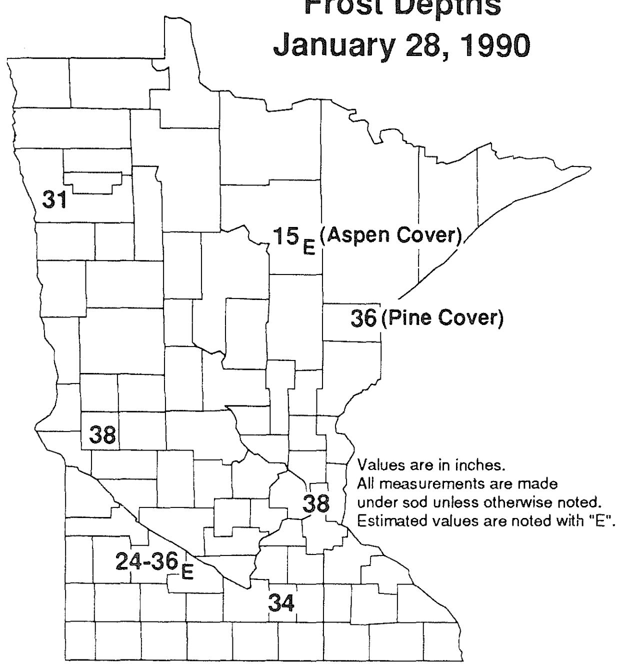


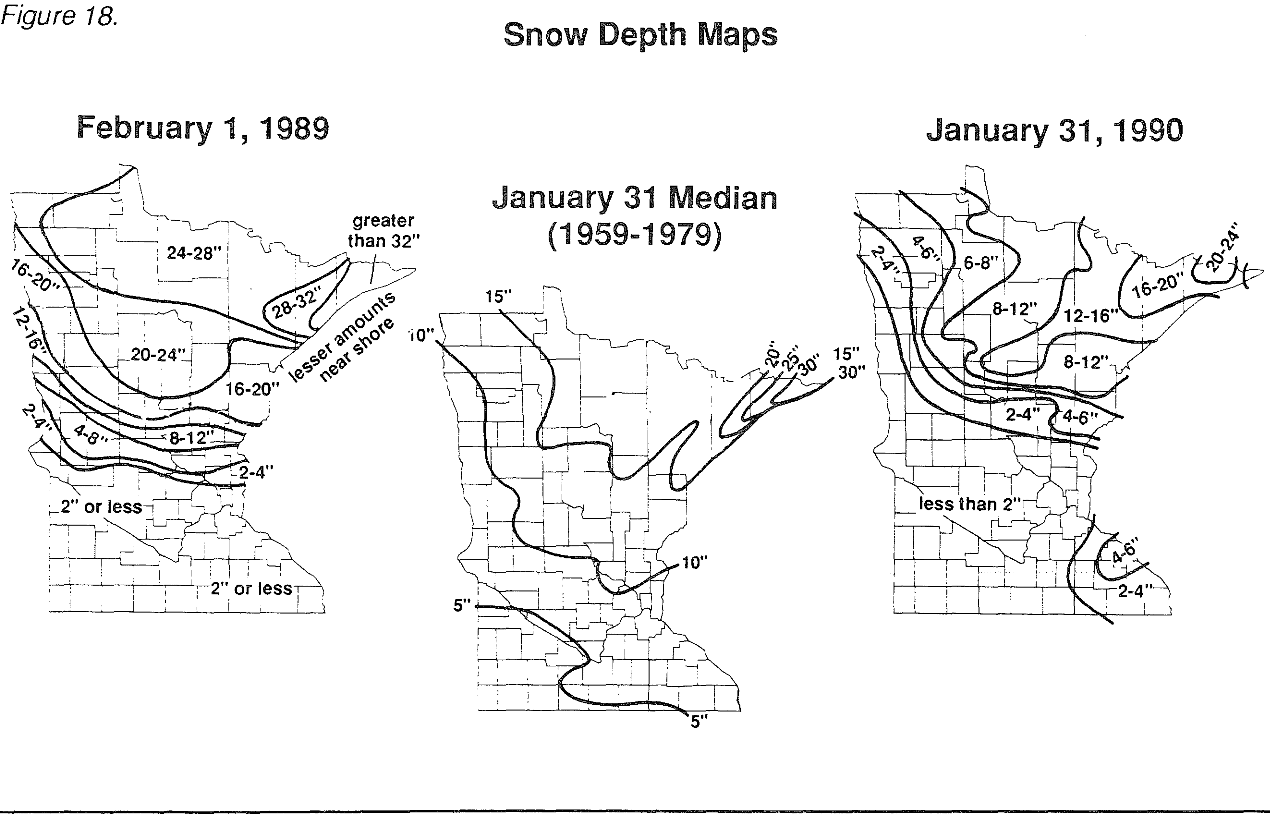
Figure 17.



Winter of 1989 - 1990

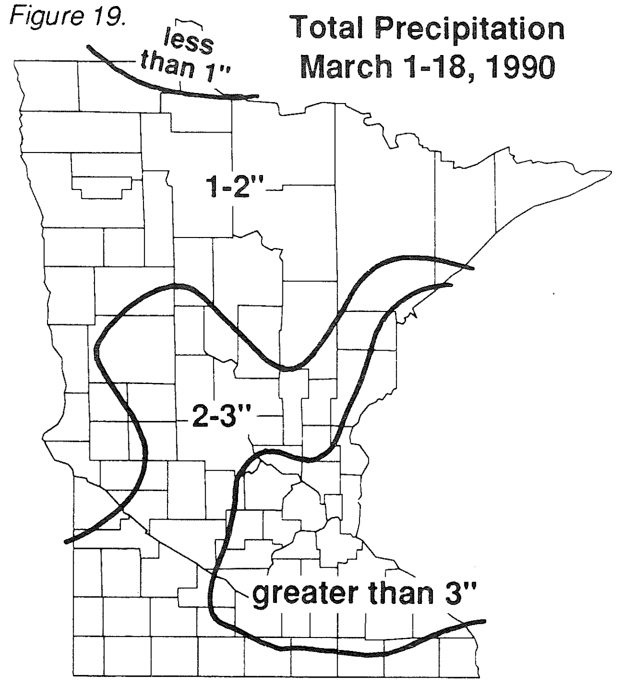
The winter of 1989-1990 began with an extremely cold mid-December where temperatures consistently fell below -20 degrees Fahrenheit. Coupled with a lack of snow, the cold temperatures caused a thorough and deep freezing of the ground (Figure 17) that would prevent over-winter precipitation from entering the soil. Fortunately, the temperature moderated for the remainder of the winter, resulting in an exceptionally mild January and February. However, snowfall was scarce and much of Minnesota displayed a brown landscape, even in late January (Figure 18).

Figure 18.



Late winter and early spring of 1990 began with a mixture of warmth and substantial moisture. For the first time in many months, heavier than normal precipitation covered much of the state. Many areas of Minnesota received double their normal March allotment of precipitation (Figure 19). Warm breezes in March thawed soils two to three weeks ahead of schedule, allowing for generous infiltration of the welcome rains. Warm temperatures also advanced lake ice-out by nearly 10 days.

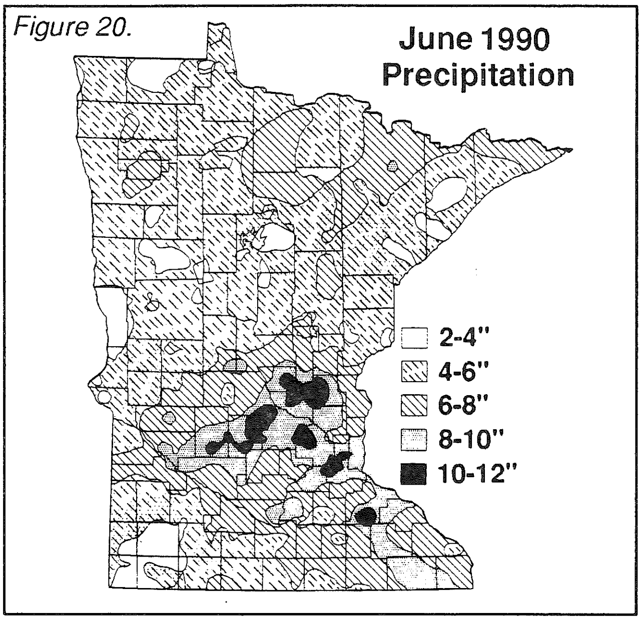
Figure 19.



Spring and Summer of 1990

The wet March was a harbinger of things to come. Spring and early summer continued at a pace that seemed destined to erase the drought. April and May finished at or above historical precipitation averages while June produced rainfalls of unusual magnitude. Several Minnesota communities received eight to ten inches of rainfall for the month (Figure 20). Excessive wetness was a problem for the first time in four years in southern Minnesota, with heavy rainfall continuing into July in the southern half of the state. However, areas of western, northwestern, and north central Minnesota were slighted by the rainfall events experienced elsewhere in the state.

Figure 20.



By the second week of August, statewide precipitation diminished abruptly. This pattern continued through the end of the Water Year with a notable exception near Cloquet (Figure 23). Southern Minnesota, bolstered by a wet June, finished well above the historical average for the growing season of April through September (Figure 21). In contrast, much of northwestern Minnesota once again finished below normal.

Figure 21.

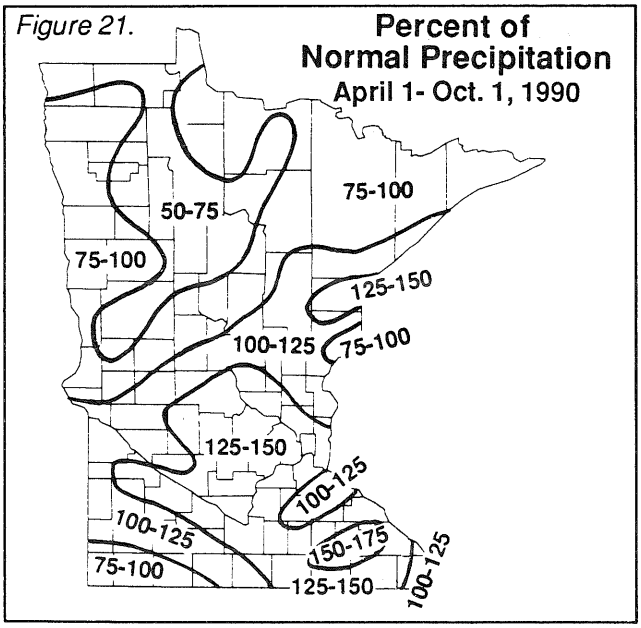
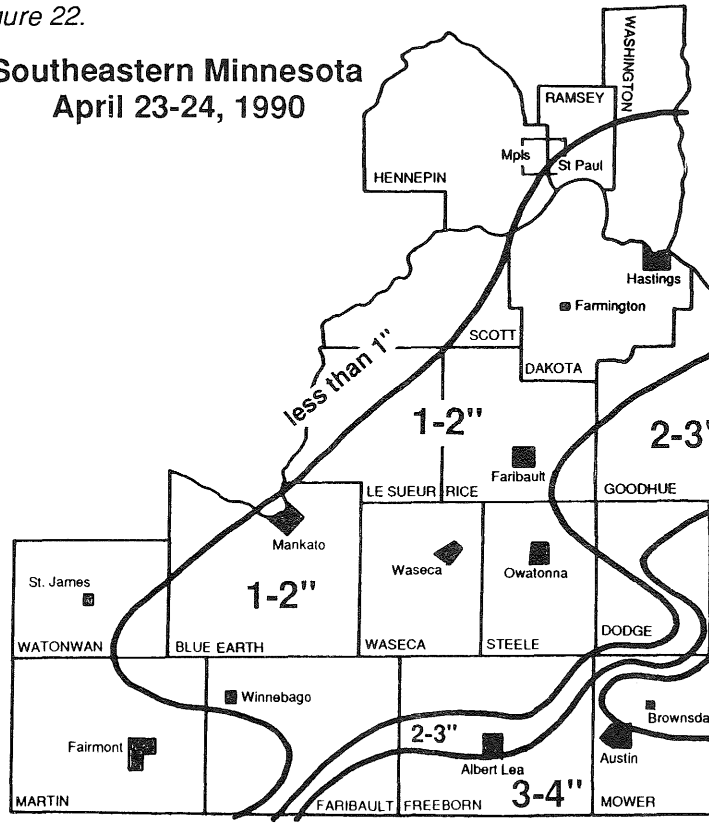


Figure 22.

Southeastern Minnesota April 23-24, 1990

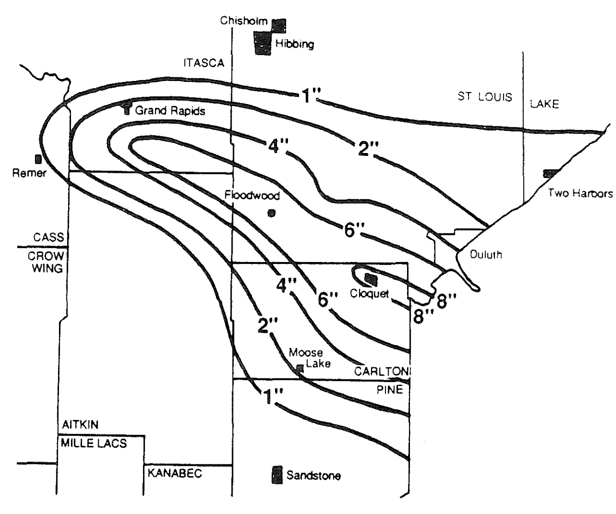


During the afternoon hours of April 23rd and the early morning hours of April 24th, much of southeastern Minnesota was doused with much needed rain.
At a few locations the heavy precipitation caused some minor flooding, however, for most, the rain was a welcome opening to the 1990 growing season.
The heaviest, confirmed 24-hour total was 5.35 inches at Chatfield on the Olmsted-Fillmore County border with an unconfirmed report of 6.6 inches northwest of Brownsdale in Mower County.

Notable Rainfall Events - 1990

Notable rainfall events included a large storm complex that drenched southeastern Minnesota in April (Figure 22). A succession of thunderstorms dropped five to seven inches of rain on parts of southwestern and central Minnesota in mid-June (see Figure 20). In early July, a powerful storm caused some flooding along a thin strip from the city of Faribault to Wabasha County. In the grand finale, a group of heavy thunderstorms pounded the Cloquet area in early September (Figure 23).

Figure 23. **Flash Flood in Duluth Area September 5-6, 1990**



Heavy thunderstorms moved through the area extending from southern Itasca County to eastern Carlton County and into northwestern Wisconsin on the evening of September 5, 1990. The heavy rain began about 6-7pm on the 5th and continued in some areas until about 6am on the 8th (12 hours). Seven inches were received at Jay Cooke State Park between 10:30pm and 5am. More than 40 reports from the National Weather Service, DNR Forestry, and County Soil and Water Conservation offices were used to create the accompanying analysis. The heaviest totals known (as of noon Sept.6) were 9.03 at DNR/Cloquet, 7.27 south Itasca County SWCD (T53N R24W) and 6.93 at Floodwood.

Figure 24. **Water Year Precipitation October 1989 - September 1990**

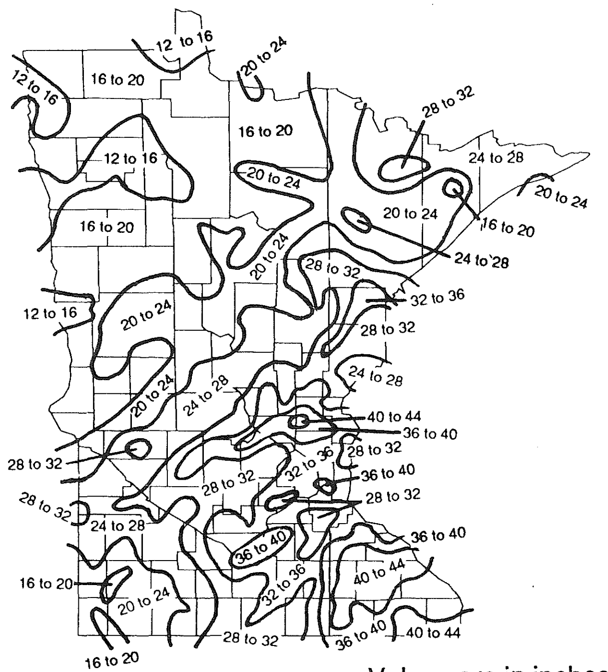


Figure 25. **Water Year Precipitation Departure from Normal October 1989 - September 1990**

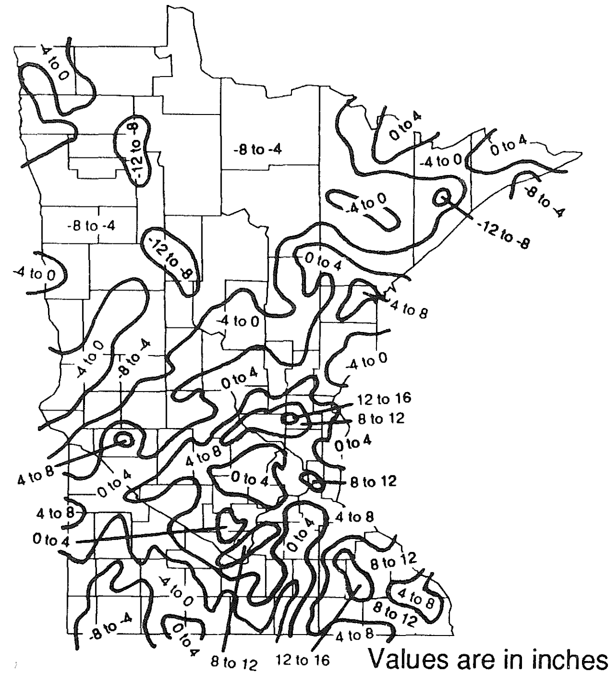
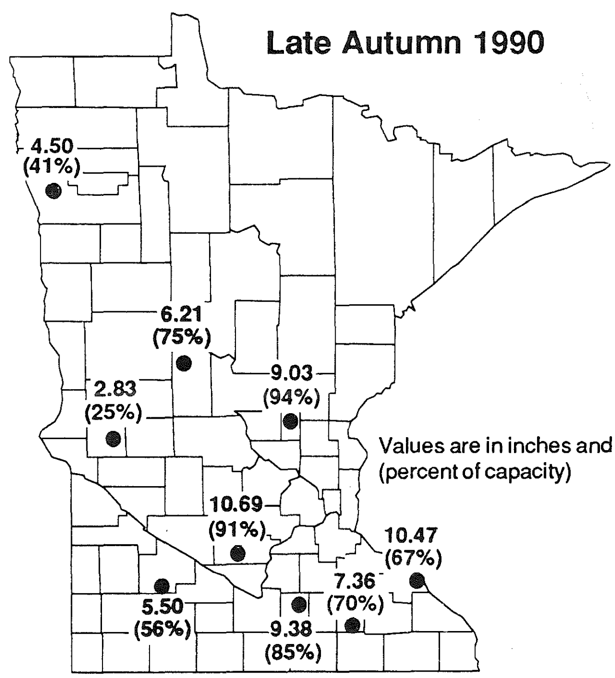


Figure 26. **Available Soil Moisture in Top Five Feet of Soil and Percent of Capacity**

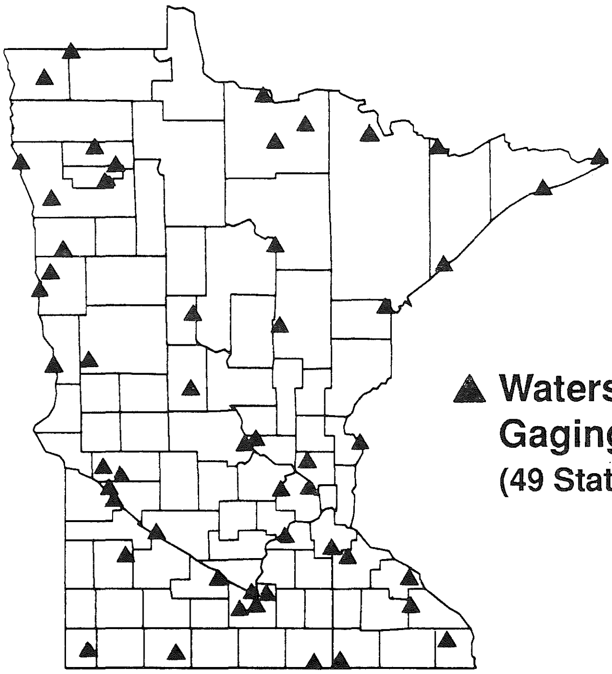


Autumn of 1990 - Water Year Summary

In Water Year 1990, a contradictory pattern of above normal, even excessive, precipitation existed in southeastern sections of the state, with below normal precipitation in the southwest, west, and north (Figures 24 & 25). A state of extreme drought persisted in the northwest where no sustained relief had materialized for four years. Despite the wet early summer in parts of Minnesota, the long term impacts of the three-year (1987-1989) drought continued. Soil moisture values were adequate to abundant in some areas (Figure 26), although the overall hydrologic situation was still in need of improvement.

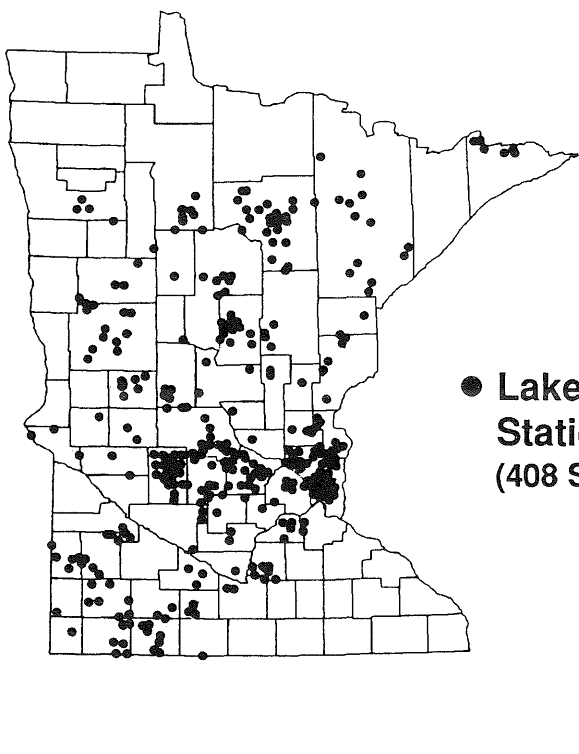
Chapter 2: SURFACE WATER

Stream Flow



▲ Watershed
Gaging Station
(49 Stations)

Lake Levels



● Lake Gaging
Station
(408 Stations)

Surface Water
Stream Flow

Introduction

Developing an Instream Flow Program and monitoring stream flow are two important functions of the Division of Waters' Surface Water Unit.

The Instream Flow Program was established for the purpose of evaluating the demands placed upon surface water resources. The major emphasis of the Instream Flow Program is to establish "protection levels" for streams, rivers and other surface water sources. Once a lake level or the discharge of a river or stream has dropped below an established protection level, all nonessential appropriations of water from that source must cease. This action is designed to provide protection of the resource and to maintain the water supply for downstream users.

Stream flow monitoring is also an important element of the Division's work. The availability of stream flow data is essential for the many day-to-day decisions that involve surface water resources. The Surface Water Unit shares this important information with the many and varied users of these resources. The Division relies primarily on the United States Geological Survey (USGS) stream gaging network for data acquisition.* Stream gaging data acquisition is supplemented through the cooperative efforts of DNR staff and a growing network of volunteers.

Figure 1 shows the 81 major watersheds in Minnesota and the location of the gages used to monitor stream flow conditions. Using these watersheds as a base, the Division selected and designated the most appropriate USGS gages to monitor stream flows around the state.

Stream Flow Reports

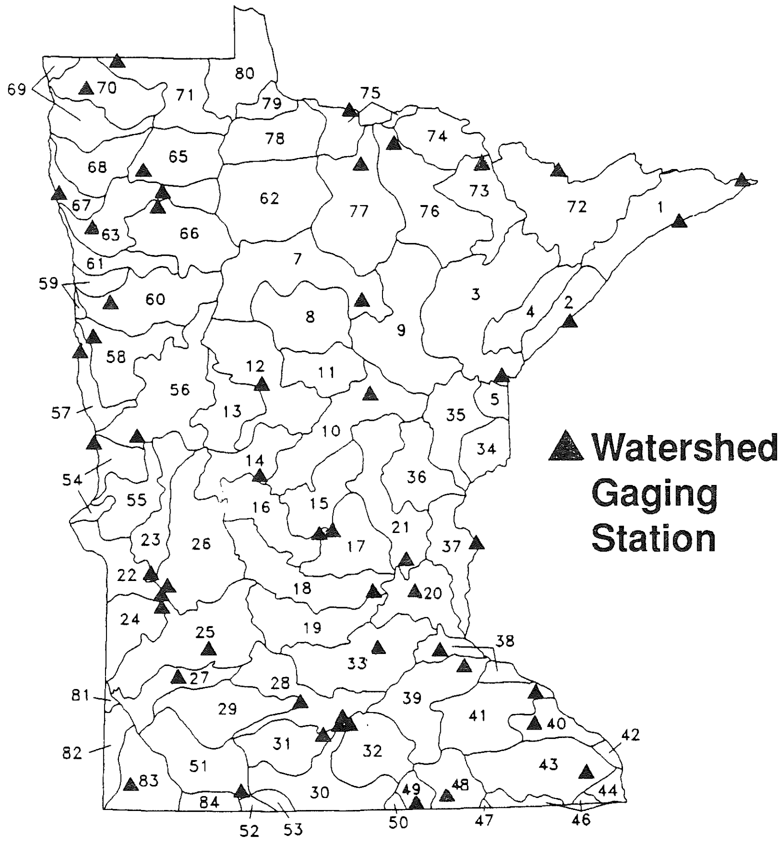
In response to the continued drought conditions, the Surface Water Unit began producing a stream flow report in 1989 to keep the Division of Waters staff and other concerned interests apprised of weekly changes in stream flow conditions around the state. Included with each weekly stream flow report is a map that reflects flow conditions in the 81 major watersheds. Figures 2 and 3 are selected stream flow maps for the 1989 and 1990 Water Years. A low flow report is also prepared to address those rivers and streams where flows are reaching critically low levels. Rivers and streams in this condition are monitored daily and a low flow report is generated three times a week or as requested.

Flow conditions are based upon monthly exceedence values. An exceedence value is a statistical parameter based upon historical discharge records, and is the probability of stream flow exceeding a certain value. For example, 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. Likewise, a 75% exceedence value (Q75) is the discharge that has been equalled or exceeded 75% of the time.

*The data supplied by the US Geological Survey, the National Weather Service and the US Army Corps of Engineers is provisional data and is subject to revision.

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 (Sartell)▲
16 Sauk River▲
17 Mississippi River (St. Cloud)
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 (Granite Falls)▲
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 (Stillwater)▲
38 Mississippi River (Red Wing) and Lake Pepin▲
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 Wapsipinicon 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 Vermilion 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

The stream flow map classifies each major watershed as having either excessive, deficient or normal flow conditions, or no report. Stream flow that is greater than the 25% exceedence (Q25) value is considered excessive while flow that is less than the 75% exceedence value (Q75) is considered deficient. Discharges between Q75 and Q25 are considered normal. Nonreporting watersheds commonly do not have a gaging station or, when they do, lack a sufficient period of record with which to calculate exceedence values. The Q90 level is also calculated as part of the weekly stream flow report. When a river drops below the Q90 value, flows are considered seriously deficient. Figure 6 shows two sample hydrographs of the Mississippi River near Anoka, Minnesota, along with the monthly Q50, Q75 and Q90 exceedence levels.

1989 and 1990 Stream Flow Conditions

Soil moisture, ground water and surface water storage areas were severely depleted in 1987-1988. By autumn of 1988, most of Minnesota was experiencing very serious drought conditions. Throughout the winter of 1988-1989, stream flows in most of the state fluctuated around the 75% exceedence value. During the spring of 1989, stream flows showed noticeable improvement over most of the state, due to a combination of autumn rains, winter snow melt and timely spring rainfall. Even with this partial recharge, near-surface ground water supplies and bank storage remained below average.

Figure 2.1 shows two distinct stream flow conditions. In the northern half of the state, most of the watersheds reported near normal flow conditions*, while in the southern half most of the watersheds were deficient. By mid-July, many of the stream flows in northern Minnesota had increased to excessive levels, while watersheds with deficient flows spread into both the west and the central parts of the state (Figure 2.2). By August 18, 1989, deficient flow conditions included most of the central part of the state, the Red River Valley and much of the northeast (Figure 2.3). Figure 2.4 shows limited improvement in many watersheds, but much of Minnesota remained in deficient conditions. Excessive flows in watersheds 7 and 8 are likely due to the annual autumn drawdown of the Mississippi River headwater reservoirs rather than improved precipitation.

Spring snow melt and runoff in 1990 occurred nearly a month early while precipitation levels continued to be well below average. By late May, however, both precipitation and stream flows over much of the state had improved (Figure 3.1). While the south-central part of the state and much of the northern half had improved into the normal range, the southeast was experiencing excessive flows. Portions of the Red River Valley, north central Minnesota and the extreme northeast remained in the deficient flow range. June of 1990 turned out to be one of the wettest on record for most of Minnesota. Stream flows in the southern half of the state and much of the northeast increased to excessive. In the Red River Valley and the north central region, stream flows increased to near normal (Figure 3.2). A continued wet spell maintained excessive flows in the southern half of the state through July and early August (Figure 3.3). Subsequently, precipitation abruptly returned to below average levels over much of the state. The Water Year ended with the southern one-third of the state experiencing near normal flows and most of the northern two-thirds returning to the deficient range (Figure 3.4).

"Normal flow conditions" for the purpose of this report are between Q25 and Q75 exceedence values.

Stream Flow Maps - 1989

Figure 2.1.

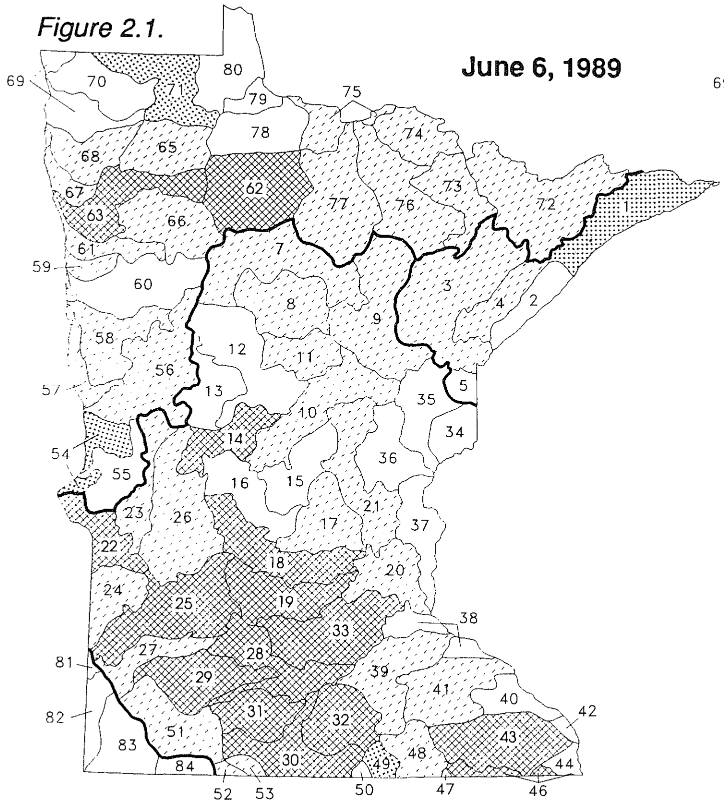
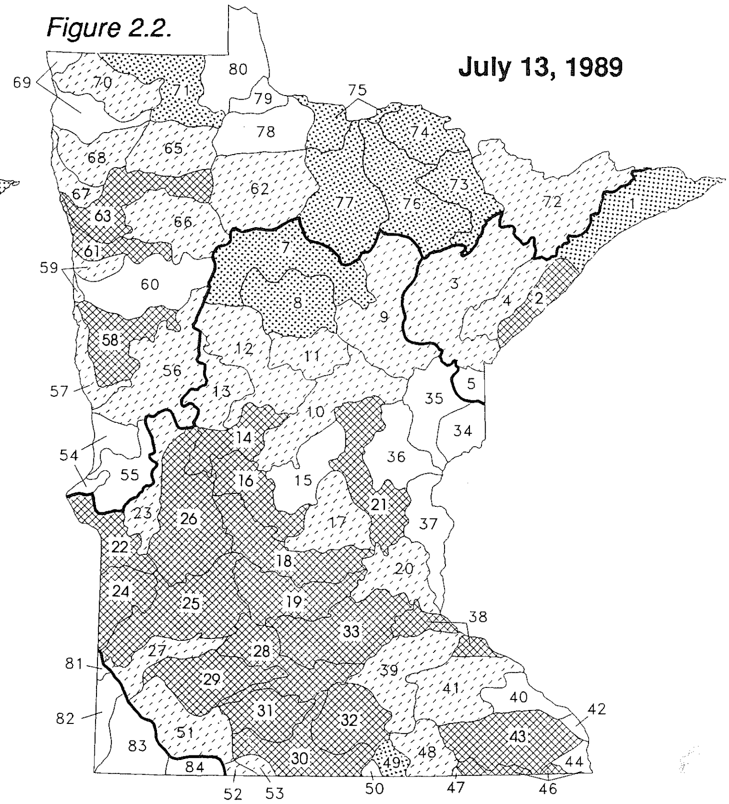


Figure 2.2.



Excessive Flow | Normal Flow | Deficient Flow | No Report

Figure 2.3.

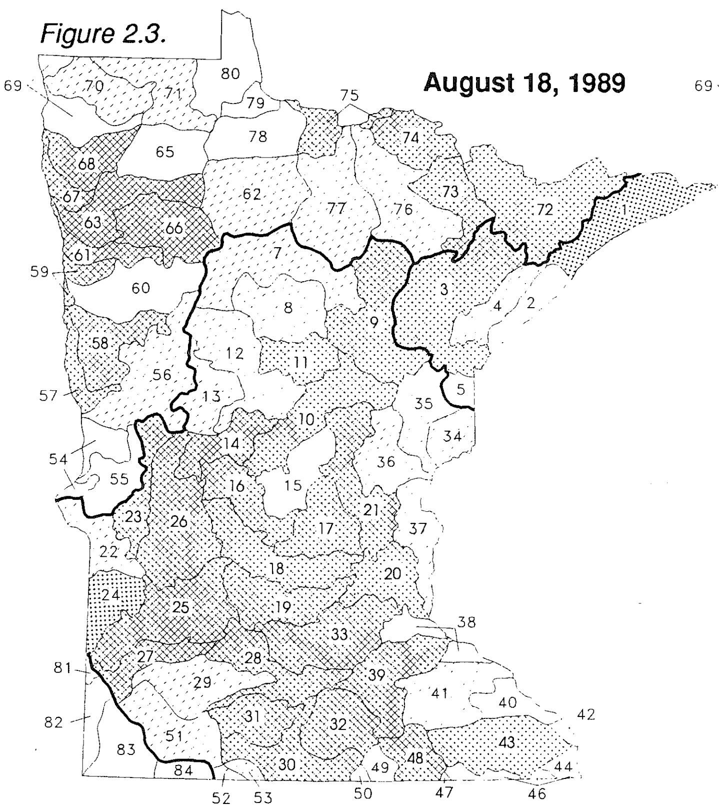
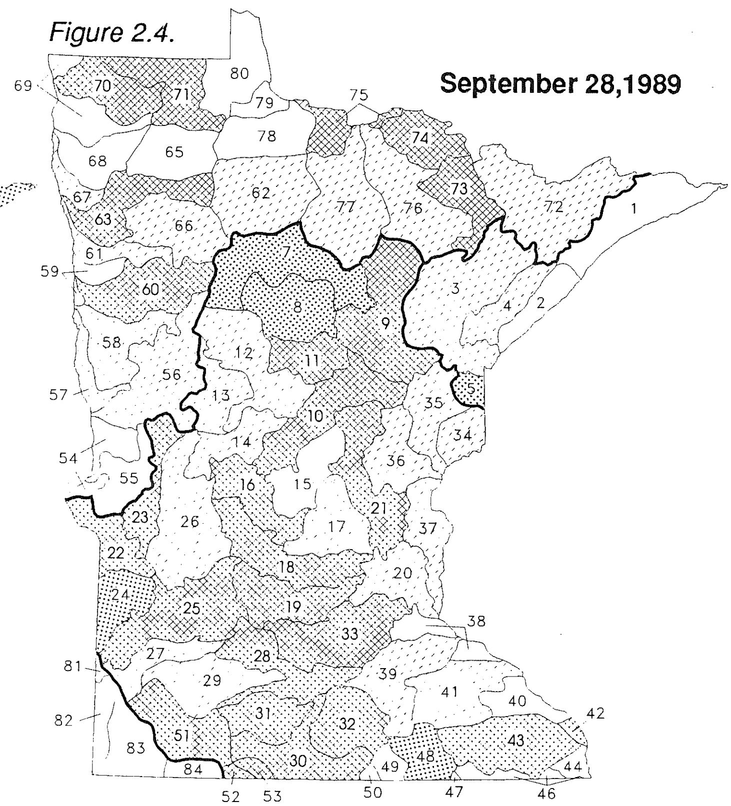


Figure 2.4.



The conditions represented are based on instantaneous gage height readings. These data are provisional and are subject to revision.

Stream Flow Maps - 1990

Figure 3.1.

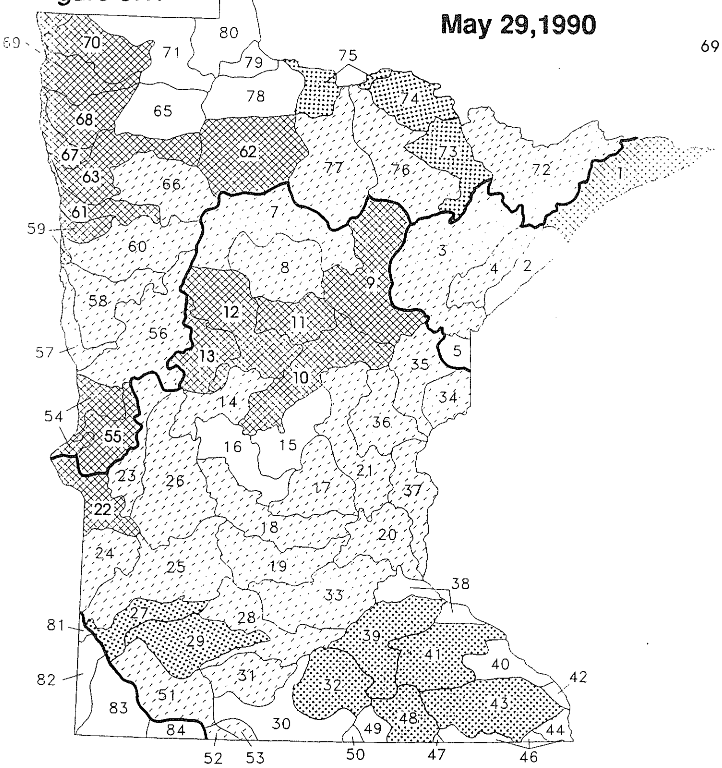
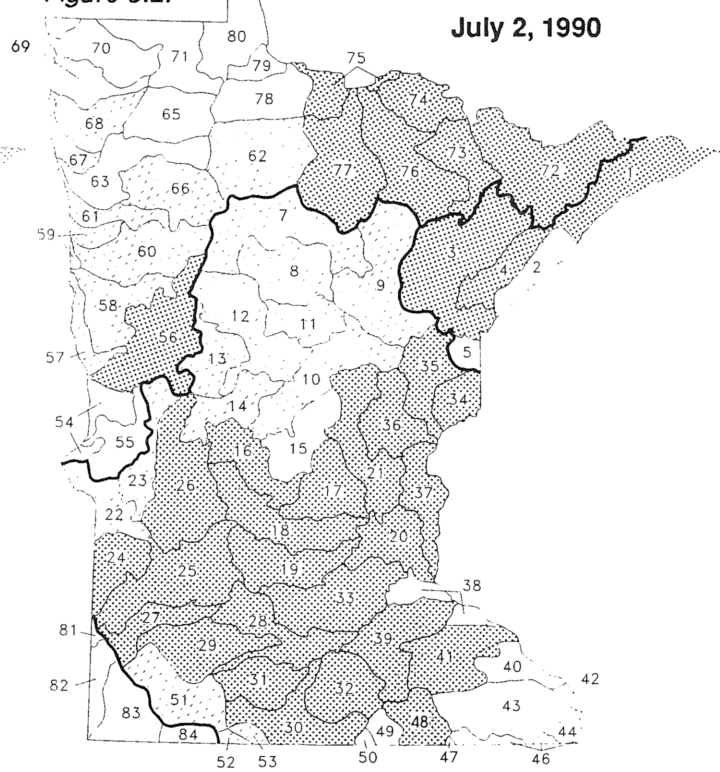


Figure 3.2.



Excessive Flow | Normal Flow | Deficient Flow | No Report

Figure 3.3.

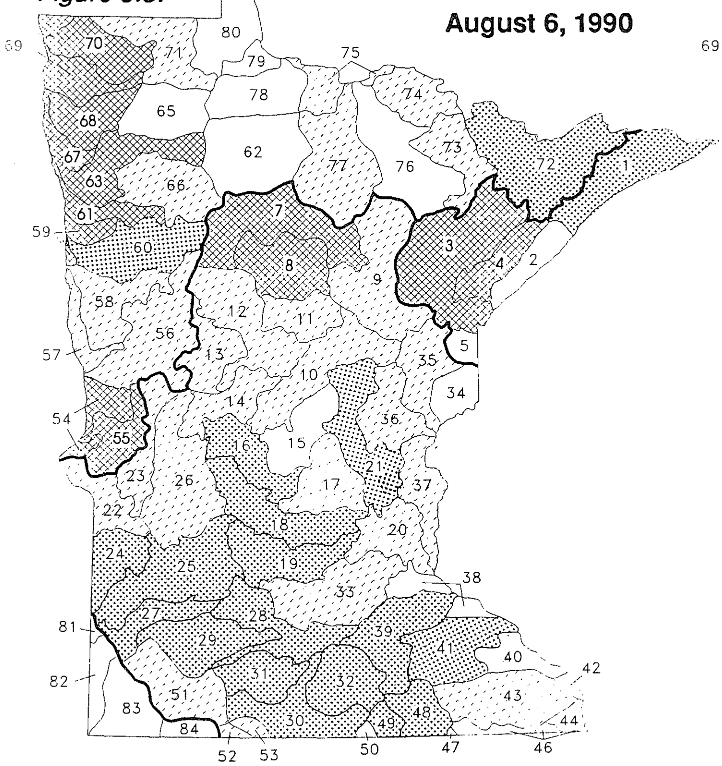
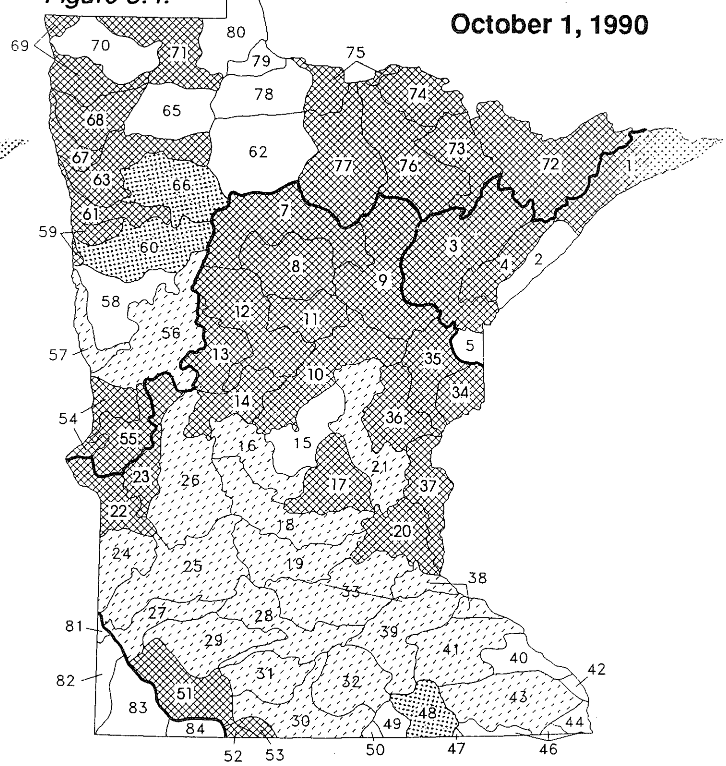


Figure 3.4.



The conditions represented are based on instantaneous gage height readings. These data are provisional and are subject to revision.

Hydrographs

Figures 6 through 10 show hydrographs for the five Minnesota rivers identified below (Figure 5). A stream flow hydrograph is a graph where the average volume of water discharged each day is plotted against the day of the year. Discharge on a hydrograph is given in Cubic Feet per Second (CFS). One CFS is equal to just under 2 acre-feet of discharge per day.

Figure 4. **Palmer Drought Severity Index* September 1990**

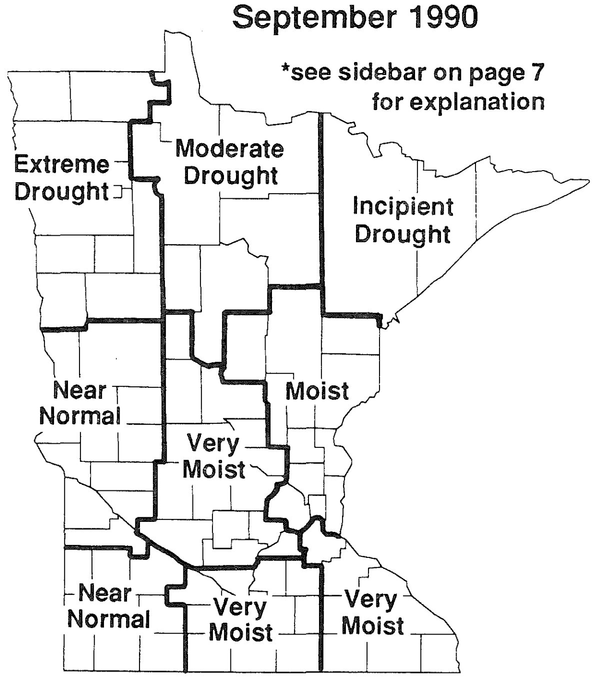


Figure 5. **River Hydrograph Locations**

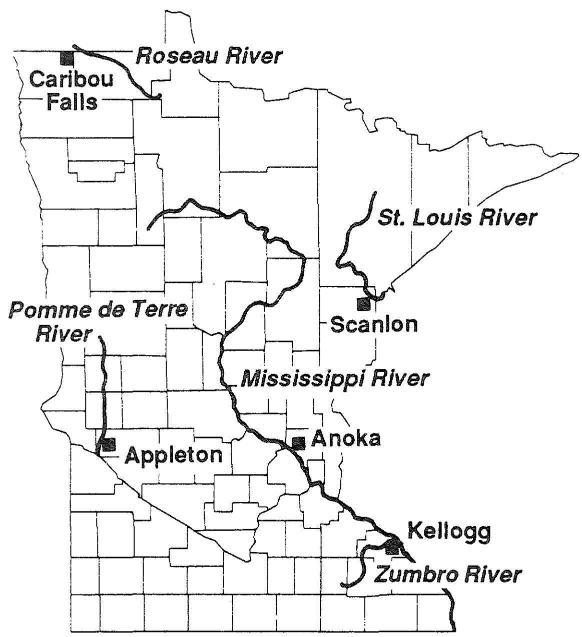


Figure 6.

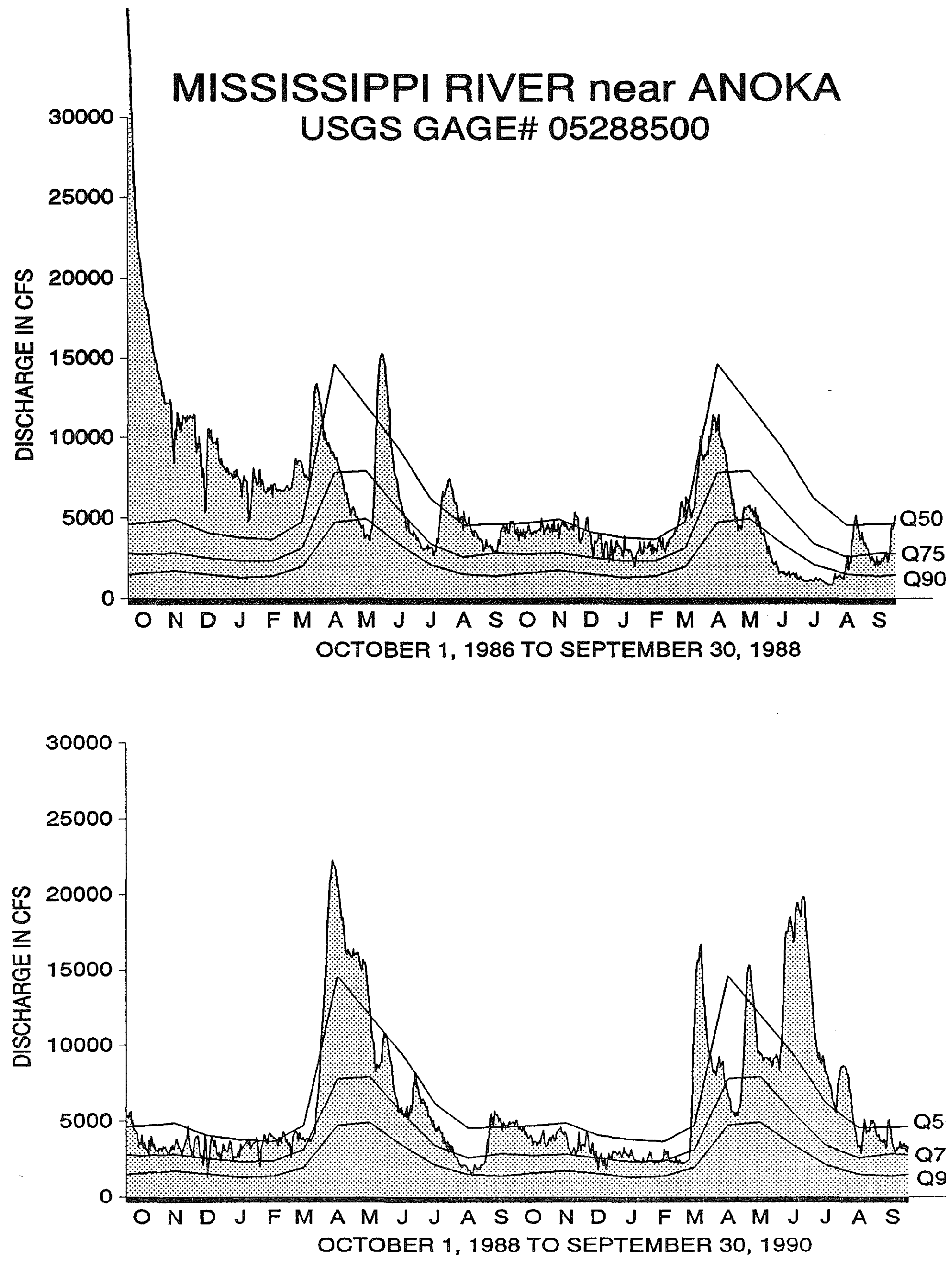


Figure 6 shows hydrographs of the Mississippi River at the Coon Rapids Dam near Anoka. The hydrographs for the 1987 and 1988 Water Years have been included in this report to give some indication of the condition of the Mississippi River prior to the 1989 and 1990 Water Years.

For the Twin Cities Metropolitan Area, the five- and ten-year periods ending in October 1986 were two of the wettest periods on record. Base flow (see sidebar at right) in the Mississippi River (Figure 6) reflects this wet period even though precipitation was well below average through the fall and winter of 1986 -1987. Discharge remained well above normal until the spring of 1987. The effects of the continuing drought on stream flow became acute by the summer of 1988 when flow dropped to extremely low levels. Releases from the headwaters reservoirs to augment the Mississippi became a serious discussion item as a result of concern over the low flow conditions in the river.

Discharge levels of the Mississippi River and precipitation generally remained below average into 1989. The spring snow melt resulted in above average flows but a lack of summer precipitation caused a rapid return to very low flows by August. Early 1990 gave indications of continued low flow conditions but late spring rains substantially bolstered flows. Lack of significant precipitation within this watershed again occurred in the late summer into fall with flow levels generally declining through the end of the year.

During periods of low precipitation, flows within Minnesota's rivers and streams are maintained by base flow. **BASE FLOW** is water supplied by the near-surface ground water aquifers, water stored in sediments along the banks of the rivers and streams, and surficial basin storage (lakes and wetlands) within the watershed. These sources of base flow are commonly recharged during the spring runoff period.

Figure 7.

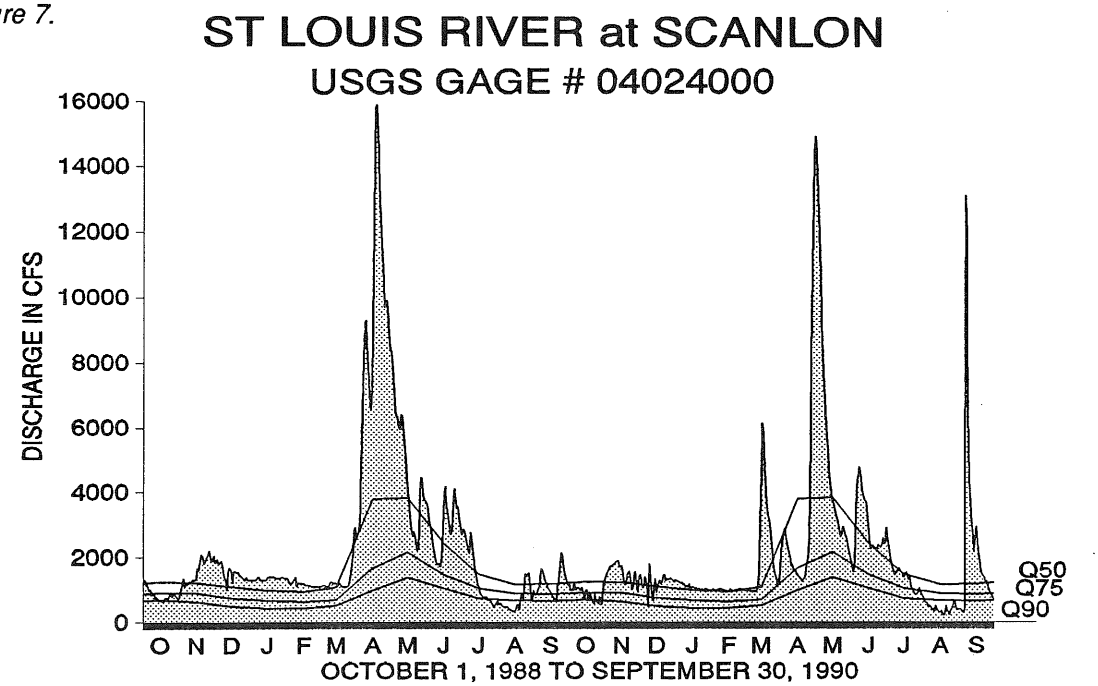


Figure 7 is a hydrograph of the St. Louis River at Scanlon in northeastern Minnesota. Flow in the St. Louis River was not as significantly impacted in 1987-1988 because precipitation amounts were generally higher than in other areas of the state. In 1989 and 1990, however, both July and August flows were seriously deficient due to drought conditions. The system recovered rapidly in early September 1990 when a superstorm dropped more than 14 inches of rain on portions of the St. Louis River watershed.

Figure 8.

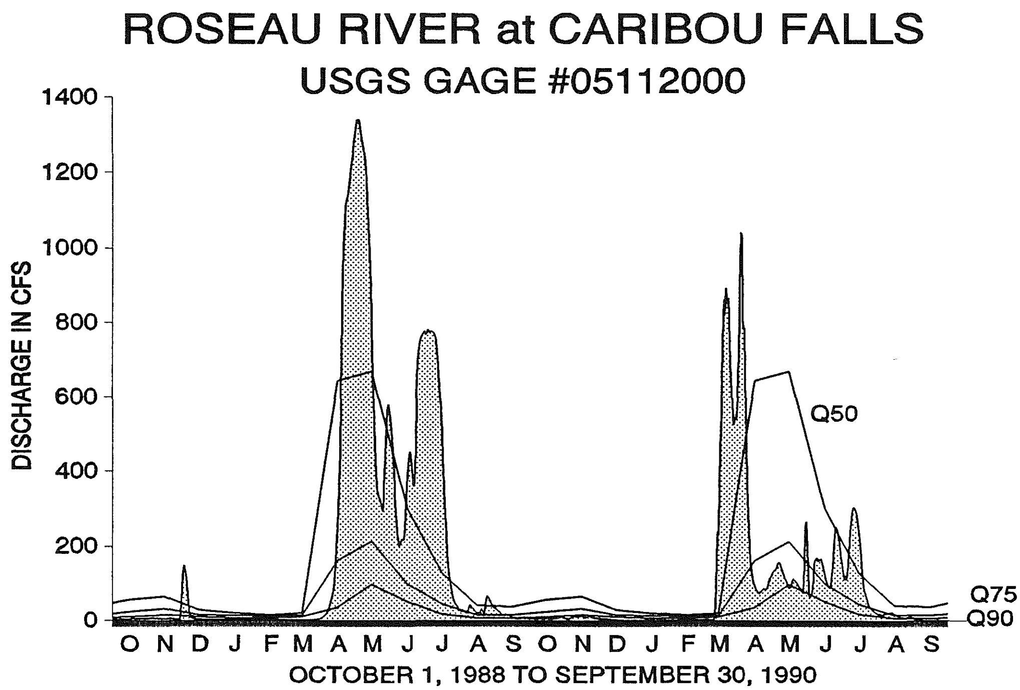


Figure 8 is a hydrograph of the Roseau River at Caribou Falls. Flows in the Roseau River were critically low at the beginning of both 1989 and 1990 and remained deficient during most of both Water Years. The exceedence values for this river indicate that the watershed does not provide much base flow, making the river more dependent on regular precipitation in order to sustain flows. As shown in Figures 2 and 3, much of northwestern Minnesota has not had normal stream flow over the last four years and remains in a drought or near-drought condition.

Figure 9 is a hydrograph of the Zumbro River at Kellogg. Flow in the Zumbro hovered near the deficient range for most of 1989 through March 1990. March precipitation and spring runoff again improved flows but they were not maintained. However, starting in May and continuing throughout the summer, precipitation was strong and Zumbro River flows remained in the excessive range. Only in the last few days in September did the flows drop to near normal levels.

Figure 10 is a hydrograph of the Pomme de Terre River at Appleton. The river was severely affected by the drought in 1988 with impacts lasting until spring precipitation and snow melt in March and April of 1989. Serious low flow conditions occurred in the late summer of 1989 and 1990 due to lack of adequate base flow and precipitation. Surface water appropriation had to be suspended in parts of Minnesota as a result of low flow conditions.

Figure 9.

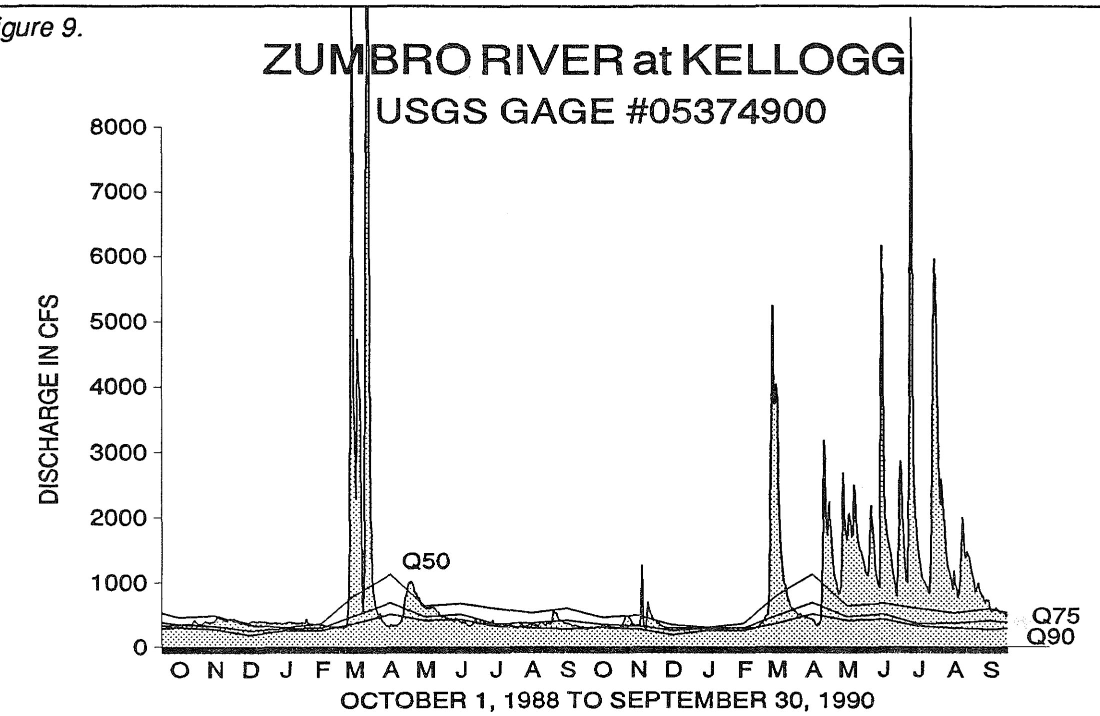
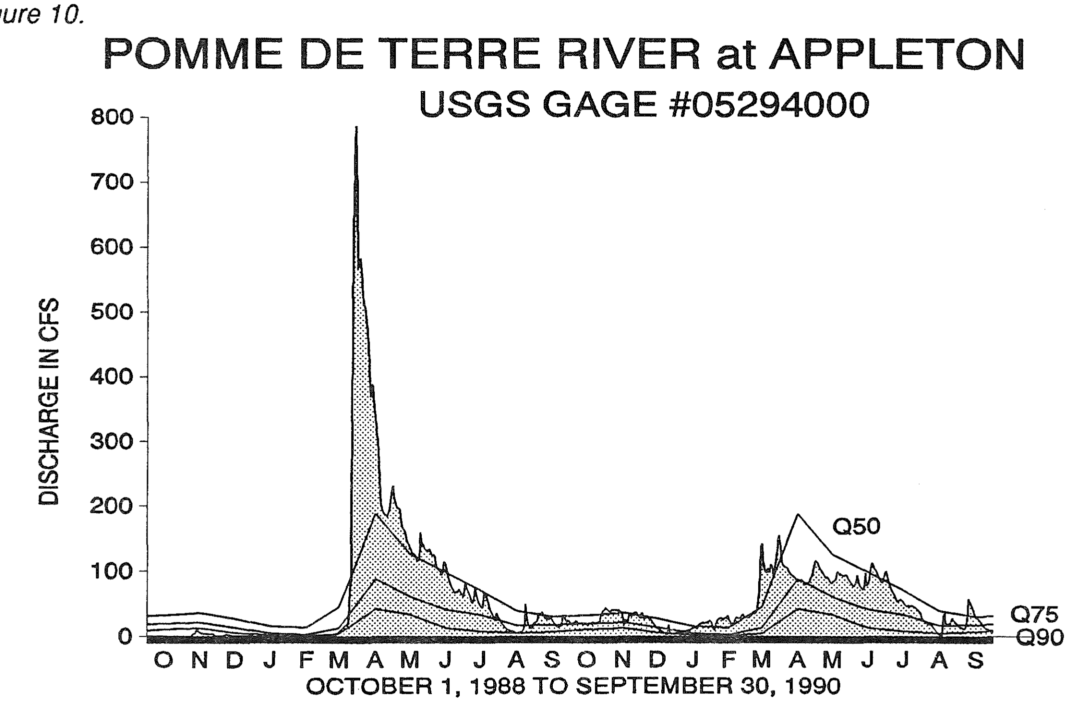


Figure 10.



Surface Water

Lake Levels

Why Monitor Lake Levels?

The water levels of all lakes fluctuate, some more than others. In Minnesota, historic fluctuations in excess of ten vertical feet have been recorded, although two to three feet in any year is typical. Fluctuations can be the result of human activities, such as construction or operation of a dam, or acts of nature, such as beaver activity. However, water level fluctuation is primarily a response to short - and long - term changes in the quantity and distribution of precipitation.

Lakeshore development and use are sometimes adversely affected by water level fluctuations. Aesthetic problems, drought-related access, and potential damage from flooding are the results of precipitation extremes. Knowing and understanding the history of water level fluctuations on a particular lake can help in coping with these problems.

Historic water level data are useful in calibrating hydrologic and hydraulic simulation models. These data also benefit watershed management authorities and other government units in preparing local water management plans.

Lake Level Monitoring in Minnesota

Lake level monitoring in Minnesota has been accomplished by various governmental units:

- Federal (USGS, COE, SCS)
- State (DNR)
- Counties
- Townships
- Cities
- Soil & Water Conservation Districts
- Watershed Districts
- Lake Improvement Districts

Monitoring has also been done by power and mining companies, consulting land surveyors and engineers, informal lakeshore owners associations and approximately 200 citizen volunteers.

Currently the Division of Waters is expanding its volunteer water level monitoring network. Funding for expansion is, in part, from the 1989 Ground Water Act which provided funding for two full-time positions to improve the lake level (and stream flow) data collection program. The Division is also increasing the amount of water level information available by searching out data collected by others. See figure 11 for a sample data summary and graph.

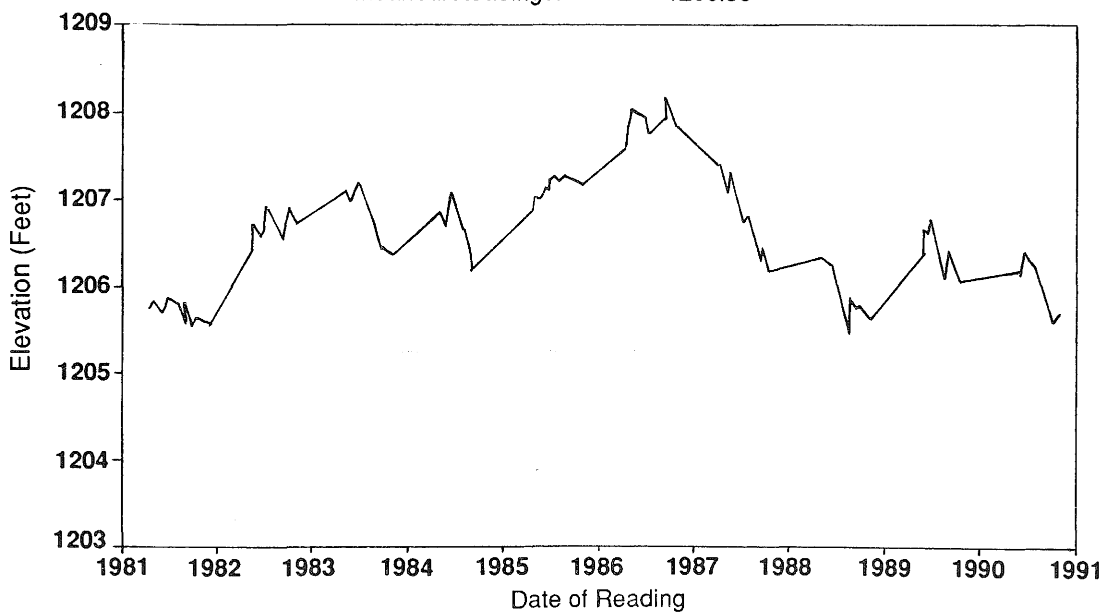
Figure 11.

EDWARD LAKE CROW WING COUNTY
ID 18-0305 Sub-basin 00

Year	Maximum	(Date)	Minimum	(Date)	Range	Average	Number of Readings
1990	1206.36	(06/19/90)	1205.56	(10/02/90)	0.80	1205.95	24
1989	1206.71	(06/26/89)	1206.01	(10/23/89)	0.70	1206.32	21
1988	1206.28	(04/27/88)	1205.46	(08/11/88)	0.82	1205.85	30
1987	1207.36	(04/17/87)	1206.15	(10/12/87)	1.21	1206.86	42
1986	1208.13	(09/23/86)	1207.56	(04/21/86)	0.57	1207.87	27
1985	1207.32	(09/08/85)	1206.84	(04/22/85)	0.48	1207.15	31
1984	1207.02	(06/22/84)	1206.20	(09/10/84)	0.82	1206.70	23
1983	1207.14	(07/08/83)	1206.38	(10/18/83)	0.76	1206.79	39
1982	1206.88	(07/19/82)	1206.40	(05/10/82)	0.48	1206.69	36
1981	1205.86	(06/30/81)	1205.42	(09/30/81)	0.44	1205.70	39
1980	1206.34	(05/27/80)	1205.61	(08/31/80)	0.73	1205.83	37
1979	1206.54	(07/03/79)	1205.68	(11/14/79)	0.86	1206.19	31
1978	1205.88	(07/10/78)	1205.34	(11/09/78)	0.54	1205.69	47
1977	1205.67	(07/05/77)	1205.11	(08/23/77)	0.56	1205.35	49
1974	1207.64	(06/05/74)	1206.62	(10/25/74)	1.02	1207.03	21
1973	1207.33	(10/17/73)	1206.59	(12/10/73)	0.74	1207.07	22
1972	1207.82	(08/22/72)	1207.26	(11/30/72)	0.56	1207.50	19
1971	1206.90	(11/30/71)	1206.26	(10/20/71)	0.64	1206.55	16
1970	1206.64	(06/15/70)	1205.48	(10/05/70)	1.16	1206.13	24
1969	1207.07	(05/08/69)	1205.90	(11/22/69)	1.17	1206.43	20
1968	1206.83	(06/20/68)	1206.18	(04/24/68)	0.65	1206.43	24
1967	1206.90	(04/25/67)	1206.76	(07/13/67)	0.14	1206.83	2
1966	1207.40	(05/25/66)	1207.07	(08/18/66)	0.33	1207.24	2
1965	1206.26	(10/27/65)	1205.92	(09/17/65)	0.34	1206.12	10
1933	1201.00	(12/15/33)	1201.00	(12/15/33)		1201.00	1

Period of Record 12/15/33 - 10/30/90
Datum Adjustment 1929

Total Number of Readings: 637
Highest Recorded: 1208.13 (09/23/86)
Lowest Recorded: 1201.00 (12/15/33)
Range All Readings: 7.13
Mean All Readings: 1206.38



Specific Cooperative Programs

In order to improve geographic coverage and to eliminate possible duplication of efforts, the Division has initiated several cooperative programs with other governmental units. As part of the program, Division of Waters staff provide the expertise to establish gages including any required survey work. "Lakes db©" software has been installed on many cooperators' computers. Staff have been trained in the software's basic functions of data storage and retrieval.

The following is a list and brief description of cooperative programs.

- **ANOKA COUNTY.** In a program started in 1989, the Anoka Soil and Water Conservation District staff obtain weekly water level readings for twenty-two lakes during the open water season. Financial contributors include the Coon Creek Watershed District, the Rice Creek Watershed District and the Sunrise River Water Management Organization. Also, the cooperation of local residents and homeowner associations allows gages to be installed and maintained at easily accessible sites.

- **CITY OF MAPLE GROVE.** Since 1989, staff from the city's engineering department have obtained weekly water level readings on five city lakes during the open water season.

- **THIRTY LAKES WATERSHED DISTRICT.** A combination of volunteers and watershed staff obtain weekly level readings on twenty-two lakes within the District during the open water season. This program was started in the spring of 1989.

- **SAUK RIVER WATERSHED DISTRICT.** Volunteer readers recruited by the District in 1988 obtain weekly water level readings on eight lakes.

- **RAMSEY COUNTY.** Dating back to the early 1920's, County Engineering Department staff have monitored water levels on twenty-nine lakes. This historical information was digitized (approximately 50,000 readings) and is now part of the Division's computer database.

- **KANDIYOHI COUNTY.** Water level information collected by the County since the early 1950's has been added to the Division's database. County Highway Department employees currently obtain monthly water level readings on twenty-two lakes within the county.

In addition, the Division receives water level information from:

- City of Big Lake
- City of Buffalo
- City of Lakeville
- City of Starbuck
- City of Virginia
- City of Worthington
- DNR Divisions of Parks, Fish and Wildlife, and Enforcement
- Jackson County Parks Department
- Nine Mile Creek Watershed District
- Nobles County Parks Department
- Nobles County SWCD
- Otter Tail Power Company
- Valley Branch Watershed District

The Division of Waters obtained over 16,000 water level readings from available sources on 540 lakes statewide during Water Years 1989 and 1990.

Water Level Trends

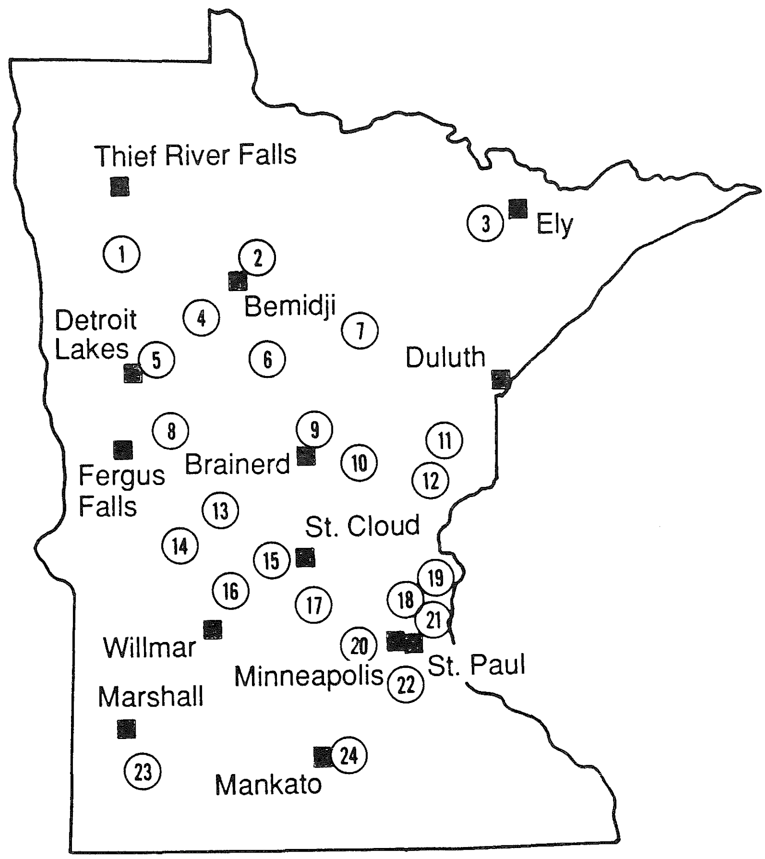
The degree of water level fluctuation on a lake depends on a number of factors:

- individual lake characteristics - size, depth
- outlet size (if any) and characteristics
- tributary watershed size and characteristics
- precipitation amounts and distribution
- ground water interaction
- artificial manipulation (authorized or unauthorized)

Given the range of variables that have an impact on lakes, it is difficult (if not impossible) to make generalized statements regarding water level trends on a large scale. An exception to this was when severe drought conditions gripped most of the state for the entire year of 1988 (except in parts of northeast Minnesota). Water levels receded dramatically over

Figure 12.

Locations of 24 Selected Lakes

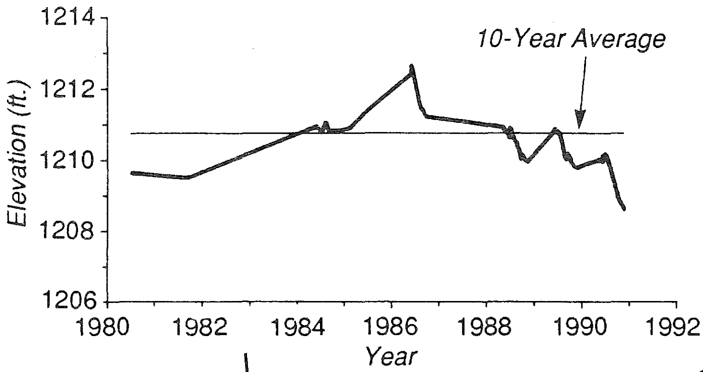


Map No.	Lake Name	County
1	Union	Polk
2	Turtle River	Beltrami
3	Vermilion	St. Louis
4	Itasca	Clearwater
5	Cotton	Becker
6	Ten Mile	Cass
7	Siseebakwet	Itasca
8	Otter Tail	Otter Tail
9	Edward	Crow Wing
10	Mille Lacs	Mille Lacs
11	Island	Pine
12	Grindstone	Pine
13	Osakis	Todd
14	Minnewaska	Pope
15	Big Fish	Stearns
16	Green	Kandiyohi
17	Twin-Sylvia	Wright
18	Coon	Anoka
19	North Center	Chisago
20	Minnetonka	Hennepin
21	White Bear	Washington
22	Marion	Dakota
23	Shetek	Murray
24	Madison	Blue Earth

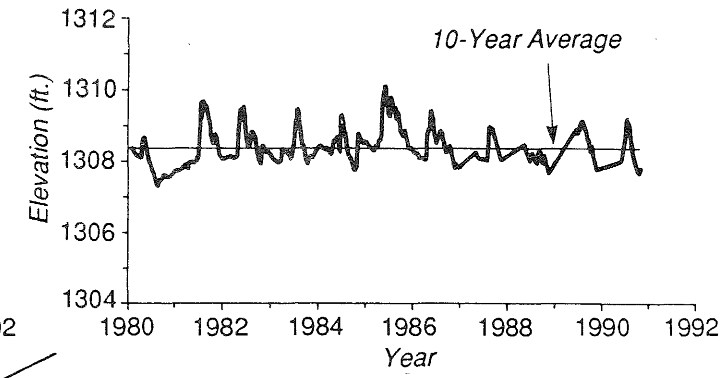
most of the state throughout the year and continued to do so in 1989, although to a lesser degree. The variability of the fluctuation was due to the individual lake and its characteristics, but most of all to the amount and distribution of precipitation. Many lakes experienced some recovery in 1990 in response to greater amounts of precipitation than the previous two to three years.

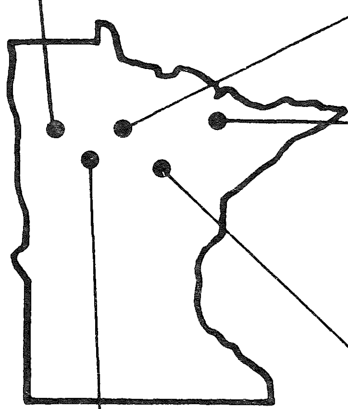
The following five pages contain graphic representations of water level changes for the twenty-four lakes shown in Figure 12 above. These lakes were selected because of their geographic locations and the availability of long-term water level data. See Figure 13 for a numeric summary of water levels for these twenty-four lakes.

Union Lake Polk County (60-217)
Water Surface Elevations

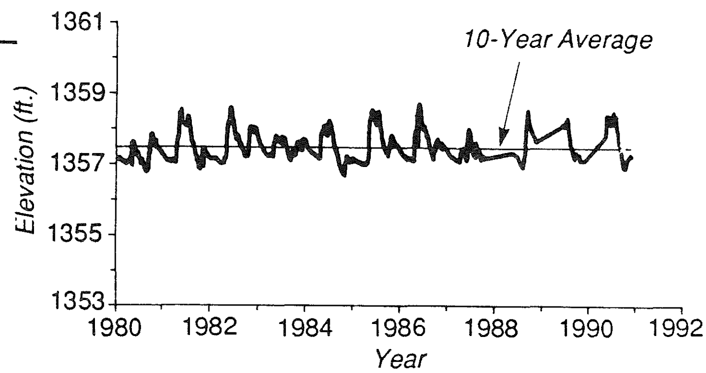


Turtle River Lake Beltrami County (4-111)
Water Surface Elevations

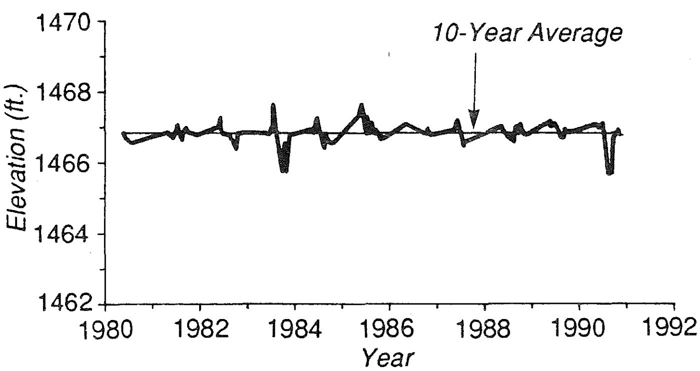




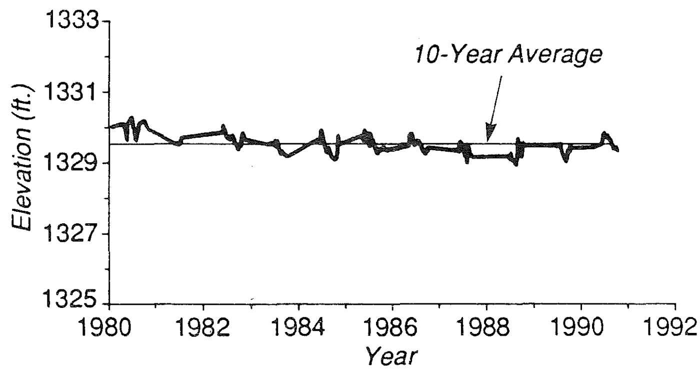
Lake Vermilion St. Louis County (69-378)
Water Surface Elevations

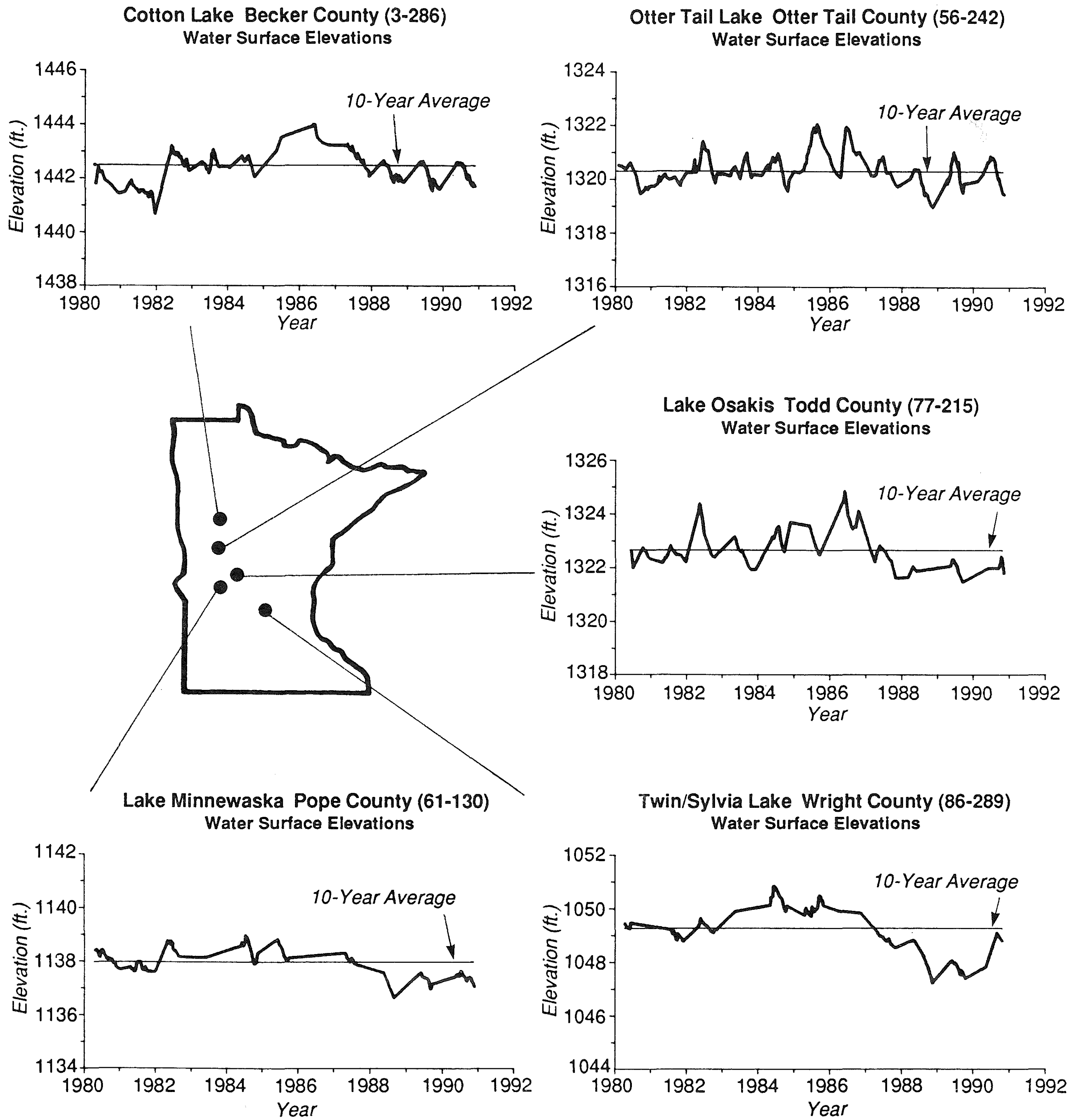


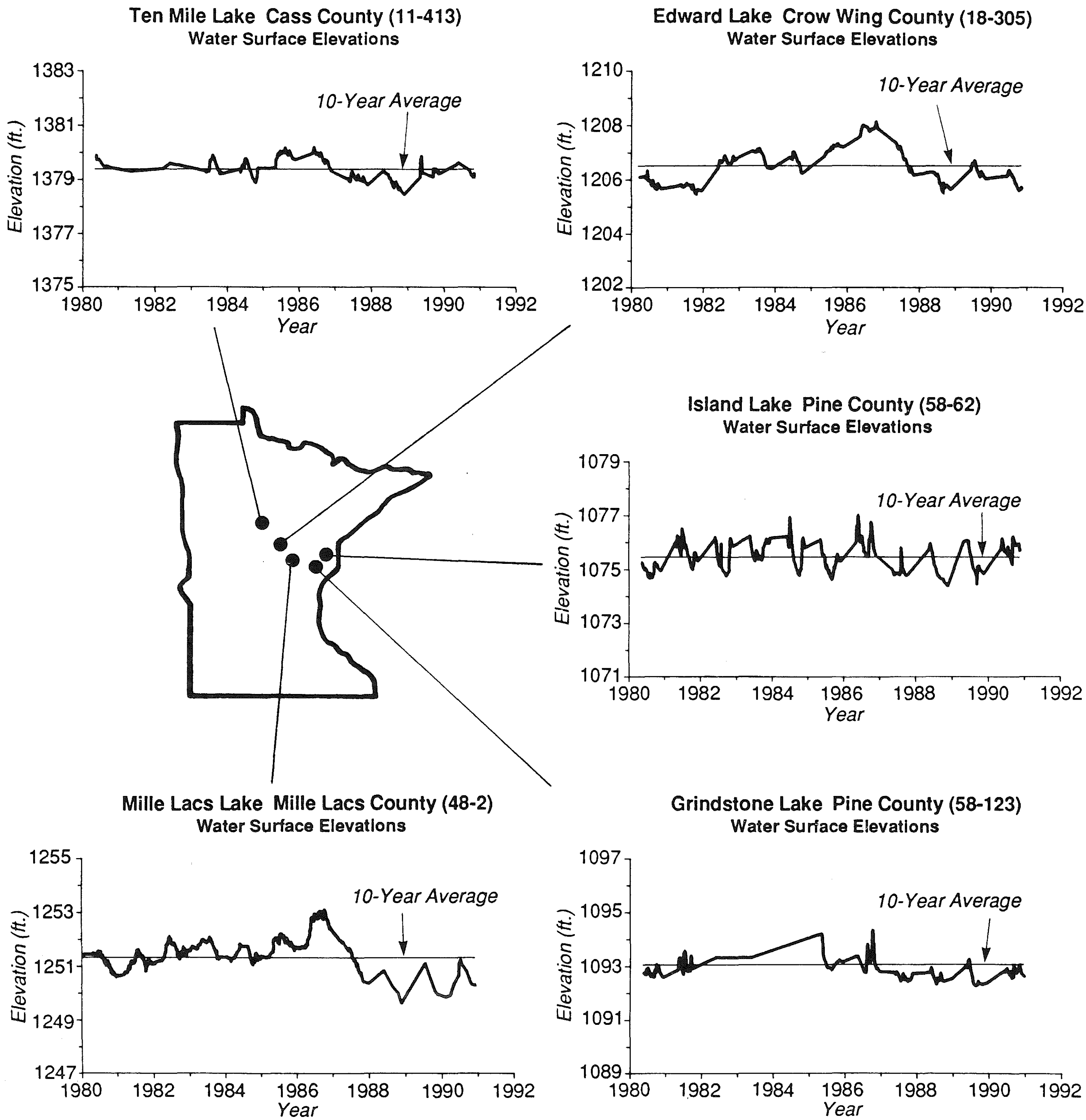
Lake Itasca Clearwater County (15-16)
Water Surface Elevations

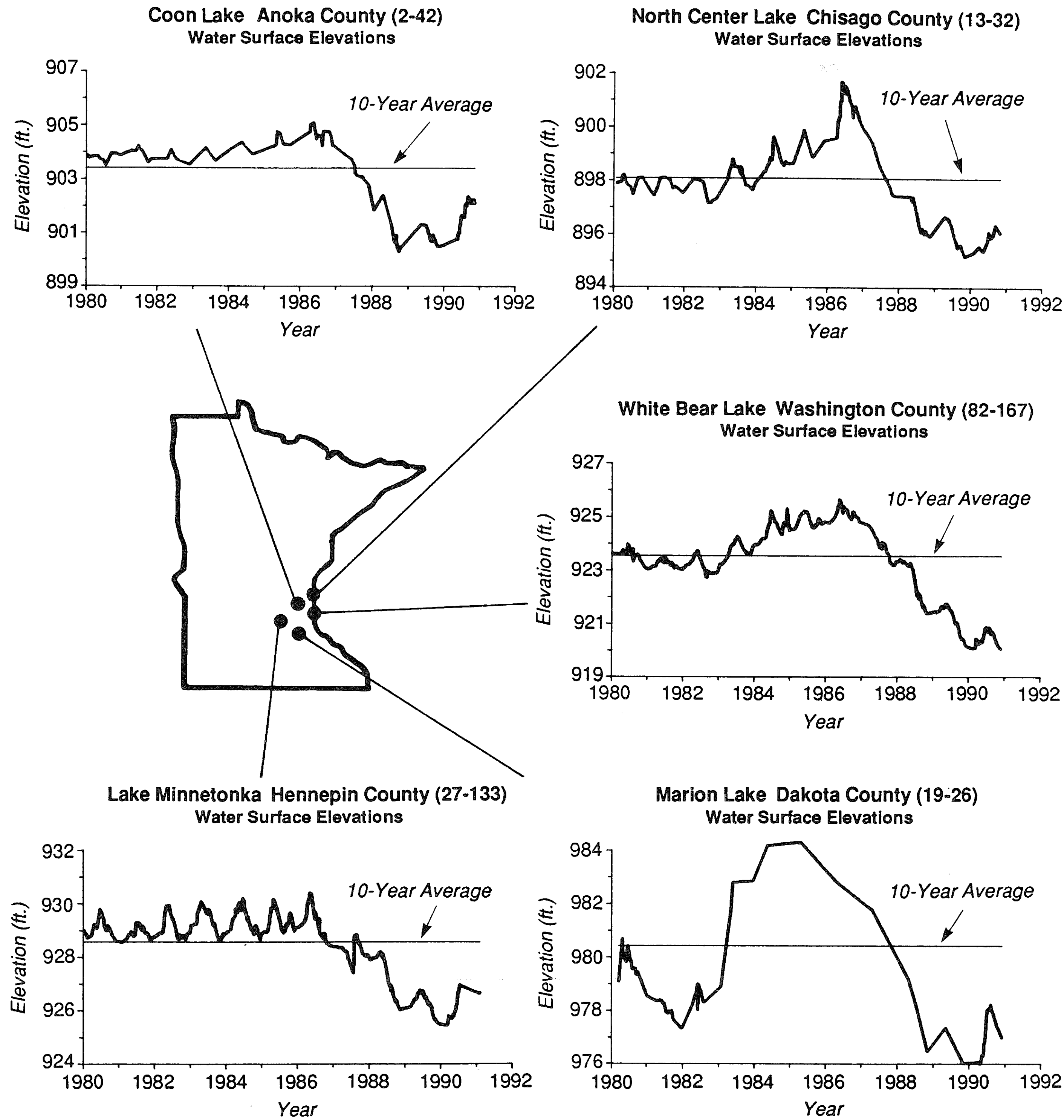


Siseebakwet Lake Itasca County (31-554)
Water Surface Elevations




Cotton Lake Becker County (3-286)
Water Surface Elevations
10-Year Average
Elevation (ft.)
1446
1444
1442
1440
1438
1980 1982 1984 1986 1988 1990 1992
Year
Otter Tail Lake Otter Tail County (56-242)
Water Surface Elevations
10-Year Average
Elevation (ft.)
1324
1322
1320
1318
1316
1980 1982 1984 1986 1988 1990 1992
Year
Lake Osakis Todd County (77-215)
Water Surface Elevations
10-Year Average
Elevation (ft.)
1326
1324
1322
1320
1318
1980 1982 1984 1986 1988 1990 1992
Year
Lake Minnewaska Pope County (61-130)
Water Surface Elevations
10-Year Average
Elevation (ft.)
1142
1140
1138
1136
1134
1980 1982 1984 1986 1988 1990 1992
Year
Twin/Sylvia Lake Wright County (86-289)
Water Surface Elevations
10-Year Average
Elevation (ft.)
1052
1050
1048
1046
1044
1980 1982 1984 1986 1988 1990 1992
Year


Ten Mile Lake Cass County (11-413)
Water Surface Elevations
10-Year Average
Elevation (ft.)
1383
1381
1379
1377
1375
1980 1982 1984 1986 1988 1990 1992
Year
Edward Lake Crow Wing County (18-305)
Water Surface Elevations
10-Year Average
Elevation (ft.)
1210
1208
1206
1204
1202
1980 1982 1984 1986 1988 1990 1992
Year
Island Lake Pine County (58-62)
Water Surface Elevations
10-Year Average
Elevation (ft.)
1079
1077
1075
1073
1071
1980 1982 1984 1986 1988 1990 1992
Year
Mille Lacs Lake Mille Lacs County (48-2)
Water Surface Elevations
10-Year Average
Elevation (ft.)
1255
1253
1251
1249
1247
1980 1982 1984 1986 1988 1990 1992
Year
Grindstone Lake Pine County (58-123)
Water Surface Elevations
10-Year Average
Elevation (ft.)
1097
1095
1093
1091
1089
1980 1982 1984 1986 1988 1990 1992
Year


Coon Lake Anoka County (2-42)
Water Surface Elevations
10-Year Average
Elevation (ft.)
907
905
903
901
899
1980 1982 1984 1986 1988 1990 1992
Year
North Center Lake Chisago County (13-32)
Water Surface Elevations
10-Year Average
Elevation (ft.)
902
900
898
896
894
1980 1982 1984 1986 1988 1990 1992
Year
White Bear Lake Washington County (82-167)
Water Surface Elevations
10-Year Average
Elevation (ft.)
927
925
923
921
919
1980 1982 1984 1986 1988 1990 1992
Year
Lake Minnetonka Hennepin County (27-133)
Water Surface Elevations
10-Year Average
Elevation (ft.)
932
930
928
926
924
1980 1982 1984 1986 1988 1990 1992
Year
Marion Lake Dakota County (19-26)
Water Surface Elevations
10-Year Average
Elevation (ft.)
984
982
980
978
976
1980 1982 1984 1986 1988 1990 1992
Year

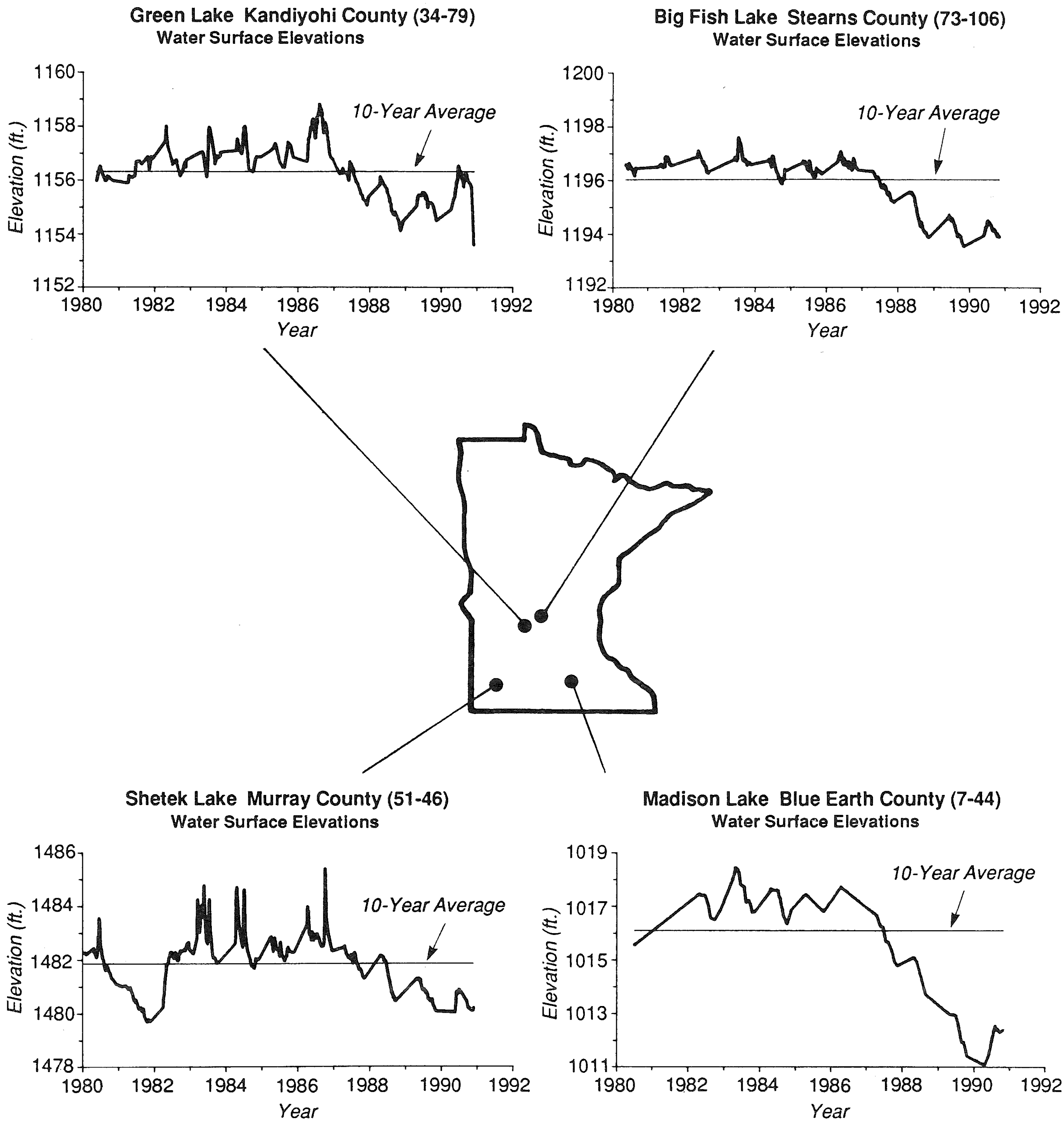

Green Lake Kandiyohi County (34-79)
Water Surface Elevations
10-Year Average
Elevation (ft.)
1152
1154
1156
1158
1160
1980
1982
1984
1986
1988
1990
1992
Year
Big Fish Lake Stearns County (73-106)
Water Surface Elevations
10-Year Average
Elevation (ft.)
1192
1194
1196
1198
1200
1980
1982
1984
1986
1988
1990
1992
Year
Shetek Lake Murray County (51-46)
Water Surface Elevations
10-Year Average
Elevation (ft.)
1478
1480
1482
1484
1486
1980
1982
1984
1986
1988
1990
1992
Year
Madison Lake Blue Earth County (7-44)
Water Surface Elevations
10-Year Average
Elevation (ft.)
1011
1013
1015
1017
1019
1980
1982
1984
1986
1988
1990
1992
Year

Figure 13. MnDNR DIVISION of WATERS
LAKES-DB WATER LEVEL SUMMARY

		MIN	(DATE)	MAX	(DATE)	RANGE	AVG	# READINGS
ANOKA COUNTY								
Coon (2-0042)	Water Yr 1990	900.47	(10/31/89)	902.37	(09/04/90)	1.90	901.31	68
	Water Yr 1989	900.39	(10/04/88)	901.31	(06/06/89)	0.92	901.16	41
	Historic (03/30/38 - 11/10/90)	900.27	(09/22/88)	905.11	(05/16/86)	4.84		324
BECKER COUNTY								
Cotton (3-0286)	Water Yr 1990	1441.58	(11/08/89)	1442.61	(05/10/90)	1.03	1442.21	96
	Water Yr 1989	1441.52	(08/26/89)	1442.64	(05/20/89)	1.12	1442.13	73
	Historic (07/16/41 - 11/10/90)	1439.68	(08/16/77)	1444.83	(12/02/42)	5.15		645
BELTRAMI COUNTY								
Turtle River (4-0111)	Water Yr 1990	1307.64	(09/30/90)	1309.20	(06/27/90)	1.56	1308.38	79
	Water Yr 1989	1307.64	(10/26/88)	1309.14	(07/14/89)	1.50	1308.54	64
	Historic (05/01/73 - 10/20/90)	1307.28	(08/06/80)	1311.00	(07/05/75)	3.72		799
BLUE EARTH COUNTY								
Madison (7-0044)	Water Yr 1990	1011.04	(04/17/90)	1012.51	(07/30/90)	1.47	1011.91	7
	Water Yr 1989	1011.90	(09/14/89)	1012.95	(04/18/89)	1.91	1012.13	5
	Historic (06/01/65 - 10/25/90)	1011.04	(04/17/90)	1018.48	(10/19/68)	7.44		243
CASS COUNTY								
Ten Mile (11-0413)	Water Yr 1990	1379.11	(09/27/90)	1379.61	(05/09/90)	0.50	1379.37	12
	Water Yr 1989	1378.41	(11/10/88)	1379.87	(04/29/89)	1.46	1379.17	26
	Historic (11/12/73 - 10/23/90)	1377.49	(11/23/76)	1380.21	(04/25/79)	2.72		597
CHISAGO COUNTY								
North Center (13-0032)								
	Water Yr 1990	895.14	(10/27/89)	896.35	(09/07/90)	1.21	895.67	14
	Water Yr 1989	895.47	(08/10/89)	896.67	(04/05/89)	1.53	895.90	17
	Historic (04/08/68 - 10/26/90)	894.42	(09/16/68)	901.68	(05/19/86)	7.26		410
CLEARWATER COUNTY								
Itasca (15-0016)	Water Yr 1990	1465.66	(07/29/90)	1467.12	(06/19/90)	1.46	1466.57	13
	Water Yr 1989	1466.69	(07/26/89)	1467.17	(05/09/89)	1.51	1466.76	15
	Historic (05/23/68 - 10/24/90)	1465.66	(08/04/90)	1467.65	(05/13/85)	1.99		208
	Historic (08/22/68 - 11/27/90)	1679.79	(09/28/76)	1681.32	(05/26/70)	1.53		42
CROW WING COUNTY								
Edward (18-0305)	Water Yr 1990	1205.62	(09/25/90)	1206.36	(06/19/90)	0.74	1206.04	23
	Water Yr 1989	1205.60	(11/01/88)	1206.71	(06/26/89)	1.11	1206.14	21
	Historic (12/15/33 - 10/30/90)	1201.00	(12/15/33)	1208.13	(09/23/86)	7.13		637

DAKOTA COUNTY

Marion (19-0026)

	MIN	(DATE)	MAX	(DATE)	RANGE	AVG	# READINGS
Water Yr 1990	975.98	(04/17/90)	978.23	(07/30/90)	2.25	977.26	32
Water Yr 1989	976.45	(10/26/88)	977.36	(04/26/89)	1.38	977.23	2
Historic (05/03/46 - 11/28/90)	971.31	(12/30/64)	984.30	(04/19/85)	12.99		2394

HENNEPIN COUNTY

Minnetonka (27-0133)

	MIN	(DATE)	MAX	(DATE)	RANGE	AVG	# READINGS
Water Yr 1990	925.42	(02/28/90)	927.42	(08/01/90)	2.00	925.99	56
Water Yr 1989	926.00	(09/29/89)	926.77	(06/01/89)	1.35	926.22	75
Historic (05/30/06 - 02/08/91)	921.78	(12/13/37)	930.51	(09/14/51)	8.73		2668

ITASCA COUNTY

Siseebakwet (31-0554)

	MIN	(DATE)	MAX	(DATE)	RANGE	AVG	# READINGS
Water Yr 1990	1329.34	(09/27/90)	1329.84	(06/13/90)	0.50	1329.59	55
Water Yr 1989	1329.01	(08/23/89)	1329.53	(07/05/89)	0.52	1329.47	49
Historic (08/31/37 - 09/29/90)	1328.40	(10/23/78)	1330.59	(05/21/43)	2.19	)	1799

KANDIYOHI COUNTY

Green (34-0079)

	MIN	(DATE)	MAX	(DATE)	RANGE	AVG	# READINGS
Water Yr 1990	1154.43	(11/06/89)	1156.50	(06/19/90)	2.07	1155.97	48
Water Yr 1989	1154.05	(11/02/88)	1155.52	(06/16/89)	1.47	1155.68	25
Historic (10/22/38 - 11/28/90)	1153.54	(11/28/90)	1158.79	(07/30/86)	5.25		843

MILLE LACS COUNTY

Mille Lacs (48-0002)

	MIN	(DATE)	MAX	(DATE)	RANGE	AVG	# READINGS
Water Yr 1990	1249.84	(01/23/90)	1251.24	(06/22/90)	1.40	1250.42	13
Water Yr 1989	1249.60	(11/03/88)	1251.12	(06/26/89)	1.52	1250.39	3
Historic (06/11/31 - 11/21/90)	1245.74	(10/19/36)	1253.43	(08/22/72)	7.69		16994

MURRAY COUNTY

Shetek (51-0046)

	MIN	(DATE)	MAX	(DATE)	RANGE	AVG	# READINGS
Water Yr 1990	1480.01	(05/11/90)	1480.90	(06/19/90)	0.89	1480.48	35
Water Yr 1989	1480.41	(09/19/89)	1481.31	(05/08/89)	1.30	1480.70	60
Historic (11/05/26 - 11/21/90)	1479.20	(11/21/52)	1486.87	(04/10/69)	7.67		2402

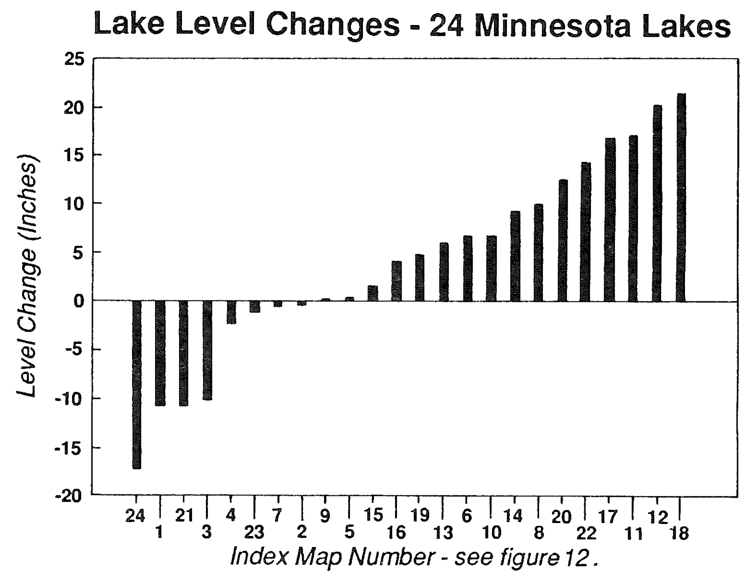
OTTER TAIL COUNTY

Otter Tail (56-0242)

	MIN	(DATE)	MAX	(DATE)	RANGE	AVG	# READINGS
Water Yr 1990	1319.77	(09/14/90)	1320.87	(06/02/90)	1.10	1320.38	21
Water Yr 1989	1318.93	(10/19/88)	1321.01	(05/25/89)	2.08	1320.32	43
Historic (07/18/19 - 10/24/90)	1317.68	(12/18/34)	1322.47	(07/16/70)	4.79		2051

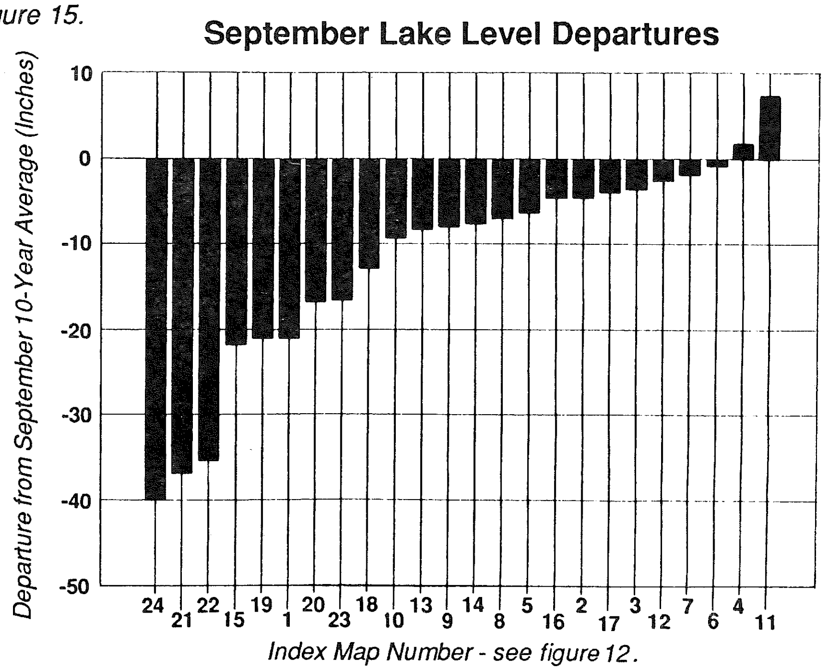
		MIN	(DATE)	MAX	(DATE)	RANGE	AVG	# READINGS
PINE COUNTY								
Grindstone (58-0123)	Water Yr 1990	1092.30	(10/08/89)	1093.04	(08/27/90)	0.74	1092.74	28
	Water Yr 1989	1092.24	(08/05/89)	1093.26	(05/31/89)	1.02	1092.68	17
	Historic (07/23/54 - 12/13/90)	1092.24	(08/05/89)	1094.89	(04/25/75)	2.65		881
Island (58-0062)	Water Yr 1990	1074.81	(10/31/89)	1076.21	(08/30/90)	1.40	1075.61	20
	Water Yr 1989	1074.35	(11/05/88)	1076.06	(05/31/89)	1.71	1075.41	22
	Historic (07/02/64 - 11/10/90)	1073.88	(08/26/77)	1077.03	(04/23/79)	3.15		1446
POLK COUNTY								
Union (60-0217)	Water Yr 1990	1208.94	(09/30/90)	1210.18	(06/20/90)	1.24	1209.72	39
	Water Yr 1989	1209.91	(11/01/88)	1210.89	(06/01/89)	1.95	1210.06	36
	Historic (09/02/81 - 11/19/90)	1208.61	(11/19/90)	1212.66	(05/21/86)	4.05		152
POPE COUNTY								
Minnewaska (61-0130)	Water Yr 1990	1137.21	(08/18/90)	1137.61	(06/23/90)	0.40	1137.41	25
	Water Yr 1989	1136.91	(08/12/89)	1137.56	(05/08/89)	0.65	1137.35	17
	Historic (05/29/35 - 11/10/90)	1129.67	(05/29/35)	1139.68	(06/02/72)	10.01		2410
ST. LOUIS COUNTY								
Vermilion (69-0378)	Water Yr 1990	1356.88	(09/27/90)	1358.50	(06/26/90)	1.62	1357.72	41
	Water Yr 1989	1357.15	(08/26/89)	1358.33	(07/01/89)	1.45	1357.73	27
	Historic (10/03/50 - 11/17/90)	1356.07	(11/28/76)	1359.22	(06/14/70)	3.15		12910
STEARNS COUNTY								
Big Fish (73-0106)	Water Yr 1990	1193.47	(10/25/89)	1194.46	(06/29/90)	0.99	1194.07	168
	Water Yr 1989	1193.73	(09/29/89)	1194.66	(05/26/89)	1.19	1194.12	161
	Historic (06/22/66 - 10/28/90)	1193.47	(10/28/89)	1197.53	(06/30/83)	4.06		2134
TODD COUNTY								
Osakis (77-0215)	Water Yr 1990	1321.96	(05/15/90)	1322.41	(09/27/90)	0.45	1322.11	3
	Water Yr 1989	1321.44	(08/31/89)	1322.29	(05/24/89)	0.85	1321.99	53
	Historic (10/26/38 - 10/24/90)	1317.45	(10/26/38)	1324.84	(05/12/86)	7.39		1038
WASHINGTON COUNTY								
White Bear (82-0167)	Water Yr 1990	920.04	(02/07/90)	920.85	(06/29/90)	0.81	920.49	45
	Water Yr 1989	920.65	(09/28/89)	921.74	(05/24/89)	1.70	920.90	38
	Historic (01/01/24 - 11/30/90)	920.03	(11/30/90)	926.70	(06/20/43)	6.67		4579
WRIGHT COUNTY								
Sylvia (86-0289)	Water Yr 1990	1047.37	(10/09/89)	1049.10	(08/30/90)	1.73	1048.14	5
	Water Yr 1989	1047.20	(11/08/88)	1048.07	(05/29/89)	0.87	1047.78	27
	Historic (02/19/63 - 10/22/90)	1047.20	(11/08/88)	1050.85	(06/11/84)	3.65		280

Figure 14.



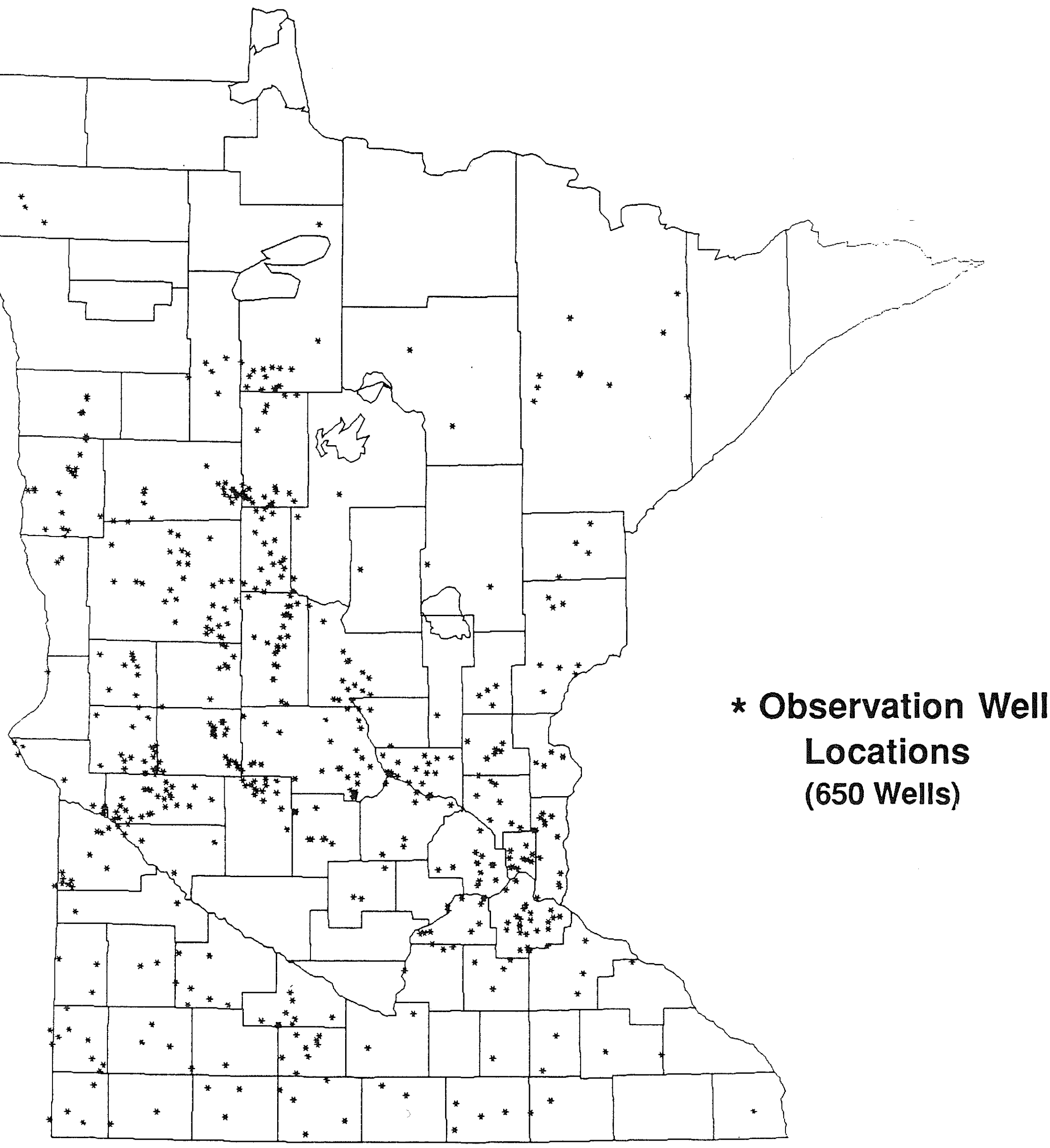
In summary, sixteen of the twenty-four lakes have experienced a net increase in water levels since October 1988 (Figure 14). However, as of September 1990, only two of the twenty-four are at or above their 10-year average levels (Figure 15).

Figure 15.



Future water levels are a function of many factors including antecedent conditions (see Figure 4, Palmer Drought Severity Index for September 1990) and the amount and distribution of future precipitation which is unpredictable. As a result, the amount of time required for many lakes to return to more desirable levels remains uncertain.

Chapter 3 : GROUND WATER



Ground Water

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 network of approximately 650 water level observation wells (obwells) statewide is maintained. Wells 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. These data are 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.

Aquifers

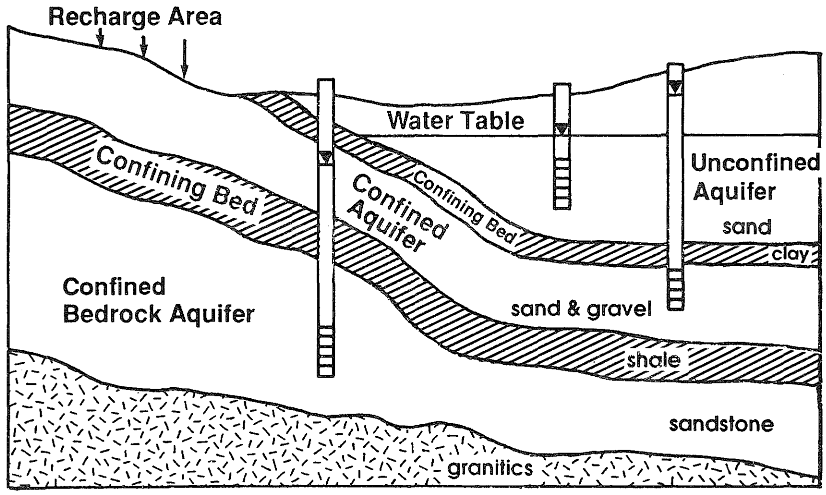
An aquifer is a geologic formation which is saturated and sufficiently permeable to transmit economic quantities of water to wells and springs. Aquifers may exist under either unconfined or confined conditions (Figure 1).

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 an impermeable material, the aquifer is confined. The water in a confined aquifer is under pressure. When a well is installed into a confined aquifer, the water level in the well casing rises above the top of the aquifer. Confined aquifers may be either buried drift (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 will usually be more pronounced in a confined aquifer.

Figure 1.

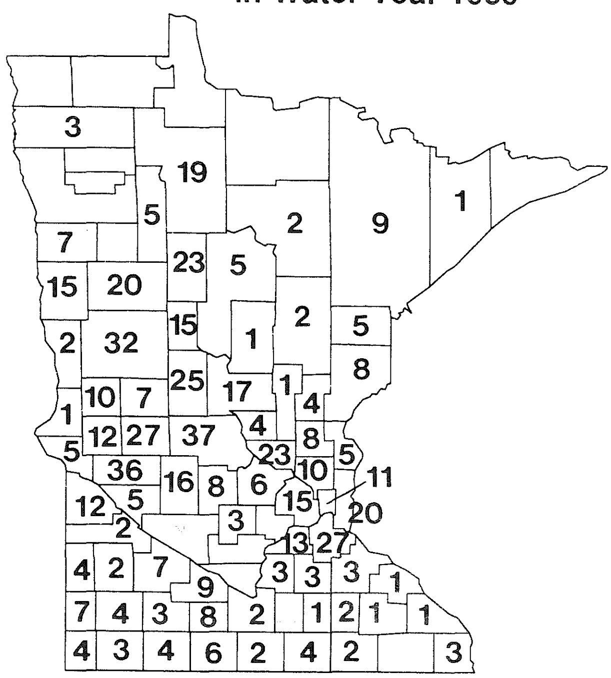


This section will discuss the ground water levels in unconfined aquifers and confined (both buried drift and bedrock) aquifers during Water Years 1989 and 1990 and compare them with levels at the end of Water Year 1988.

Obwell Network

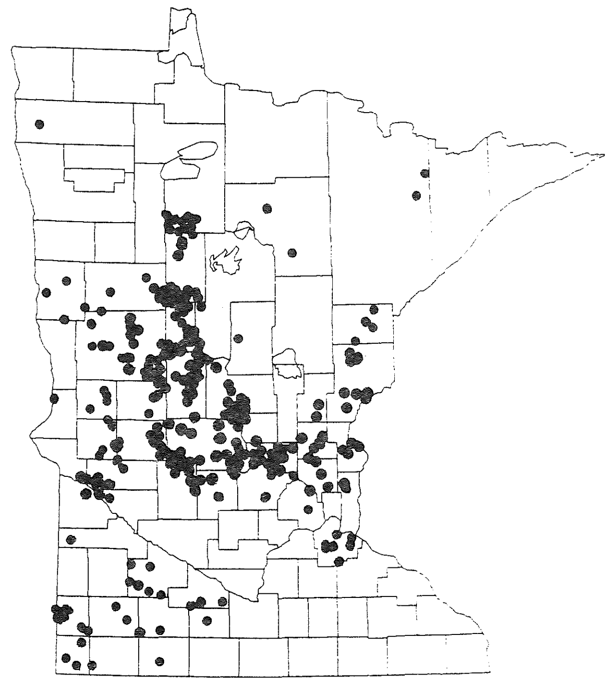
Figure 2 illustrates the total number of obwells by county. Locations of the obwells in each of the three groups that are discussed in this section are shown in Figures 3, 4 and 5, respectively. No analysis has been done on the possible effects on obwells from nearby pumping wells. Wells that are known to be within the cone of influence of a pumping well were not selected for this summary.

Figure 2.
Number of Active Obwells in Water Year 1989



Unconfined Aquifers

Figure 3.
Water Table Aquifer Obwells



The drought conditions that have gripped much of Minnesota to varying degrees since late 1986 were preceded by ten years of above average precipitation. In the fall of 1986, precipitation declined and water tables in unconfined aquifers began to drop. Water tables statewide generally have responded to increased precipitation in 1989 and 1990. Compared to the end of Water Year 1988, water tables at the end of Water Year 1990 were up 1' to 2' in the northeast, nearly the same or up 1' in the Twin Cities Metro area, up .25' to 1.5' in the southwest and up .5' to 2.5' in west central Minnesota. However, water tables are still dropping in some parts of the northwest in response to continued below average precipitation. In Becker County obwell #3009 for example, the water table is 2' lower than at the end of Water Year 1988.

Overall, water tables are still approximately 1' below average statewide* (except for the extreme southwest and northeast where water tables are slightly above average). Water tables in northwest and west central counties such as Stevens and Swift are nearly 2.5' below average.

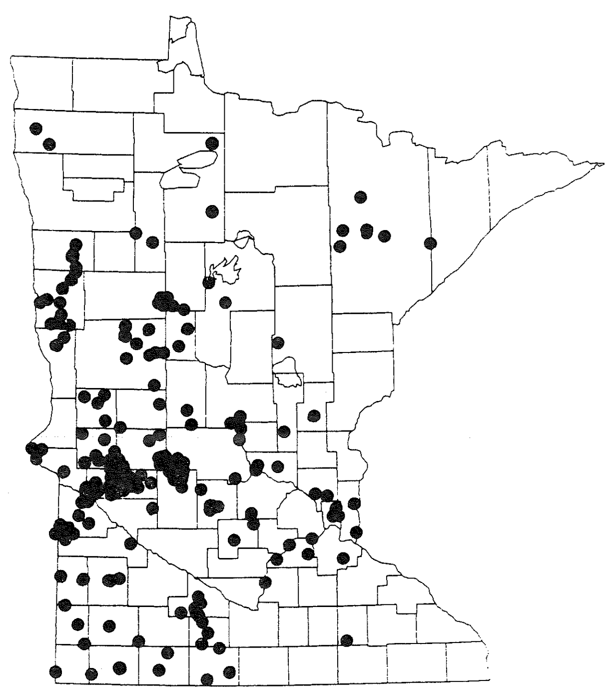
Wells in some unconfined aquifers may have experienced problems since 1987. In most cases an adequate water supply is available if wells are deepened or the pump intakes are lowered. Hydrographs for selected unconfined aquifers are shown in Figure 6. A ground water hydrograph is a graph where the water levels in a well are plotted against time.

*Approximately half of the referenced wells in unconfined aquifers contained in this report have a total period of record in excess of 20 years. Three have records less than 10 years.

Confined Aquifers-Buried Drift

Figure 4.

Buried Drift Aquifer Obwells



Confined aquifers, whether buried drift or bedrock, are usually slower to show the effects of climatic changes than unconfined aquifers. In addition, the effects are often more pronounced in the confined aquifer and recovery is often slower.

Buried drift aquifers throughout the state that were affected by the 1987-1989 drought are still declining, especially the deeper aquifers. Water levels in buried drift aquifers in the northwest are .5' to 2.5' below the levels at the end of Water Year 1988. Many obwells in this type of aquifer lack a sufficient period of record to develop a reliable average level. However, one well in Clay County with a 41- year period of record is presently 6.5' below its average water level.

In the southwest, water levels in the shallower buried drift aquifers appear to be slowly recovering with increases over 1988 levels ranging from .5' to 2'. Levels in deeper buried drift aquifers in this area, however, continue to decline from 1988 with decreases ranging from .75' to 3.5'.

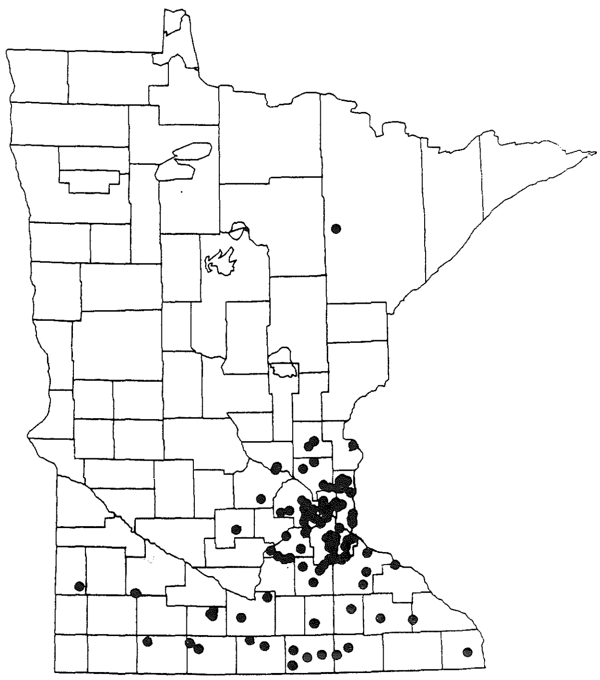
In central Minnesota, buried drift aquifer water levels appear to be increasing (by as much as 4' in some cases) from 1988 levels. Water levels in the buried drift aquifers in the northeast and the Twin Cities Metropolitan Area are generally still declining with decreases ranging from 1.25' to 2'. Hydrographs for selected confined aquifers are shown in Figure 7.

Confined Aquifers-Bedrock

Bedrock aquifers are monitored only in the central and south-southeast portions of the state where they are most often used for water supply. Most of the bedrock aquifers monitored by obwells are confined although bedrock aquifers may be either confined or unconfined. Figure 7 shows two hydrographs in the Prairie du Chien-Jordan aquifer.

The Mt. Simon aquifer in central Minnesota is monitored by a series of wells stretching from McLeod to Chisago Counties. These wells have been monitored for a period of 12 to 22 years. The levels range from 2' to 3' below the 1988 levels in McLeod and Sherburne Counties, 1' above 1988 levels in Isanti County and about the same level as 1988 in the other counties. Although some rebounding has occurred, the levels in all these wells are below the average. In one McLeod County well which has been monitored for 12 years, the level is 5.5' below average. The deficit slowly decreases northeast to Chisago County where the levels are nearly average. Along the Mississippi River south of the Twin Cities, the Mt. Simon wells indicate that the levels are lower than 1988 levels by as much as 2' and are below average by as much as 4'.

Figure 5.
Bedrock Aquifer Obwells



The Prairie du Chien-Jordan aquifer is monitored on a limited basis in a few counties southeast of the Twin Cities. The trend in this aquifer appears to be downward from 1988 about .5' to 2', but as much as 10' to 13' in two wells. All measurements are below average. Since there are relatively few wells monitored, care should be taken in using this data.

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 as noted below.

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 wells. They 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 rising at the end of Water Year 1990. These levels were above average in both Minneapolis and St. Paul. This increase in water levels was attributed to decreased pumpage because of cool summer weather. On the outer edges of the Twin Cities basin, levels in this aquifer were generally down 2' to 3' below 1988, with a 6' drop noted in one well.

In the Mt.Simon-Hinckley aquifer (the Twin Cities' second principal aquifer), levels in St. Paul and Minneapolis were about 20 feet below average. Levels in wells outside the pumping centers have dropped 2' to 3' since the end of Water Year 1988.

Figure 6.

Historical Water Tables in Unconfined Aquifers

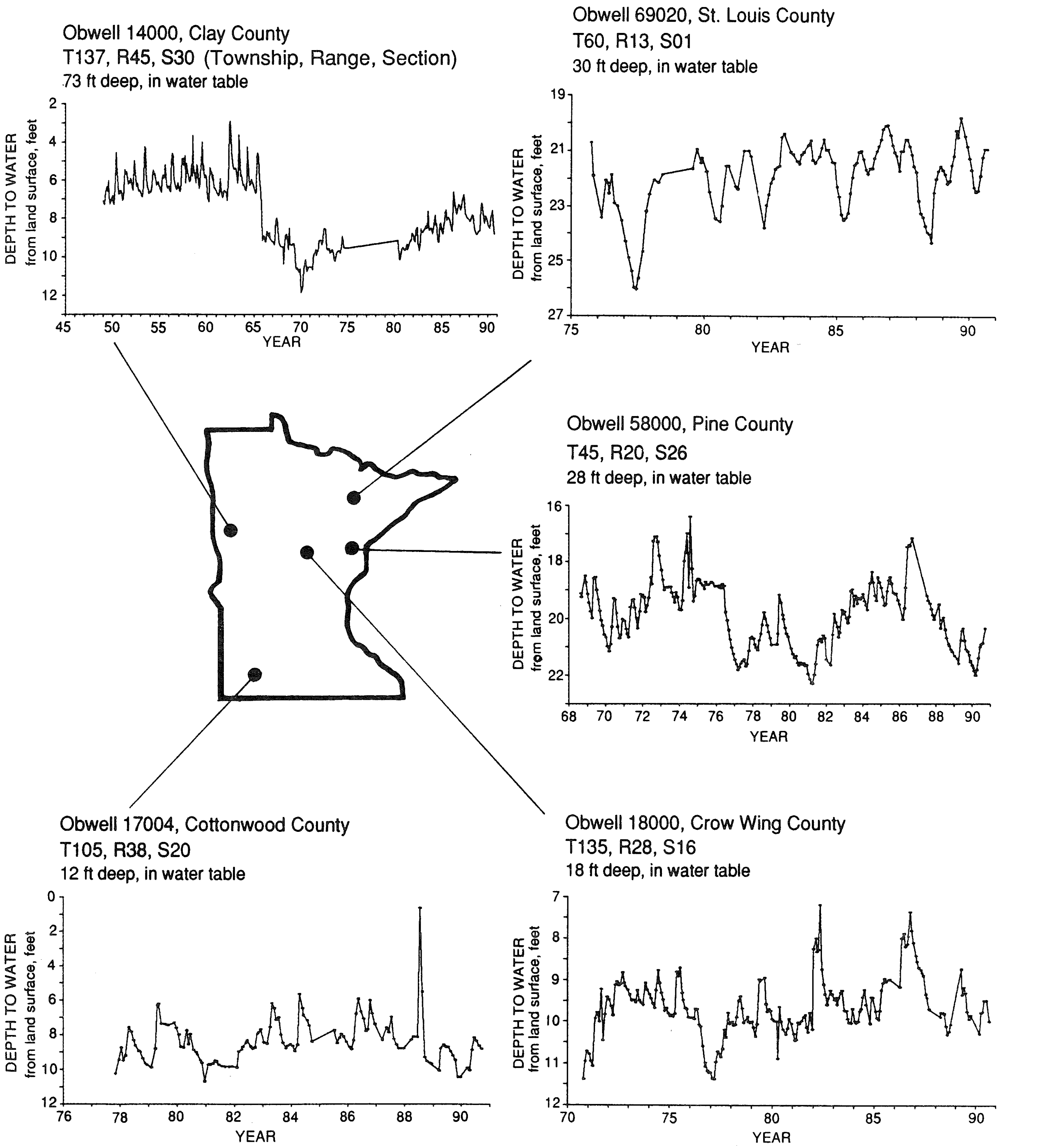
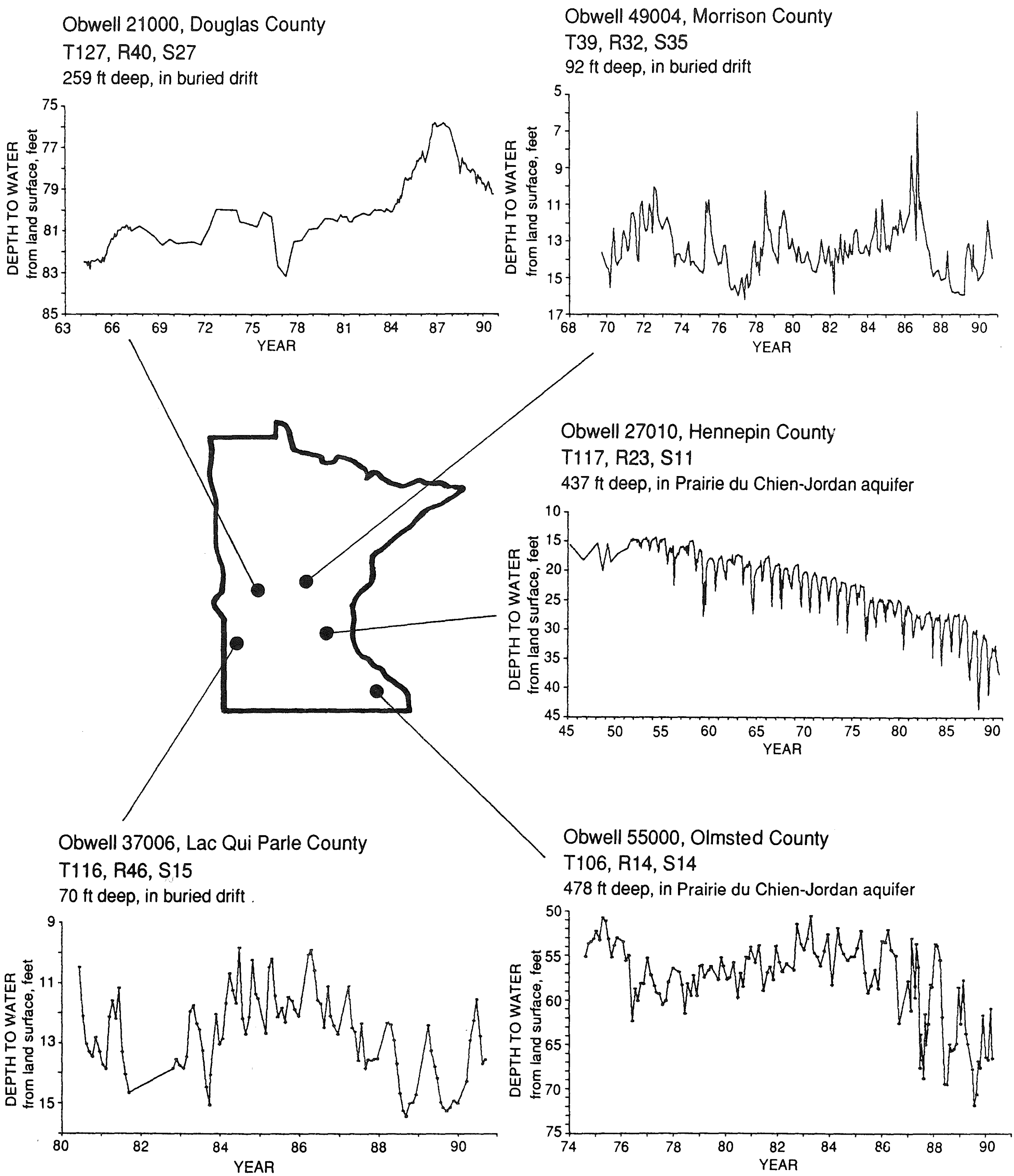


Figure 7. **Historical Water Levels in Confined Aquifers**



Obwell Data Availability

Figure 8 is a sample of the data summary for each obwell published annually. Copies of the Observation Well Data Summary are available for inspection at DNR Regional and Area offices and at local Soil and Water Conservation District (SWCD) offices. Unpublished data may be available at the DNR/St. Paul office for specific locations where water level monitoring may be required by a water appropriation permit or where data may have been collected as part of a study.

Obwell Network Expansion

Network expansion is funded in part from the 1989 Ground Water Act which also provided funding for two full-time positions to manage the obwell network. The network includes almost all the aquifers in common use and is constantly being expanded. Fifty-two of the ninety-one SWCDs statewide are currently participating in obwell monitoring activities. Discussions are underway with at least four other SWCDs in the southeast and Twin Cities area who have indicated interest. Several unused Mt. Simon wells may also be available for use as obwells. Additional obwells were drilled in 1990 near Mille Lacs Lake in Aitkin County, near Breckenridge in Wilkin County and at Carlos Avery Wildlife Management Area in Anoka County. Future network expansion is targeted at the bedrock aquifers statewide and the buried drift aquifers in the west and southwest. Additional obwell sites are actively pursued.

Figure 8.

Anoka County DNR Region 6

SUMMARY FOR 1989 WATER YEAR

T31 R22 S18 QQQ: AAA1 Aquifer: CFRNCIGL Depth: 270.0
Obwell # **2007** Observer: SWCD Years of Record: 19

MONTHLY WATER LEVEL SUMMARY

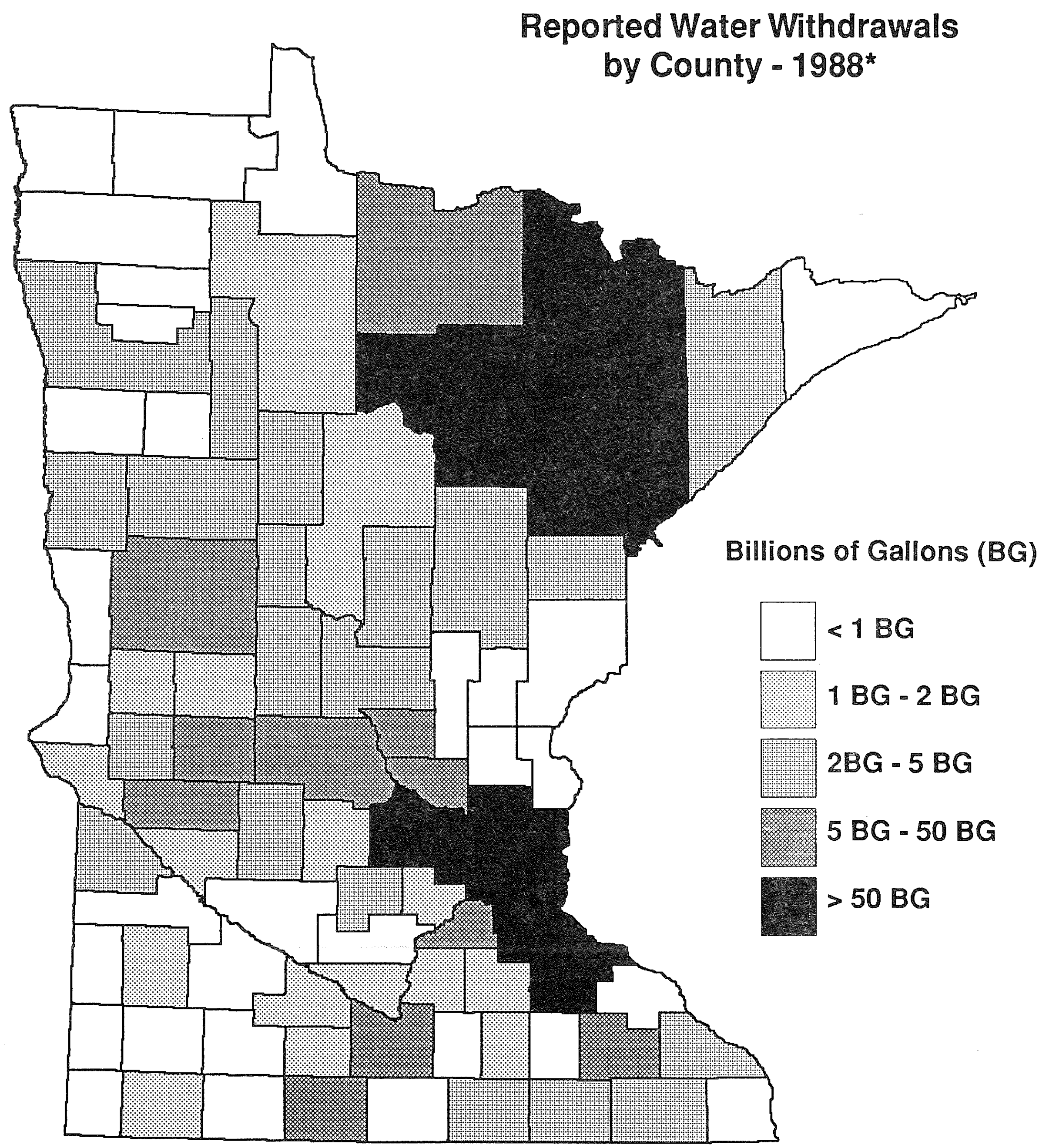
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
HISTORICAL												
Ave	11.7	11.0	10.7	10.3	11.1	10.9	10.5	10.8	12.3	12.9	13.0	12.5
High WL	9.3	8.4	7.9	8.3	9.7	8.1	7.1	8.0	9.2	6.4	9.5	8.1
Hi Yr	1986	1975	1975	1976	1971	1976	1976	1975	1971	1975	1972	1975
Low WL	16.9	15.6	15.3	11.7	12.3	15.1	15.3	16.2	17.0	23.9	18.7	20.3
Lo Yr	1988	1988	1988	1977	1977	1989	1989	1989	1989	1988	1988	1988
WATER YEAR 89												
Rdg	16.94	15.64	15.28			15.05	15.28	16.19	16.96	19.92	18.26	18.58
Day	17	17	7			30	28	30	30	30	31	29

T31 R22 S18 QQQ: AAA2 Aquifer: QBAAQBAA Depth: 214.0
Obwell # **2008** Observer: SWCD Years of Record: 19

MONTHLY WATER LEVEL SUMMARY

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
HISTORICAL												
Ave	12.1	11.2	11.0	10.5	11.4	11.2	10.7	11.3	12.7	13.0	13.3	12.7
High WL	9.7	8.8	8.3	8.7	10.1	8.5	7.5	8.4	9.5	6.8	9.8	8.4
Hi Yr	1986	1975	1975	1976	1971	1976	1976	1975	1971	1975	1972	1975
Low WL	17.4	16.0	15.7	12.1	12.7	15.4	15.4	16.7	21.9	24.3	19.1	20.7
Lo Yr	1988	1988	1988	1977	1977	1989	1989	1989	1988	1988	1988	1988
WATER YEAR 89												
Rdg	17.35	16.01	15.66			15.42	15.40	16.67	18.78	20.42	18.56	18.12
Day	17	17	7			30	28	30	30	30	31	29

Chapter 4 : WATER USE



* Water use by county was similar in 1989; see pages 50-51 for complete summary.

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. Approximately 10-15% of public water supply is consumptive use.

* **IRRIGATION** - water withdrawn from both surface water and ground water sources for both major crop and noncrop uses. Approximately 90% of irrigation is considered to be consumptive use where little or none of the water withdrawn is returned to its source.

* **INDUSTRIAL PROCESSING** - water used in mining activities, paper mill operations, food processing, etc. Approximately 75% of withdrawals are from surface water sources. Consumptive use varies up to a high of 50% depending on the type of industrial process.

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

See pages 52 to 56 for a detailed breakdown of reported water use for CY 1985-1989. 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.

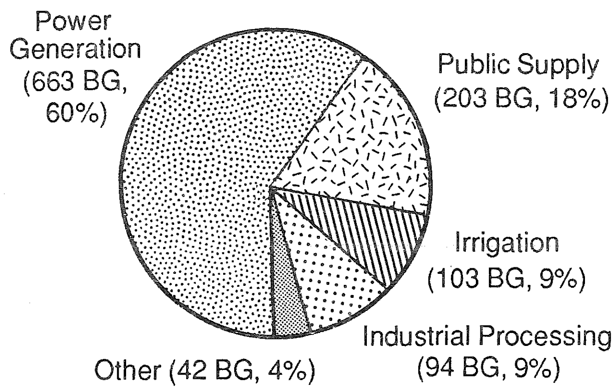
Water Use

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 are 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 are reported on a calendar year basis and are presented here in the same manner for Calendar Year (CY)1988 and 1989 (CY 1990 data are 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.

Figure 1. **1988 Reported Water Use**
1105 Billion Gallons (BG)



Statewide Water Use - CY 1988

Minnesota water use during 1988 was the highest ever reported in the state. During that drought year, 1105 billion gallons were withdrawn (Figure 1), an increase of 10% over the previous year. Seventy- eight percent or 858 billion gallons came from surface water sources, primarily rivers (Figure 2), while ground water sources accounted for 247 billion gallons or 22% of the total (Figure 3).

Figure 2. **1988 Surface Water Use**
858 Billion Gallons (BG)

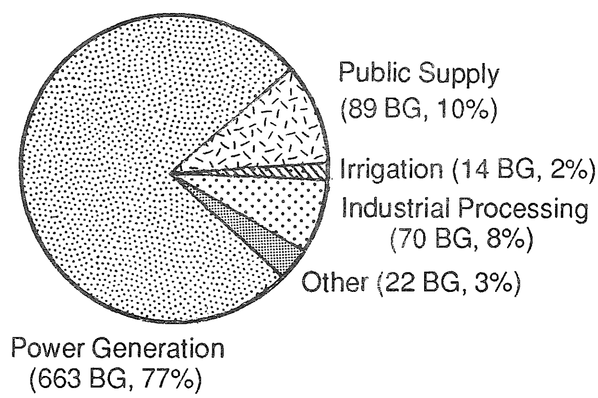
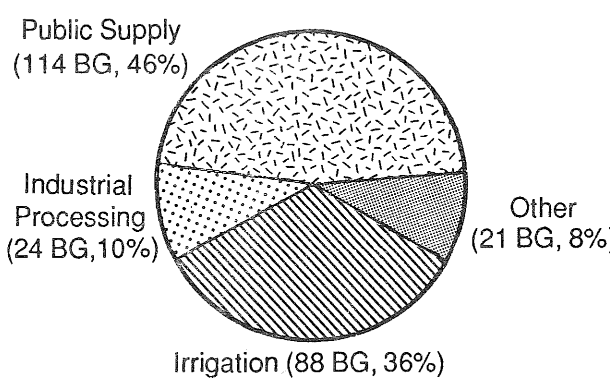


Figure 3.
1988 Ground Water Use
247 Billion Gallons (BG)



Statewide Water Use - CY 1989

Minnesota water use remained high in 1989. Overall appropriation reported in 1989 was almost as high as the record use of 1988, declining only 1% to 1092 billion gallons. Although the overall level of use was similar, there were some shifts in the way the water was used and in the sources from which it was withdrawn (Figure 4).

Figure 4.

Water Use Comparison: 1988-1989

Billions of Gallons (BG)

Use Category	1988 BG/	% of total	1989 BG/	% of total	Gain or loss in 1989 (BG)
Power Generation	663	60	664	61	1
Public Supply	203[1]	18	174	16	-29
Irrigation	103[2]	9	86	8	-17
Industrial Processing	94	9	120	11	26
Other	42	4	48	4	6
	1105	100	1092	100	-13

1. Record high for public supply in Minnesota.
2. Irrigation showed the largest percent increase (54%) of all categories over CY 1987. Crop irrigation from ground water sources alone increased by 72% (49 BG in 1987 to 84 BG in 1988).

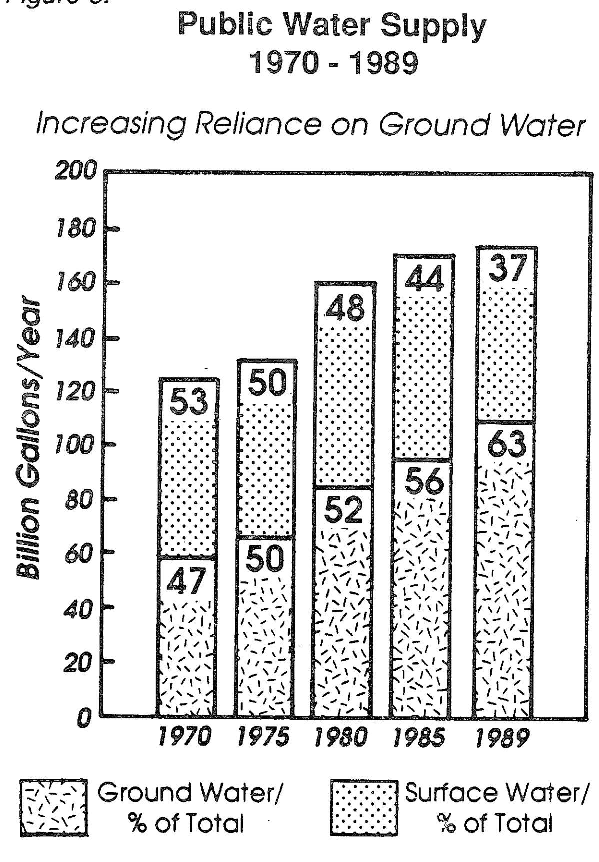
Surface water use increased by 1% in 1989 with the largest volume reported for thermoelectric power production. Water withdrawn for mine processing in northeastern Minnesota doubled between 1988 and 1989 (from 28 billion to 56 billion gallons) while withdrawals for public supply and irrigation declined.

Ground water use decreased by 9% in 1989. Notable changes were a 20% lower use for crop irrigation, 5% lower for air conditioning, 4% lower for public supply and 3% lower for golf course irrigation. Withdrawals worth mentioning are 1.4% for pollution confinement and approximately 1% for major construction dewatering for Interstate Highway 394 and the Seneca Wastewater Treatment Plant.

Public Supply Growth

Minnesota has experienced tremendous growth in public supply. Public supply increased from 53 billion gallons of use in 1950 to 174 billion gallons in 1989. Much of the growth can be attributed to an improved standard of living, increased population, and industrial/commercial users switching to public supply.

Figure 6.



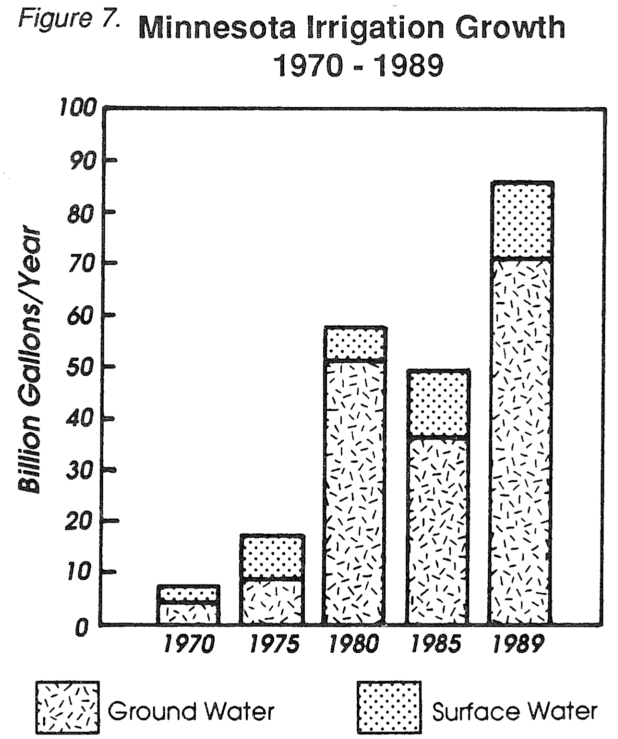
Withdrawals from more reliable ground water sources for public supply are increasing. While ground water accounted for 47% of public supply in 1970, it accounted for 63% in 1989 (Figure 6). In 1950, only 34% of public water supply was from ground water sources.

Irrigation Growth

Irrigation has become a major use of water in Minnesota in the last 20 years. In response to drought periods in 1976 and the late 1980s, irrigation has grown rapidly and remained high. While irrigation from surface water sources has substantially leveled off, irrigation from ground water sources continues to increase (Figure 7), maintaining a trend toward more reliable ground water sources for appropriation.

Although irrigation comprises less than 10% of water use reported statewide, the withdrawals are important because irrigation is a major "consumptive" use of water. Irrigation withdrawals are approximately 90% consumptive use, either through absorption by plants or through evaporation. Very little is returned to the sources from which it is drawn. In 1988, 86% of withdrawals for irrigation came from ground water sources.

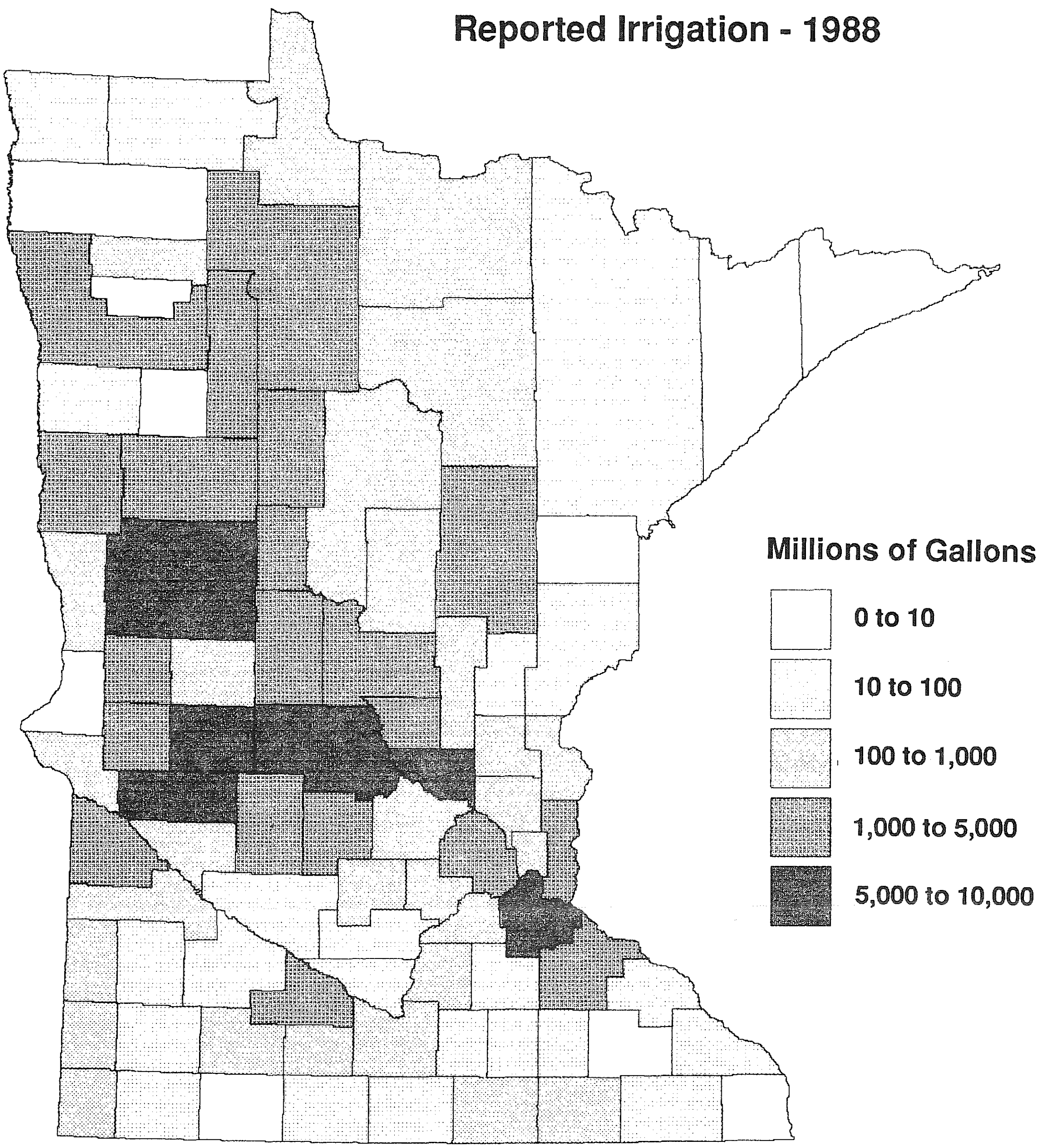
Figure 7.



Irrigation is reported in all counties except Lake and Cook, although it is concentrated in central and west central Minnesota (Figure 8). Dakota County had the highest irrigation use in 1988, followed closely by Sherburne, Stearns, and Otter Tail Counties, each reporting more than 9 billion gallons for major crop irrigation. Along with Pope and Swift Counties, they showed the largest irrigation volumes drawn from ground water sources. Clearwater, Aitkin, and Polk Counties reported the highest surface water irrigation at approximately 2 billion gallons each, primarily for wild rice flooding. Noncrop irrigation was highest in the Twin Cities area, with Hennepin, Ramsey, Washington, and Dakota Counties combining for more than 2 billion gallons in 1988.

Major crop irrigation (corn, beans, potatoes, alfalfa, etc.) accounted for most irrigation use with 95% of withdrawals coming from ground water. Wild rice production, which uses almost entirely surface water, made up half of the surface water irrigation in 1988 and 7% of irrigation reported overall. Golf course irrigation more than tripled since 1985, totaling 4% of irrigation use statewide.

Figure 8.



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

Water Use by County - CY 1988

Water appropriation varies by county in the source of the withdrawals, amounts of withdrawals and intended uses. In CY 1988, nine counties accounted for 80% (882 billion gallons) of all reported water use (Figure 5).

Figure 5.

CY 1988
Water Appropriation by County
Billions of Gallons (BG)

County	Surface	Ground	Total	Primary Use(s)
1) Goodhue	172	3	175	*Power Generation*
2) Wright	130	2	182	
3) Washington	102	12	114	
4) Hennepin	58	35	93	*Power Generation & Public Supply*
5) Ramsey	69	21	90	
6) Dakota	55	24	79	
7) Anoka	48	10	58	
8) St. Louis	88	2	90	*Industrial Processing*
9) Itasca	50	1	51	
			882, 80% of total use	

Goodhue and Wright Counties reported the largest withdrawals in the state for power plant cooling, almost entirely from the Mississippi River. Washington County had a high proportion of water withdrawn for power generation and also used significant amounts of ground water.

Hennepin, Ramsey, and Dakota Counties had major withdrawals for power generation combined with the highest ground water withdrawals in the state. St. Louis and Itasca Counties withdrew large volumes of surface water for industrial processing. Anoka County used 97% of its withdrawals for public supply including the intake for the City of Minneapolis.

The next major group of counties (10 in all) reported significantly lower withdrawals of between 5 and 20 billion gallons each. Large portions of ground water were used by Sherburne, Stearns, Benton, Pope, Swift and Otter Tail Counties for irrigation; by Olmsted and Scott Counties for public supply. Notable surface water withdrawals were used by Sherburne, Otter Tail and Martin Counties for power generation, by Stearns County for public supply and by Benton and Koochiching Counties for industrial processing.

Thirty-seven counties reported withdrawals between one and five billion gallons in 1988. The remaining 30 counties reported less than one billion gallons each.

Water use patterns among the counties in 1989 were similar. Pages 50-51 contain a summary of reported water use in all 87 counties for CY 1988 and CY 1989. See the cover page of this chapter for a graphic representation of reported use by county for 1988.

Reported Water Use By County
1988 - 1989 (Millions of Gallons)

REPORTED PUMPAGE

	COUNTY	1988 Surface	1988 Ground	1988 Total	1989 Surface	1989 Ground	1989 Total	PRIMARY USE(S) 1989
1	AITKIN	1929.7	105.9	2035.6	1729.9	113.1	1843.0	Irrigation 93%, Waterworks 6%
2	ANOKA	48505.0	9840.4	58345.4	43046.2	9928.6	52974.8	Waterworks 97%
3	BECKER	40.3	2100.2	2140.5	37.5	2397.5	2435.0	Irrigation 71%, Waterworks 28%
4	BELTRAMI	980.9	625.3	1606.2	995.8	614.5	1610.3	Irrigation 67%, Waterworks 31%
5	BENTON	3919.1	3788.0	7707.1	3596.1	2970.5	6566.6	Industrial 54%, Irrigation 39%, Waterworks 7%
6	BIG STONE	751.3	663.0	1414.3	1769.4	1030.8	2800.3	Power Generation 62%, Irrigation 27%
7	BLUE EARTH	3272.3	3377.4	6649.7	4819.6	3539.8	8359.4	Power 56%, Waterworks 22%, Industrial 16%
8	BROWN	106.1	2041.3	2147.4	127.8	1835.9	1963.7	Waterworks 49%, Irrigation 46%
9	CARLTON	3254.3	629.6	3883.9	3062.2	543.3	3605.5	Industrial 76%, Waterworks 15%, Water Levels 8%
10	CARVER	47.2	1820.2	1867.4	35.4	1663.6	1699.0	Waterworks 90%
11	CASS	398.4	911.7	1310.1	264.4	1294.6	1559.1	Irrigation 62%, Waterworks 14%, Fisheries 19%
12	CHIPPEWA	1465.5	375.2	1840.7	1940.9	337.1	2278.0	Power Generation 79%, Waterworks 16%
13	CHISAGO	48.4	757.9	806.3	125.4	903.3	1028.6	Waterworks 54%, Irrigation 39%
14	CLAY	1494.9	2082.3	3577.2	1528.6	1723.3	3251.8	Waterworks 65%, Irrigation 31%
15	CLEARWATER	2039.6	117.4	2157.0	3584.2	60.5	3644.7	Irrigation 98%
16	COOK	110.4	4.6	115.0	106.2	1.5	107.7	Waterworks 88%, Snowmaking 12%
17	COTTONWOOD	40.8	617.1	657.9	63.1	705.3	768.5	Waterworks 56%, Irrigation 26%, Industrial 17%
18	CROW WING	1320.1	1596.4	2916.5	1450.7	1479.2	2929.9	Industrial 46%, Waterworks 37%, Irrigation 11%
19	DAKOTA	54898.7	24022.9	78921.6	42836.5	19854.1	62690.6	Power 64%, Waterworks 17%, Irrigation 10%
20	DODGE	16.0	360.8	376.8	18.8	337.5	356.3	Waterworks 93%
21	DOUGLAS	25.2	1434.7	1459.9	14.0	1565.0	1579.0	Irrigation 57%, Waterworks 36%
22	FARIBAULT	14.5	817.1	831.6	26.9	783.2	810.1	Waterworks 74%, Industrial 18%
23	FILLMORE	7.5	3270.7	3278.2	5.7	2767.9	2773.6	Fisheries 76%, Waterworks 17%
24	FREEBORN	182.1	3226.0	3408.1	81.0	3065.7	3146.7	Waterworks 49%, Industrial 38%, Irrigation 11%
25	GOODHUE	171699.2	3326.5	175025.7	190637.0	2406.0	193043.0	Power Generation 99%
26	GRANT	1.1	1281.2	1282.3	10.0	922.5	932.5	Irrigation 81%, Waterworks 18%
27	HENNEPIN	58243.8	35213.9	93457.7	59301.2	37524.1	96825.2	Power 60%, Waterworks 27%, Air Conditioning 7%
28	HOUSTON	38.7	372.7	411.4	0.4	854.1	854.5	Temporary 40%, Waterworks 31%, Fisheries 19%
29	HUBBARD	92.8	3596.7	3689.5	94.7	3613.6	3708.3	Irrigation 84%
30	ISANTI	14.6	8 95.1	909.7	7.0	831.3	838.3	Irrigation 45%, Waterworks 46%
31	ITASCA	50490.9	867.2	51358.1	78989.1	897.3	79886.4	Power Generation 59%, Industrial 38%
32	JACKSON	33.5	243.7	277.2	8.7	245.6	254.3	Waterworks 95%
33	KANABEC	0.0	197.6	197.6	0.2	181.8	182.0	Waterworks 79%, Irrigation 21%
34	KANDIYOHI	516.4	3381.8	3898.2	460.1	2966.8	3426.9	Waterworks 44%, Irrigation 42%, Fisheries 12%
35	KITTSON	329.3	296.8	626.1	293.1	236.4	529.5	Industrial 50%, Waterworks 45%
36	KOOCHICHING	16149.3	39.0	16188.3	15243.9	49.1	15293.0	Industrial 99%
37	LAC QUI PARLE	77.1	2408.6	2485.7	71.2	1400.4	1471.6	Irrigation 43%, Industrial 39%, Waterworks 14%
38	LAKE	2452.7	0.4	2453.1	3480.3	1.4	3481.7	Industrial 78%, Waterworks 13%, Power 9%
39	LAKE OF THE WOODS	138.7	70.0	208.7	159.9	70.8	230.8	Irrigation 69%, Waterworks 31%
40	LE SUEUR	782.4	1197.8	1980.2	703.4	1184.9	1888.3	Waterworks 43%, Industrial 30%
41	LINCOLN	18.1	648.6	666.7	2.3	606.1	608.4	Waterworks 86%
42	LYON	62.1	1076.9	1139.0	87.3	1136.2	1223.5	Waterworks 93%
43	McLEOD	30.5	2235.3	2265.8	24.3	1820.6	1844.8	Industrial 45%, Waterworks 40%, A/C 13%

REPORTED PUMPAGE

	COUNTY	1988 Surface	1988 Ground	1988 Total	1989 Surface	1989 Ground	1989 Total	PRIMARY USE(S) 1989
44	MAHNOMEN	0.0	80.8	80.8	0.0	161.0	161.0	Irrigation 51%, Waterworks 49%
45	MARSHALL	59.1	187.1	246.2	47.8	188.3	236.1	Waterworks 100%
46	MARTIN	14940.5	508.1	15448.6	12353.0	565.1	12918.0	Power Generation 91%
47	MEEKER	74.7	1886.7	1961.4	17.8	1546.00	1563.8	Irrigation 58%, Waterworks 36%
48	MILLE LACS	106.1	560.1	666.2	71.0	594.3	665.4	Waterworks 60%, Irrigation 32%
49	MORRISON	734.3	3624.8	4359.1	128.9	3193.7	3322.6	Irrigation 76%, Waterworks 23%
50	MOWER	16.8	2438.9	2455.7	0.0	2537.4	2537.4	Waterworks 55%, Industrial 26%, Irrigation 18%
51	MURRAY	20.4	237.6	258.0	12.4	253.9	266.3	Waterworks 95%
52	NICOLLET	29.1	1492.9	1522.0	31.3	1335.9	1367.2	Waterworks 94%
53	NOBLES	21.1	1125.1	1146.2	20.7	558.1	578.8	Waterworks 92%
54	NORMAN	2.9	240.3	243.2	11.7	249.9	261.5	Waterworks 61%, Irrigation 39%
55	OLMSTED	36.4	5119.7	5156.1	33.2	5127.0	5160.2	Waterworks 88%, Industrial 8%
56	OTTERTAIL	5176.5	9874.8	15051.3	12396.0	9395.9	21791.9	Power Generation 52%, Irrigation 40%
57	PENNINGTON	655.9	30.3	686.2	588.2	32.4	620.5	Waterworks 62%, Irrigation 37%
58	PINE	32.4	404.2	436.6	126.4	385.1	511.5	Waterworks 70%, Irrigation 25%
59	PIPESTONE	72.2	858.8	931.0	72.8	643.9	716.7	Irrigation 64%, Waterworks 35%
60	POLK	4148.5	483.8	4632.3	4473.5	389.4	4862.9	Waterworks 57%, Irrigation 35%
61	POPE	176.6	7975.3	8151.9	84.6	6132.2	6216.8	Irrigation 96%
62	RAMSEY	69544.9	20942.3	90487.2	48226.3	19830.1	68056.4	Power 71%, Waterworks 13%, Industrial 9%
63	RED LAKE	1.8	462.7	464.5	0.0	473.7	473.7	Waterworks 100%
64	REDWOOD	37.3	450.9	488.2	30.5	456.9	487.4	Waterworks 92%
65	RENVILLE	45.8	559.6	605.4	58.1	377.1	435.2	Waterworks 75%, Irrigation 21%
66	RICE	13.7	1060.6	1074.3	26.6	1044.2	1070.8	Waterworks 73%, Industrial 16%, Irrigation 6%
67	ROCK	89.5	772.6	862.1	33.1	576.9	610.1	Waterworks 88%, Irrigation 12%
68	ROSEAU	0.0	268.7	268.7	0.0	314.4	314.4	Waterworks 90%, Irrigation 12%
69	ST. LOUIS	87978.1	1550.3	89528.4	107140.4	1514.6	108654.9	Power 39%, Industrial 37%, Waterworks 14%
70	SCOTT	2005.5	3030.9	5036.4	264.9	2954.7	3219.5	Waterworks 52%, Industrial 19%, Temporary 16%
71	SHERBURNE	8708.6	9985.2	18693.8	12490.6	7957.6	20448.2	Power 43%, Irrigation 36%, Water Levels 17%
72	SIBLEY	0.0	506.4	506.4	2.0	477.8	479.8	Waterworks 86%, Industrial 11%
73	STEARNS	2887.3	10962.3	13849.6	2941.6	9019.0	11960.6	Irrigation 60%, Waterworks 33%
74	STEELE	111.4	1617.7	1729.1	131.3	1733.6	1864.9	Waterworks 83%, Irrigation 7%
75	STEVENS	30.7	3569.9	3600.6	29.2	2066.4	2095.5	Irrigation 82%, Waterworks 17%
76	SWIFT	67.8	6739.0	6806.8	59.8	6124.8	6184.6	Irrigation 96%
77	TODD	663.5	2290.5	2954.0	341.0	2345.9	2687.0	Irrigation 79%, Waterworks 16%
78	TRAVERSE	3.7	102.0	105.7	25.5	89.5	114.9	Waterworks 78%
79	WABASHA	21.7	880.3	902.0	19.5	873.4	892.9	Waterworks 83%, Industrial 15%
80	WADENA	771.4	2120.1	2891.5	1613.8	1920.2	3534.1	Irrigation 89%, Waterworks 9%
81	WASECA	41.3	859.3	900.6	54.9	723.0	777.9	Waterworks 92%
82	WASHINGTON	102176.7	11785.8	113962.5	106428.8	9928.7	116357.5	Power Generation 88%
83	WATONWAN	42.0	1065.8	1107.8	27.7	922.8	950.5	Waterworks 65%, Irrigation 35%
84	WILKIN	94.3	465.7	560.0	121.9	424.3	546.2	Irrigation 64%, Waterworks 36%
85	WINONA	0.0	3840.6	3840.6	0.0	1560.3	1560.3	Waterworks 54%, Industrial 21%, A/C 19%
86	WRIGHT	130328.6	1689.2	132017.8	95069.7	1580.6	96650.3	Power Generation 98%
87	YELLOW MEDICINE	73.5	516.5	590.0	102.6	399.8	502.5	Irrigation 49%, Waterworks 44%
	TOTALS	**858082**	**247160**	**1105242**	**866549**	**225445**	**1091994**	

Reported Water Use

1985 -1989 (Millions of Gallons)

Power Generation	1985	1986	1987	1988	1989
HYDROPOWER*	0.0	120.0	120.0	120.0	120.0
Surface Water:	0.0	120.0	120.0	120.0	120.0
Ground Water:	0.0	0.0	0.0	0.0	0.0
STEAM POWER COOLING - ONCE THROUGH	48564.8	64576.5	97312.0	132832.7	130291.1
Surface Water:	48564.8	64576.5	97312.0	132832.7	130290.1
Ground Water:	0.0	0.0	0.0	0.0	1.0
STEAM POWER COOLING - WET TOWER	184.7	126.6	184.4	142.6	131.6
Surface Water:	0.0	0.0	0.0	0.0	0.0
Ground Water:	184.7	126.6	184.4	142.6	131.6
STEAM POWER - OTHER THAN COOLING	84500.1	95659.8	115460.9	96069.2	102736.5
Surface Water:	84172.9	95215.7	114917.0	95640.6	102281.9
Ground Water:	327.2	444.1	543.9	428.6	454.6
NUCLEAR POWER PLANT	278079.0	275222.3	293775.6	288975.9	271854.7
Surface Water:	278079.0	275222.3	293775.6	288975.9	271854.7
Ground Water:	0.0	0.0	0.0	0.0	0.0
THERMO ELECTRIC POWER GENERATION	96219.3	103518.8	130333.5	144932.4	159162.8
Surface Water:	96174.5	103486.3	130288.2	144889.9	159065.0
Ground Water:	44.8	32.5	45.3	42.5	97.8
SUBTOTALS	507547.9	539224.0	637186.4	663072.8	664296.7
Surface Water:	506991.2	538620.8	636412.8	662459.1	663611.7
Ground Water:	556.7	603.2	773.6	613.7	685.0

Public Supply	1985	1986	1987	1988	1989
MUNICIPAL WATERWORKS	168274.0	167073.5	189745.0	200512.7	171928.6
Surface Water:	75693.2	74540.0	85090.0	89045.9	64912.4
Ground Water:	92580.8	92533.5	104655.0	111466.8	107016.2
PRIVATE WATERWORKS	605.2	567.9	667.6	767.2	778.1
Surface Water:	13.4	16.9	2.7	3.1	2.5
Ground Water:	591.8	551.0	664.9	764.1	775.6
COMMERCIAL & INSTITUTIONAL	1463.6	1419.0	1373.8	1563.3	1443.8
Surface Water:	0.0	0.0	0.0	0.0	0.0
Ground Water:	1463.6	1419.0	1373.8	1563.3	1443.8
COOPERATIVE WATERWORKS	134.0	217.3	133.9	243.9	226.1
Surface Water:	0.0	0.0	0.0	0.0	0.0
Ground Water:	134.0	217.3	133.9	243.9	226.1
FIRE PROTECTION	12.6	11.5	12.5	13.0	25.0
Surface Water:	0.0	0.0	0.0	0.0	0.2
Ground Water:	12.6	11.5	12.5	13.0	24.8

*St. Anthony Falls Hydraulics Laboratory only

Public Supply, cont.	1985	1986	1987	1988	1989
STATE PARKS, WAYSIDES, REST AREAS	20.3	29.0	34.5	50.0	52.0
Surface Water:	0.0	0.0	0.0	0.0	0.0
Ground Water:	20.3	29.0	34.5	50.0	52.0
SUBTOTALS	170509.7	169318.2	191967.3	203150.1	174453.6
Surface Water:	75706.6	74556.9	85092.7	89049.0	64915.1
Ground Water:	94803.1	94761.3	106874.6	114101.1	109538.5

Irrigation

	1985	1986	1987	1988	1989
GOLF COURSE IRRIGATION	1298.8	1629.4	2954.6	4306.8	3634.9
Surface Water:	361.7	405.1	895.8	1350.7	773.5
Ground Water:	937.1	1224.3	2058.8	2956.1	2861.4
CEMETERY IRRIGATION	33.0	32.9	33.7	51.1	86.9
Surface Water:	0.0	0.0	0.0	0.0	0.0
Ground Water:	33.0	32.9	33.7	51.1	86.9
LANDSCAPING IRRIGATION	413.3	521.2	421.5	608.4	518.6
Surface Water:	14.4	18.9	26.3	36.6	25.1
Ground Water:	398.9	502.3	395.2	571.8	493.5
SOD IRRIGATION	26.2	6.2	91.8	147.1	322.0
Surface Water:	0.0	0.0	2.3	9.0	126.1
Ground Water:	26.2	6.2	89.5	138.1	195.9
NURSERY IRRIGATION	118.3	95.1	171.2	380.4	264.5
Surface Water:	11.5	11.0	20.1	21.8	18.7
Ground Water:	106.8	84.1	151.1	358.6	245.8
ORCHARD IRRIGATION	6.2	3.6	11.1	15.4	11.3
Surface Water:	6.2	3.6	9.7	14.9	6.9
Ground Water:	0.0	0.0	1.4	0.5	4.4
NON CROP IRRIGATION	2.6	4.7	7.2	9.5	59.4
Surface Water:	1.7	2.4	3.6	0.6	7.8
Ground Water:	0.9	2.3	3.6	8.9	51.6
MAJOR CROP IRRIGATION	37577.5	18857.7	52293.3	90104.1	72777.6
Surface Water:	2761.0	1193.7	3550.1	5912.0	5438.6
Ground Water:	34816.5	17664.0	48743.2	84192.1	67339.0
WILD RICE IRRIGATION	9796.8	8463.5	10864.5	7083.9	8536.7
Surface Water:	9789.5	8452.3	10831.0	7079.0	8536.4
Ground Water:	7.3	11.2	33.5	4.9	0.2
SUBTOTALS	49272.7	29614.3	66848.9	102706.7	86211.8
Surface Water:	12946.0	10087.0	15338.9	14424.6	14933.0
Ground Water:	36326.7	19527.3	51510.0	88282.1	71278.8

Industrial Processing

	1985	1986	1987	1988	1989
AGRICULTURAL PROCESSING	9975.9	10372.0	10670.5	11452.2	11215.2
Surface Water:	789.4	485.8	594.1	291.1	380.0
Ground Water:	9186.5	9886.2	10076.4	11161.1	10835.2
PULP AND PAPER PROCESSING	29518.0	29833.1	30829.3	30762.4	29720.7
Surface Water:	27795.3	28359.9	29539.2	29213.2	28024.0
Ground Water:	1722.7	1473.2	1290.1	1549.2	1696.7
MINE PROCESSING	17613.1	15234.8	8252.3	28460.9	56192.7
Surface Water:	17612.3	15206.1	8243.0	28458.7	56192.5
Ground Water:	0.8	28.7	9.3	2.2	0.3
SAND AND GRAVEL WASHING	2268.5	2009.0	2124.2	2086.4	1850.6
Surface Water:	1680.4	1561.2	1584.8	1493.8	1336.1
Ground Water:	588.1	447.8	539.4	592.6	514.5
SEWAGE TREATMENT	1097.4	1087.7	1010.0	618.6	977.2
Surface Water:	1.1	1.3	1.1	1.1	1.3
Ground Water:	1096.3	1086.4	1008.9	617.5	975.9
PETROLEUM OR CHEMICAL PROCESSING	2057.3	2002.8	2328.4	2809.2	2657.0
Surface Water:	0.0	0.0	0.0	0.0	0.0
Ground Water	2057.3	2002.8	2328.4	2809.2	2657.0
METAL PROCESSING	4444.8	4116.5	1553.5	4141.6	3363.6
Surface Water:	0.0	0.0	0.0	0.0	0.0
Ground Water:	4444.8	4116.5	1553.5	4141.6	3363.6
NON-METALLIC PROCESSING	827.8	896.1	830.2	748.4	622.3
Surface Water:	1.4	1.3	1.9	1.9	2.1
Ground Water:	826.4	894.8	828.3	746.5	620.1
OTHER INDUSTRIAL PROCESSING	41668.5	10719.5	11268.1	12813.9	13332.7
Surface Water:	38977.4	8214.5	9819.0	10178.9	10935.8
Ground Water:	2691.1	2505.0	1449.1	2635.0	2396.9
SUBTOTALS	109471.3	76271.5	68866.5	93893.6	119931.9
Surface Water:	86857.3	53830.1	49783.1	69638.7	96871.7
Ground Water:	22614.0	22441.4	19083.4	24254.9	23060.2

Other

COMMERCIAL BUILDING AIRCONDITIONING (A/C)	400.1	361.8	384.3	471.3	503.8
Surface Water:	0.0	0.0	0.0	0.0	0.0
Ground Water:	400.1	361.8	384.3	471.3	503.8
INSTITUTIONS - SCHOOLS, HOSPITALS A/C	113.4	168.9	21.6	308.8	19.8
Surface Water:	0.0	0.0	0.0	0.0	0.0
Ground Water:	113.4	168.9	21.6	308.8	19.8

Other, cont.	1985	1986	1987	1988	1989
HEAT PUMPS	0.5	0.0	0.0	0.0	0.0
Surface Water:	0.0	0.0	0.0	0.0	0.0
Ground Water:	0.5	0.0	0.0	0.0	0.0
COOLANT PUMPS	464.3	222.8	295.3	554.6	468.5
Surface Water:	227.0	153.0	225.0	398.6	329.9
Ground Water:	237.3	69.8	70.3	156.0	138.6
DISTRICT HEATING	46.4	24.2	29.0	30.3	26.6
Surface Water:	0.3	0.0	0.0	0.0	0.0
Ground Water:	46.1	24.2	29.0	30.3	26.6
ONCE-THROUGH HEATING OR A/C	9136.8	9411.1	10622.2	11034.3	10717.3
Surface Water:	0.0	0.0	0.0	0.0	0.0
Ground Water:	9136.8	9411.1	10622.2	11034.3	10717.3
OTHER AIR CONDITIONING	459.2	235.2	220.2	302.9	191.7
Surface Water:	444.6	222.2	209.7	246.3	162.7
Ground Water:	14.6	13.0	10.5	56.6	29.0
TEMPORARY CONSTRUCTION NON-DEWATERING	0.0	0.0	0.6	0.3	6.2
Surface Water:	0.0	0.0	0.6	0.3	6.2
Ground Water:	0.0	0.0	0.0	0.0	0.0
TEMPORARY CONSTRUCTION DEWATERING	0.0	21.1	176.9	14.7	1852.8
Surface Water:	0.0	5.8	101.6	5.0	0.5
Ground Water:	0.0	15.3	75.3	9.7	1852.3
TEMPORARY PIPELINE AND TANK TESTING	15.4	32.2	35.1	43.0	118.3
Surface Water:	0.1	30.0	0.0	0.0	51.9
Ground Water:	15.3	2.2	35.1	43.0	66.4
OTHER TEMPORARY	0.0	253.0	0.0	20.1	10.0
Surface Water:	0.0	253.0	0.0	20.1	10.0
Ground Water:	0.0	0.0	0.0	0.0	0.0
BASIN (LAKE) LEVEL MAINTENANCE	1454.4	2350.9	2023.1	1813.0	1841.4
Surface Water:	1026.3	1943.4	1 325.4	627.5	638.9
Ground Water:	428.1	407.5	697.7	1185.5	1202.4
MINE DEWATERING	14759.2	9681.4	7744.5	10061.6	12491.2
Surface Water:	14759.2	9681.4	7744.5	10061.6	12491.2
Ground Water:	0.0	0.0	0.0	0.0	0.0
QUARRY DEWATERING	13075.8	10253.6	7553.8	8736.7	7409.8
Surface Water:	13075.8	10253.6	7553.8	8736.7	7409.8
Ground Water:	0.0	0.0	0.0	0.0	0.0
SAND/GRAVEL PIT DEWATERING	25.5	25.8	0.9	12.1	19.5
Surface Water:	25.5	25.8	0.9	12.1	19.5
Ground Water:	0.0	0.0	0.0	0.0	0.0
TILE DRAINAGE AND PUMPED SUMPS	212.7	497.9	90.9	72.8	44.7
Surface Water:	212.7	497.9	90.4	72.3	44.7
Ground Water:	0.0	0.0	0.5	0.5	0.0
OTHER WATER LEVEL MAINTENANCE	1035.3	1103.2	2197.7	1004.6	3666.4
Surface Water:	1022.4	1092.9	2184.9	969.0	3623.6
Ground Water:	12.9	10.3	12.8	35.6	42.8

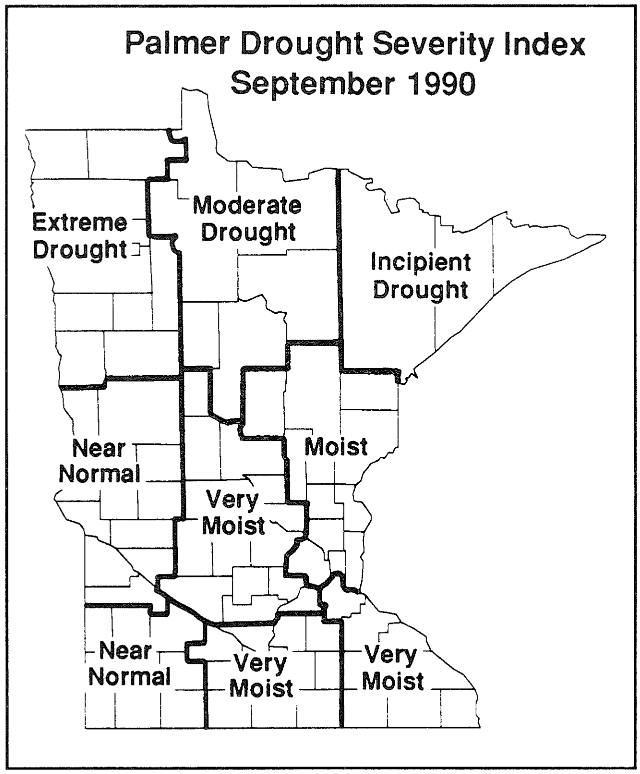
Other, cont.	1985	1986	1987	1988	1989
POLLUTION CONFINEMENT	1518.7	1816.4	646.9	2456.3	3086.2
Surface Water:	0.0	0.0	0.0	0.0	0.0
Ground Water:	1518.7	1816.4	646.9	2456.3	3086.2
HATCHERIES AND FISHERIES	5276.7	4916.3	5313.1	5164.7	3717.9
Surface Water:	786.5	541.1	869.3	743.8	744.9
Ground Water:	4490.2	4375.2	4443.8	4420.9	2973.0
SNOW MAKING	271.9	211.7	336.2	299.9	344.1
Surface Water:	60.3	51.3	64.9	72.2	82.1
Ground Water:	211.6	160.4	271.3	227.7	262.0
PEAT FIRE CONTROL	0.0	0.0	0.2	0.7	0.8
Surface Water:	0.0	0.0	0.0	0.0	0.0
Ground Water:	0.0	0.0	0.2	0.7	0.8
OTHER SPECIAL CATEGORIES	768.4	728.2	749.0	545.2	602.2
Surface Water:	768.4	728.2	749.0	545.2	602.2
Ground Water:	0.0	0.0	0.0	0.0	0.0
SUBTOTALS	49034.7	42315.7	38441.5	42947.9	47138.9
Surface Water	32409.1	25479.6	21120.0	22510.7	26217.9
Ground Water:	16625.6	16836.1	17321.5	20437.2	20921.0

GRAND TOTALS OF REPORTED WATER USE
1985-1989 (Millions of Gallons)

	1985	1986	1987	1988	1989
TOTALS	885681.5	856607.5	1003133.3	1105242.2	1091994.0
Surface Water:	714910.2	702574.4	807747.5	858082.1	866549.4
Ground Water:	170771.3	154033.1	195385.8	247160.1	225444.5

CONCLUSIONS

Minnesota's hydrologic situation has improved since 1988. However, a significant portion of the state remained in a drought or near-drought condition at the end of WY 1990 (see Palmer Drought Severity Index at right). The overall hydrologic situation is still in need of improvement.



CLIMATOLOGY Precipitation amounts generally continued at below normal levels in 1989 but events were more timely in nature. In addition, air temperatures moderated from 1988 which improved crop production in 1989. However, the long-term impacts of the drought period of 1987-1989 lingered into 1990 in spite of increased precipitation amounts. Overall, parts of central and southeastern Minnesota experienced above normal to excessive precipitation in 1990 while the northwest continued in a state of extreme drought with no significant relief in the past four years.

SURFACE WATER Stream flows improved some in WY 1989; especially so in WY 1990 over much of the state. Surficial basin storage areas (lakes, wetlands) continued to recede in 1989 but began to recover in 1990. However, much of the near surface ground water supply, lakes and wetlands have not been fully recharged, even in areas where precipitation returned to near average. These storage areas supply the base flow for rivers and streams which will continue to show rapid fluctuations between periods of precipitation and runoff without adequate base flow. The amount and distribution of future precipitation will determine the time required to achieve full recovery.

GROUND WATER Water tables in unconfined aquifers respond more readily to changes in precipitation patterns than do water levels in confined aquifers. These water tables dropped in 1988 but have generally responded to increased precipitation amounts in 1989 and 1990. An exception is in northwest Minnesota which has had no substantial drought relief in four years. Water levels in confined aquifers are much slower to fluctuate in response to climatic changes and generally receded throughout 1989 and much of 1990. Depending on the type (buried drift or bedrock) and the depth, levels in some continue to drop. While many confined aquifers were showing signs of recovery toward the end of WY 1990, nearly all remain below average levels.

WATER USE Reported water use was at an all time high in 1988 in response to severe climatic conditions that year. Although the weather moderated considerably in 1989, reported use declined by only 1%. The primary reductions in reported water use for 1989 were in the categories of public supply and irrigation while a substantial increase was reported in use for industrial processing. However, appropriations for public supply and irrigation continue to switch to more reliable ground water sources for both quality and quantity reasons.

While Minnesota is considered to be a water-rich state, recent drought periods have focused attention on the water shortages that may occur from time to time. As demands for water use increase, the state may face shortages that are no longer limited to drought periods. Presently, some areas of the state lack sufficient water to serve all demands. Wise planning and allocation management is needed to address future growth needs.