Water Year Data Summary 1993 and 1994

Water Year Data Summary

1993 and 1994

May 1995

Minnesota
Department of Natural Resources
Division of Waters

Water Year Data Summary 1993 and 1994

October 1, 1992 - September 30, 1994

by the Division of Waters Staff

St. Paul, MN
May 1995

Minnesota
Department of Natural Resources
Division of Waters

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Introduction

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

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

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

Water Year

The climatology, surface water and ground water data presented are for Water Years 1993 and 1994.

WY 1993: October 1, 1992 - September 30, 1993
WY 1994: October 1, 1993 - September 30, 1994

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

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

Acknowledgements

I wish to express my gratitude to the authors who contributed to this report.
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Department of
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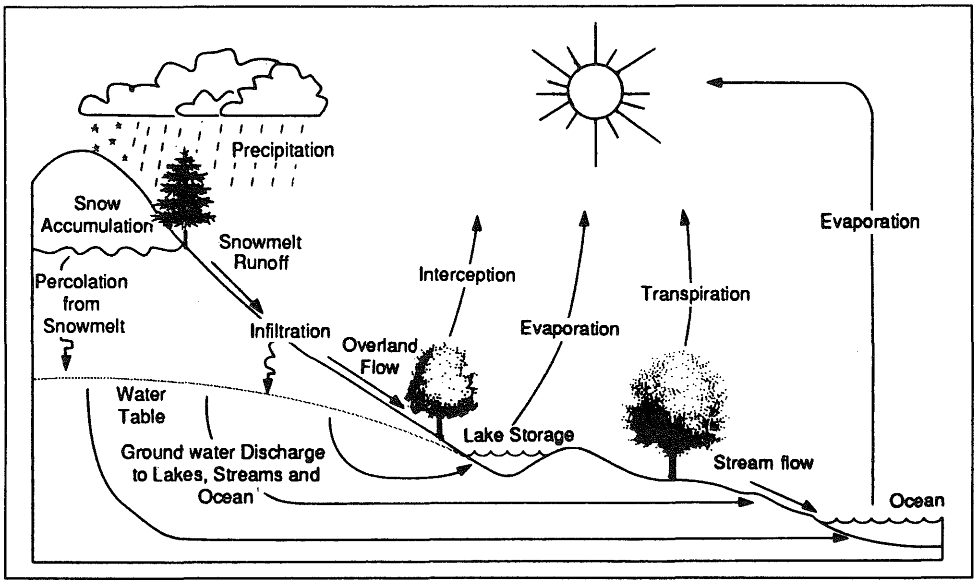
Division of Waters

Kent Lokkesmoe, Director

Hydrologic Cycle

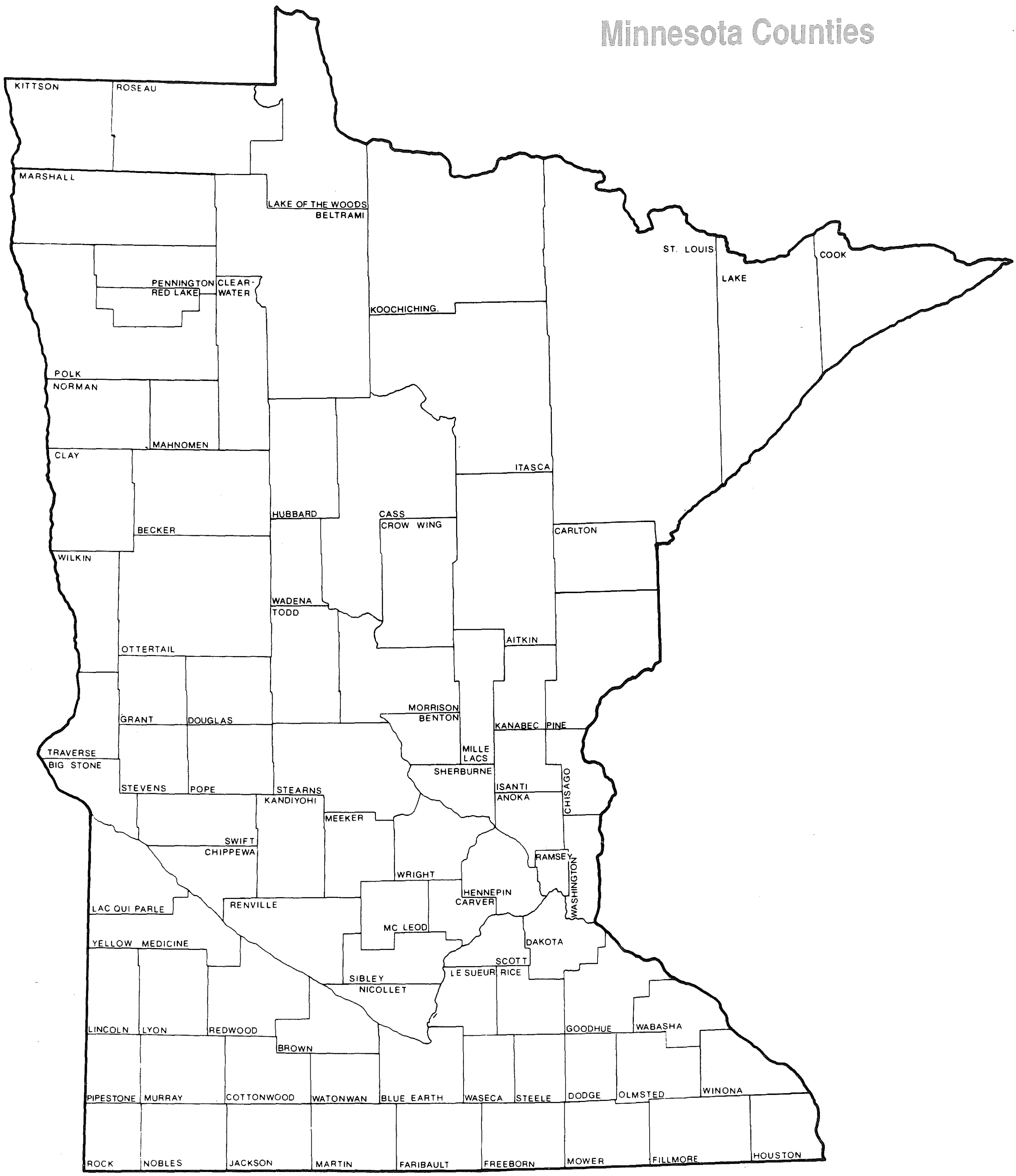


The hydrologic cycle is a concept used to explain the movement of water around the earth. This movement is continuous and has no beginning or end. Affecting it at any point in the cycle will be reflected later in the cycle.

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

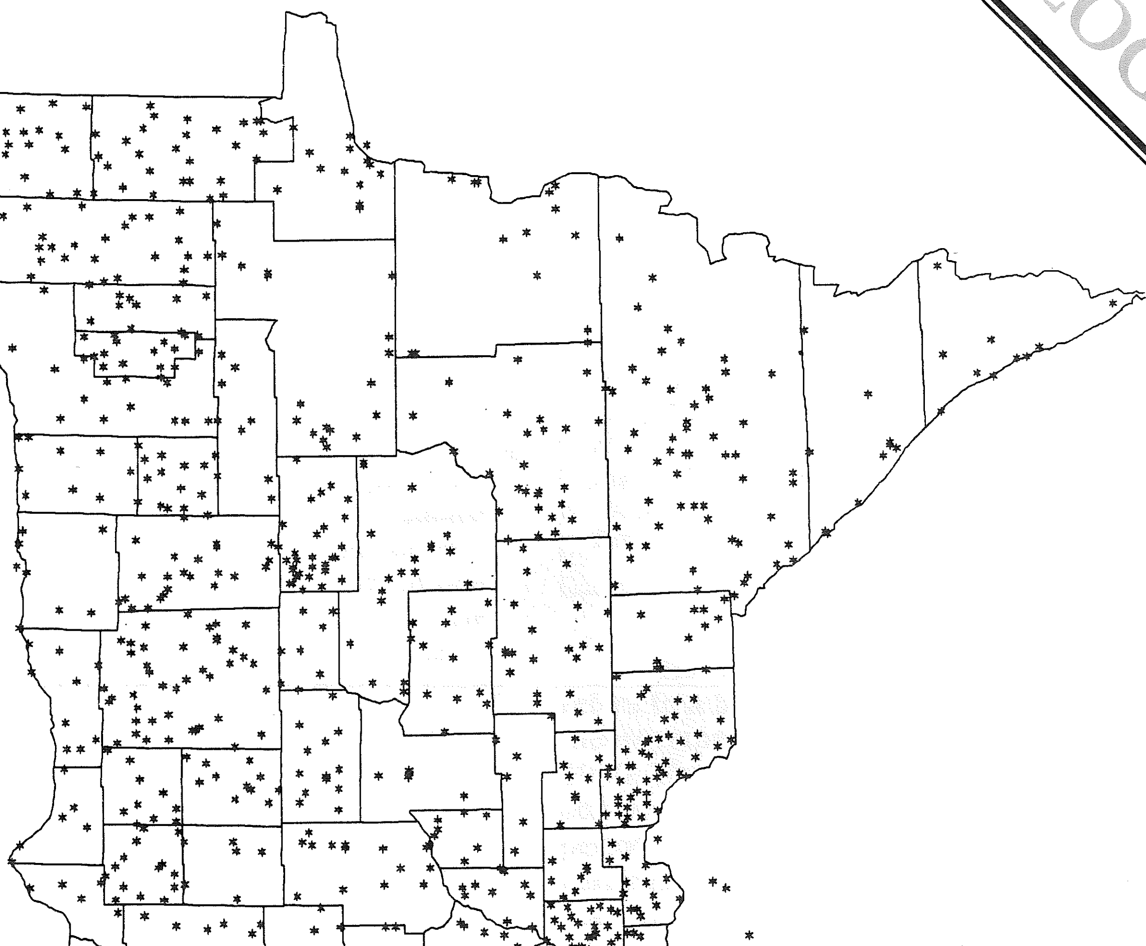
At any point where water is on the ground surface, it is subject to evaporation into the atmoshere or infiltration into the soil.

Minnesota Counties



Chapter 1: CLIMATOLOGY

Precipitation Observer Network
June 1994
(1441 Observers)



Introduction

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

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

Climate Data Sources:

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

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

WATER YEAR 1993

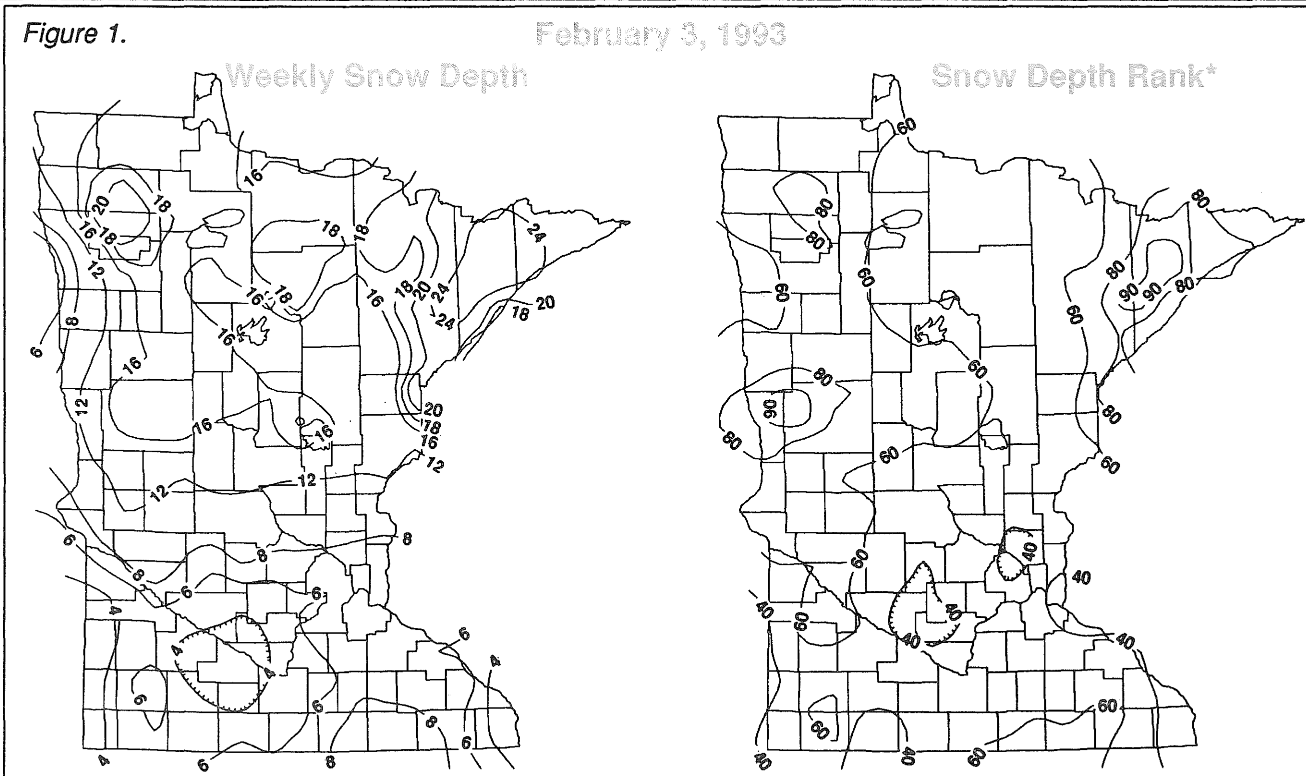
October 1, 1992 - September 30, 1993

Highlights

- Early snow, late spring ice-out
- Dry spring in northwest, wet elsewhere
- Very wet, cool summer; drier in autumn
- May-August among wettest periods on record

Like the winter of 1991-1992, the winter of 1992-1993 began with an unusually early November snow storm which blanketed many portions of the state. Some locations received more than six inches of snow. While this storm did not match the intensity of the Great Halloween Blizzard of 1991, it set the tone for a winter distinguished more for its longevity than its harshness. Relatively small but periodic snowfalls kept Minnesota's snow pack at or above the median throughout the winter (Figure 1). Notable events over the winter included a January ice storm in southern and eastern Minnesota, and a bitter cold spell in mid-March.

Figure 1.



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

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

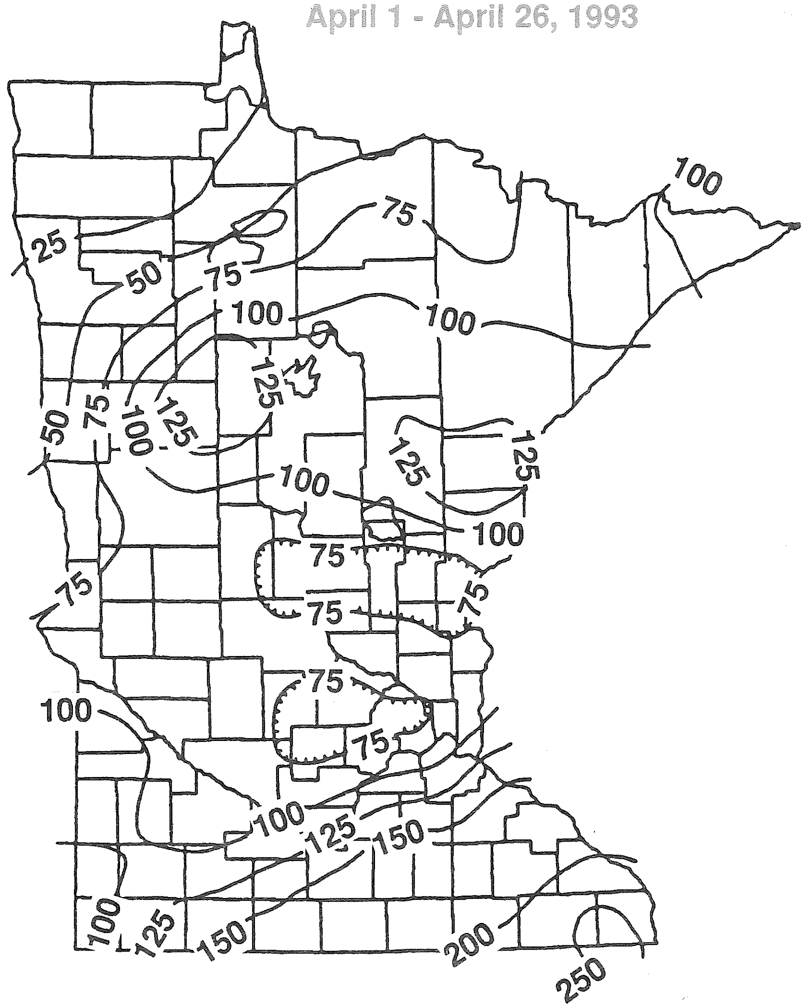
* Snow Depth Rank is a measure of the rarity of the absolute snow depth. The numbers represent an estimate of the number of years out of 100 in which the depth is less than the observed depth on the stated date. Thus a "95" would mean: "in 95 out of 100 years, the snow depth will be less" or "the snow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

Minnesota entered the spring of 1993 with most hydrologic systems at or above long-term average levels. The moist conditions resulted from extremely low evaporation rates during the summer of 1992, one of the coolest summers ever recorded.

The spring of 1993 brought a disparate pattern of near to above normal temperatures and below normal precipitation in the northwest, with cold and wet conditions affecting the south. Figure 2 shows that April precipitation was sparse in the northwest, whereas portions of southeast Minnesota received more than 200 percent of normal precipitation (much of which came as snow). The heavy spring precipitation in the south, falling on already moist soil, led to some moderate flooding. Fortunately, the cool spring weather reduced the rate of snow melt, and somewhat diminished flooding potential. The unusually late snow in the south (plus very cool April temperatures) delayed lake ice-out by two weeks. Elsewhere around Minnesota, lake ice-out ranged from a few days behind to right on schedule.

Figure 2.

Percent of Normal Precipitation
April 1 - April 26, 1993



The spring and summer of 1993 combined to produce one of the wettest periods in Minnesota's recorded climate history. Rainfall was notable in both its volume and its persistence.

The unceasing thunderstorms began in early May in southwestern Minnesota which led to significant urban and rural flooding in the Marshall and Pipestone areas (Figure 3). Throughout southern Minnesota in May, extremely wet soils delayed or eliminated prospects for agricultural field work.

Heavy rains continued during June, drenching many areas of the southern third of Minnesota. Some locations reported June totals exceeding 15 inches. The pivotal rainfall event of the period was a large storm system that struck southern Minnesota on June 16 and 17 when four or more inches of rain fell across much of the Minnesota River basin (Figure 4). This rain fell on already saturated ground and swollen water bodies and led to large scale flooding. Flooding in southern Minnesota marked the beginning of a natural disaster that plagued the Midwest for many months (see side bar, page 5).

Figure 3. May 6 -8, 1993

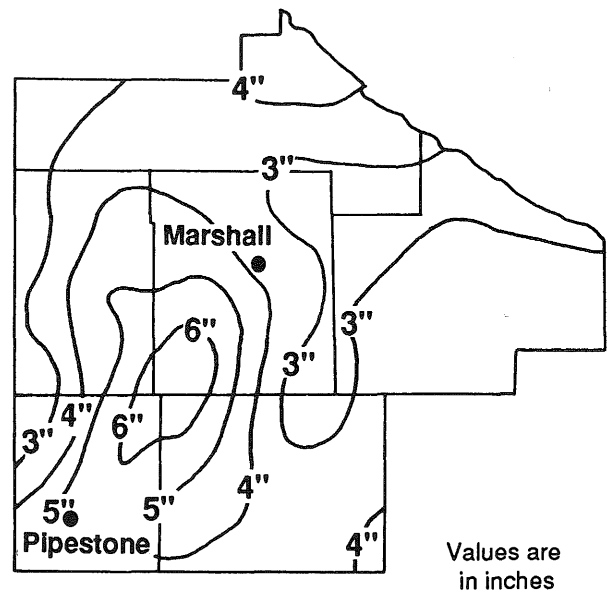
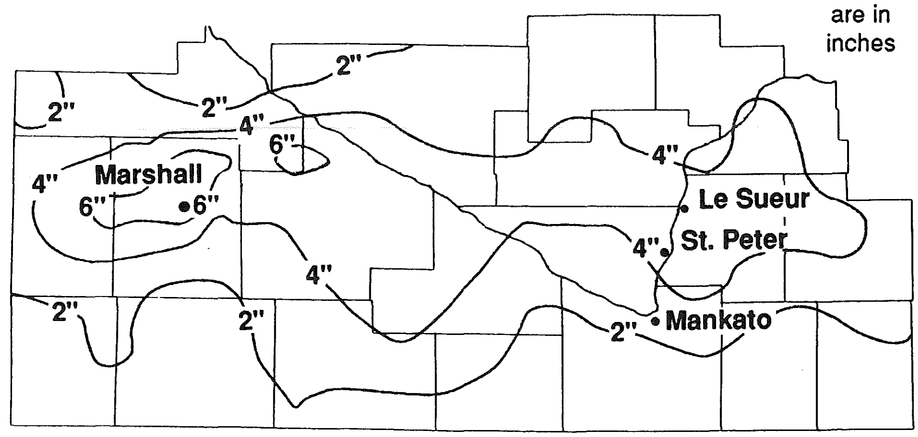


Figure 4. Heavy Rains - Southern Minnesota June 16 - 17, 1993



the GREAT FLOOD of 1993

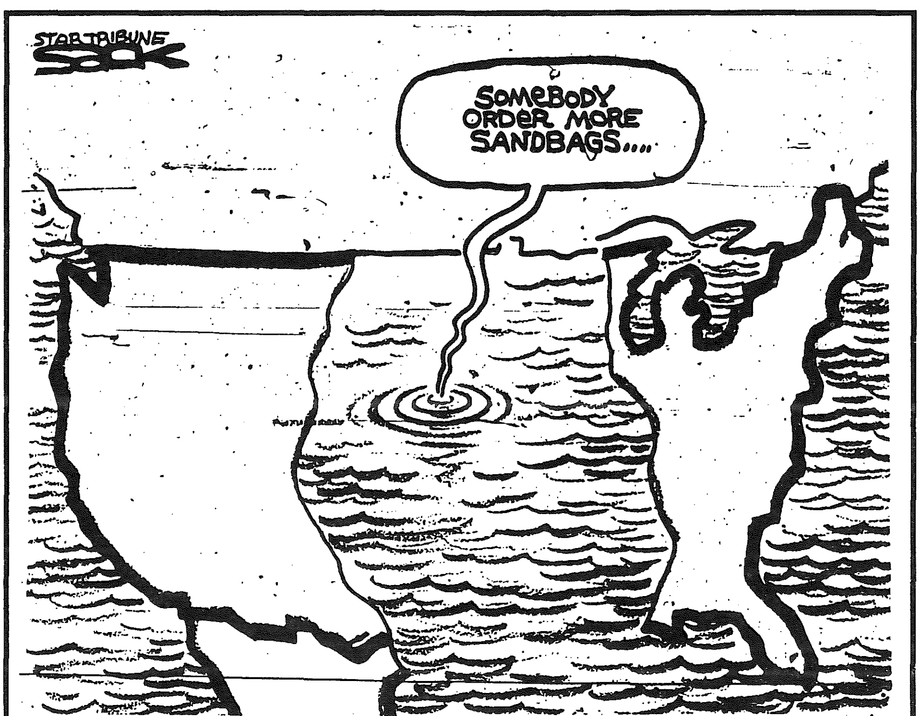
The Great Flood of 1993 had its origins in an extended wet period starting 9-10 months prior to the onset of major flooding. This wet period moistened soils to near saturation and raised many stream levels to bank full or flood levels. This set the stage for rapid runoff and record flooding that followed excessive June and July 1993 rainfall.

The event was exceptional in many ways:

- the weather pattern which caused the excessive rainfall from mid-June to August was uncommonly persistent
- the flooding occurred during the summer months as opposed to the more typical spring snow-melt season.
- major flooding and record flooding occurred along portions of dozens of rivers, including portions of the main stems of the Mississippi and Missouri
- while most significant floods last days to weeks, this flood lasted weeks to months.

Over 15 million acres across 9 states were inundated by the flood of 1993. The entire state of Iowa was designated as a federal disaster area. Large sections of 8 other states (North Dakota, South Dakota, Minnesota, Wisconsin, Illinois, Missouri, Nebraska and Kansas) were also declared federal disaster areas. The toll was heavy all across the region, with 48 deaths and some 70,000 people left homeless in the 421 counties declared federal disaster areas. Farmers suffered greatly with $8 billion in damage to crops. Although the exact amount may never be known, the total damage from the Great Flood of 1993 could rival the $21 billion of Hurricane Andrew, the nation's costliest disaster.

-From the executive summaries of the following reports:
The Great Flood of 1993, the Minnesota Experience, March, 1994, MN Department of Public Safety
Coastal Oceanographic Effects of 1993 Mississippi River Flooding, 1994, NOAA/National Weather Service



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July brought a continuation of the extremely wet weather. Heavy rains persisted in southern Minnesota, but also influenced the west and north. West central, northwestern and northeastern Minnesota experienced downpours, raining many inches in just a few hours. One such event in mid-July led to significant urban and rural flooding in Clay and Becker Counties (Figure 5).

Figure 5. Flash Flood - Northwestern Minnesota July 15-16, 1993

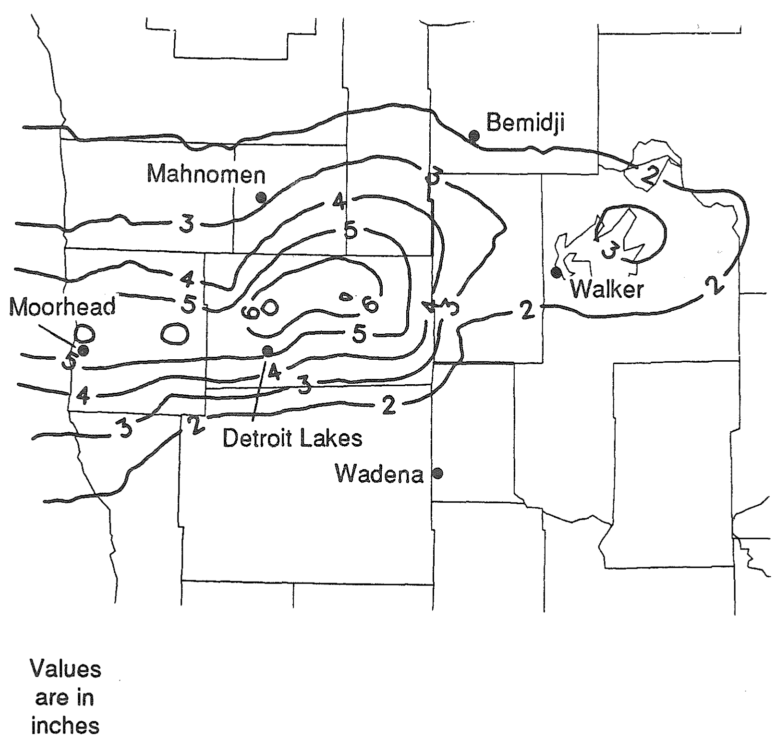
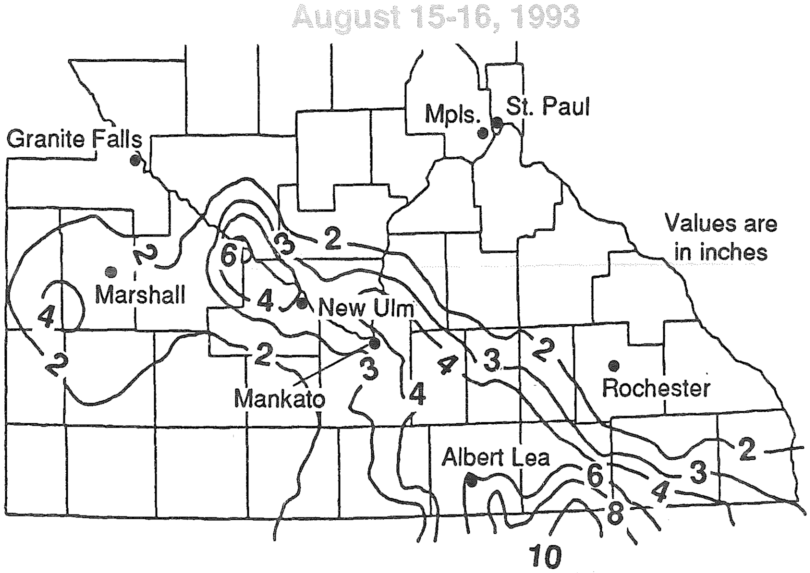


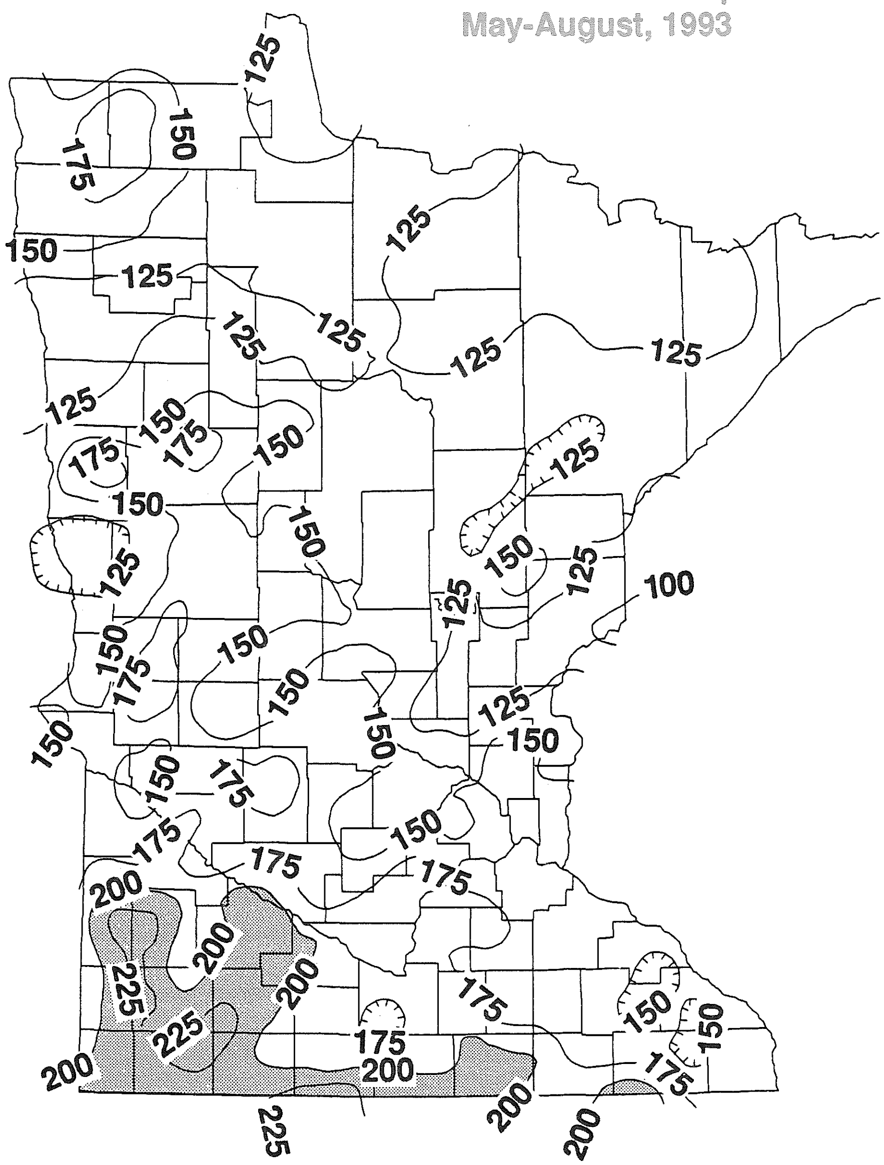
Figure 6. Heavy Rains in Southern Minnesota August 15-16, 1993



The most significant rainfall event of late summer occurred on August 15 and 16 along a line that stretched from near New Ulm to south of Austin (Figure 6). A multi-county area received more than four inches of precipitation from this storm. Eight or more inches fell in some areas leading to widespread soil erosion and flooding in and around Austin.

Figure 7.

Percent of Normal Precipitation May-August, 1993

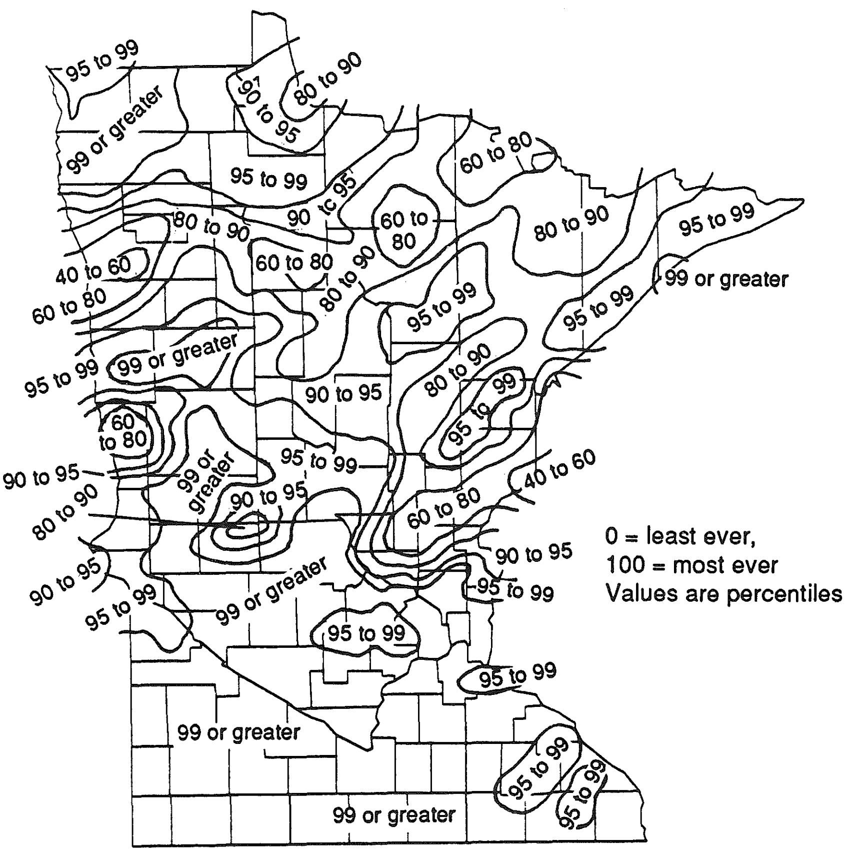


The months of May through August of 1993 constituted one of the wettest multi-month periods in Minnesota's recorded climate history. The torrential rains that impacted nearly all of the Midwest left many locations in Minnesota with precipitation totals exceeding 200 percent of the mean, the equivalent of two summers worth of rain (Figure 7).

Figure 8 shows that roughly one half of Minnesota ranked at, or above, the 99th percentile for May through August rainfall. A value above the 99th percentile means that those locations broke, or nearly broke, all-time May through August rainfall records. Four-month totals exceeded 28 inches over much of southern Minnesota, the normal *annual* rainfall for many of those areas. Record breaking rainfall over such a broad area, for such an extended period of time, is nearly unprecedented in Minnesota's 100-year climate history.

The same atmospheric conditions that caused the heavy rains also led to very low evaporation rates. Cloudy and cool weather, in tandem with persistently high relative humidity, combined to reduce the atmosphere's ability to evaporate water from the surface. For the first time since such records have been kept, precipitation totals exceeded pan evaporation values for the May through August period. The lack of evaporation exacerbated the existing hydrologic imbalance.

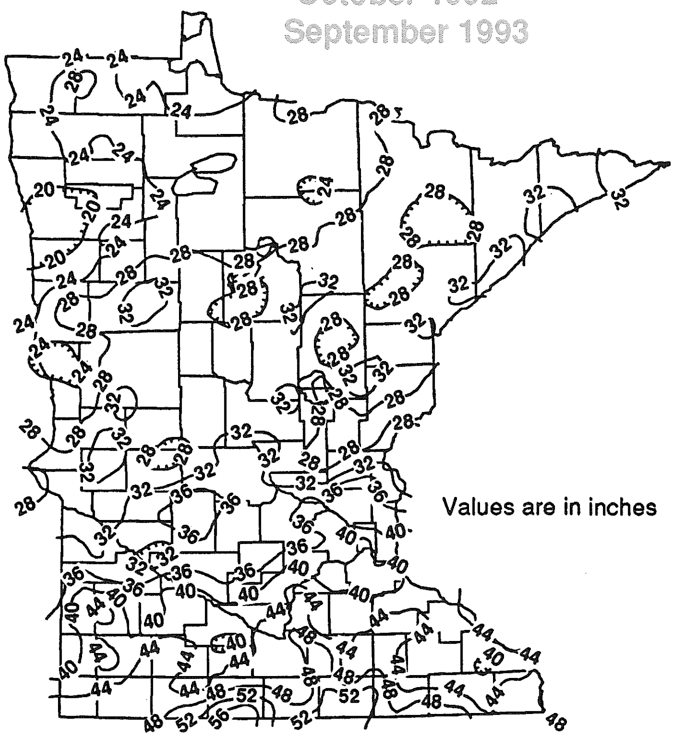
Figure 8. May-August, 1993 Precipitation Historical Ranking



This map depicts where the May to August, 1993 precipitation totals fall in the context of history (100 years of climate data). A value of 99 or greater means the May to August all-time rainfall record was nearly matched or broken. A value of 90 means that greater amounts would only be expected one out of ten years.

The deluge led to numerous problems for nearly all elements of society. Rising rivers and streams damaged private property and endangered lives. Damage to and closure of roads and bridges hindered transportation. Heavy rains flooded croplands, eroded soils, hampered or eliminated agricultural field work and decreased production. The wetness also impacted other weather sensitive industries such as construction and outdoor recreation.

Figure 9. Water Year Precipitation October 1992 - September 1993

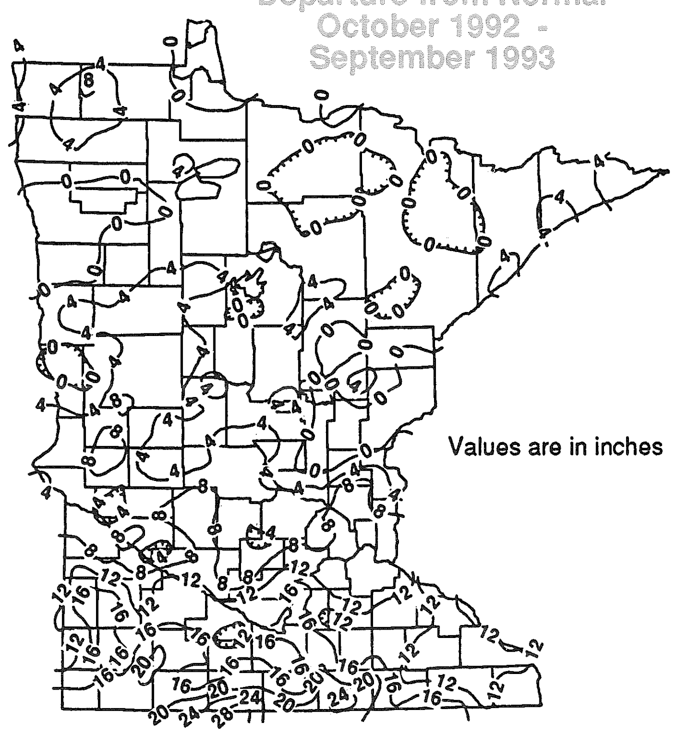


Fortunately the rain slackened by late summer and early fall, but warm temperatures needed to adequately dry crops and soils did not accompany the dryer weather. September was one of the coolest on record, as was October (with some exceptions). Fall soil moisture levels were very high over nearly all of Minnesota.

Figure 9 shows that all of the southern third of Minnesota received over 36 inches of precipitation during 1993. Some areas in Martin County received well over 50 inches of precipitation for that period.

Elsewhere across the state, precipitation totals ranged from 20 to 32 inches. Over two dozen counties in southern Minnesota reported precipitation departures of over one foot above normal (Figure 10). With very few exceptions, the entire state received greater than normal precipitation for the period. This heavy precipitation fell on a landscape already wet from the climate events of the early 1990's.

Figure 10. Water Year Precipitation Departure from Normal October 1992 - September 1993



WATER YEAR 1994

October 1, 1993 - September 30, 1994

Highlights

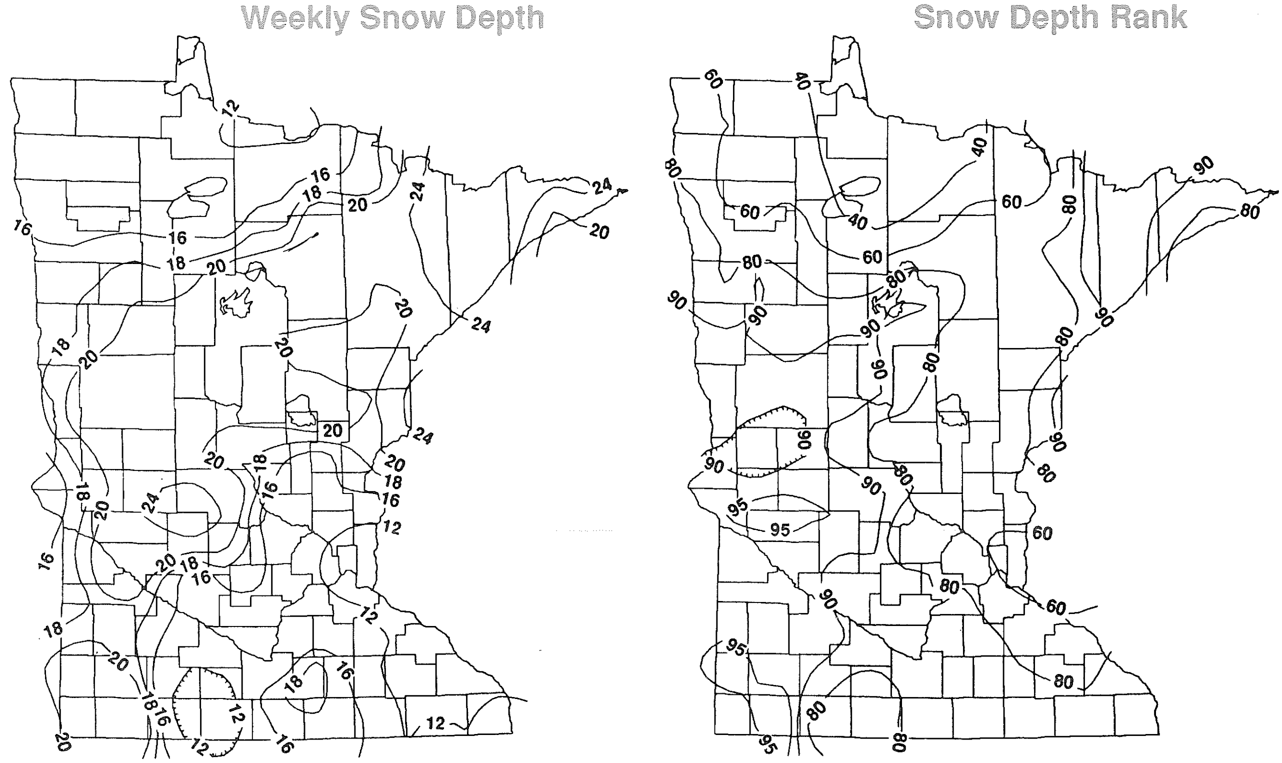
- Snowy winter, cold January
- Early spring, early lake ice-out
- Mild summer and autumn
- Normal precipitation for year

The winter of 1994 brought significant snow cover. Early in January, Finland (located along the North Shore) received over 4 feet of snow in a single storm, and by early February, nearly all of Minnesota reported snow depths that ranked at least in the 80th percentile (Figure 11). The snow pack contained from one to four inches of water and acted as an insulating blanket for the soil, inhibiting frost penetration. A shallower frost layer meant fewer broken water pipes and less energy required to warm the ground in spring, opening the soils earlier to infiltration. Frost protection was critical during January when Minnesota experienced its coldest month in over a decade. Many minimum temperature records were broken as the thermometer dropped well below zero for extended periods of time.

Figure 11.

February 2, 1994

Weekly Snow Depth | Snow Depth Rank

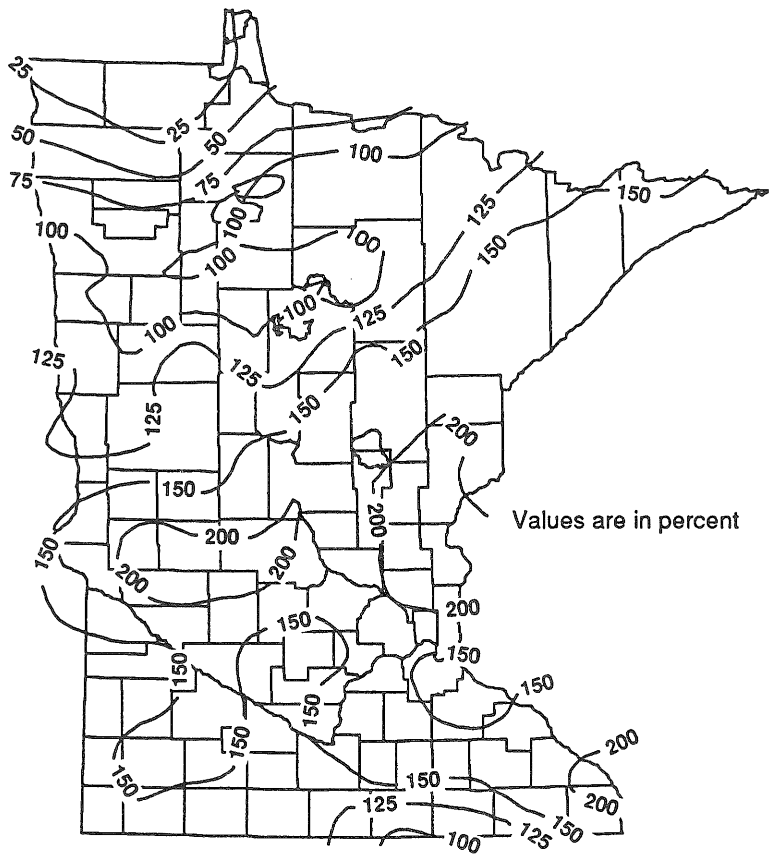


Values are in inches.
Snow depths are generally measured on grassy, protected areas.

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

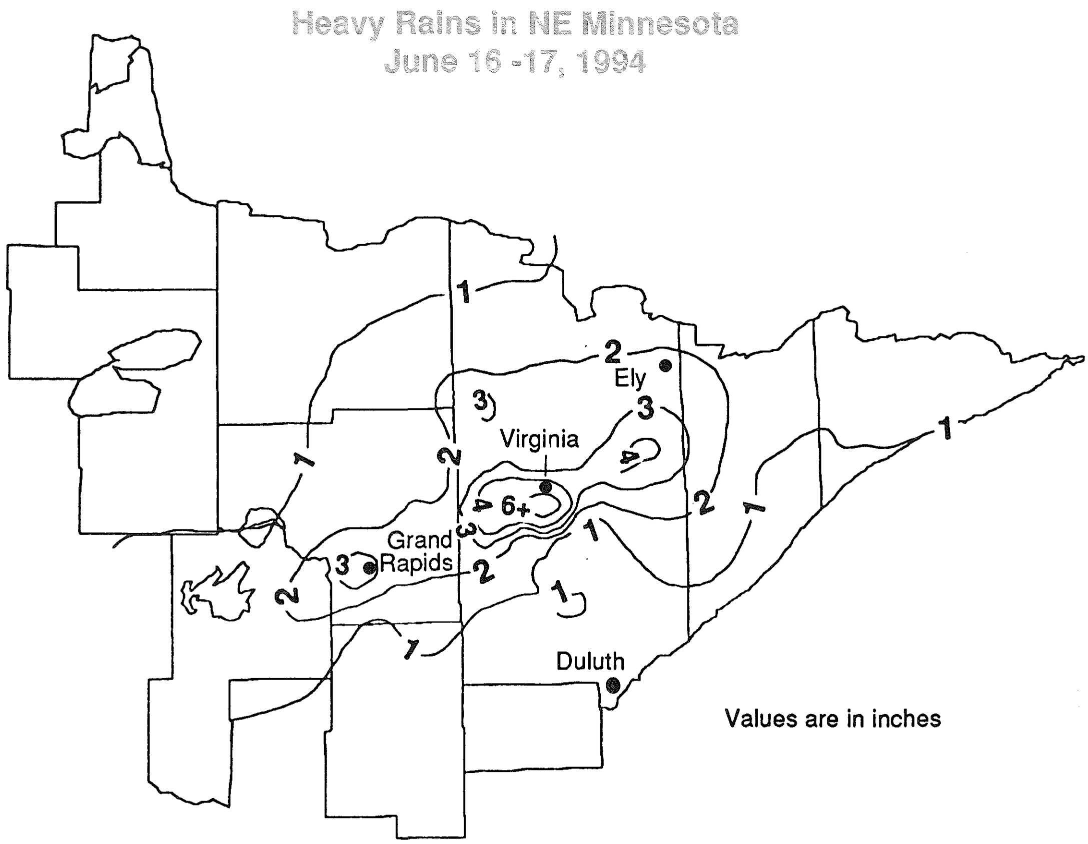
Entering late winter and early spring, a significant potential existed for spring flooding. The components for possible heavy flooding included: an above average snow pack, waterlogged soils, and unusually high stream base flow. Fortunately, the weather from mid-February through early April was favorable for reducing the flood threat. Light precipitation and moderate temperatures led to a gradual snow melt. The result was light to moderate flooding in some areas of the south and west, with no significant problems.

Figure 12. Percent of Normal Precipitation April 1 - May 2, 1994



The lack of late winter snow cover and the moderate March temperatures also helped to accelerate lake ice-out, with most lakes open three to seven days earlier than usual. A dry, early to mid-April allowed farmers to perform much needed field work, especially in the south. However, field work came to a halt during the last week of April when the State experienced heavy rains, severe weather, and a spring snow storm. Figure 12 shows that, except for the extreme northwest, Minnesota's April precipitation totals were well above normal. River levels were again on the rise, and agricultural field operations experienced delays during a critical period. In contrast, May was mild and relatively dry and featured more 'summer-like' weather than nearly the entire summer of 1993. Temperatures above 80 were common, and many weekends were sunny and mild.

Figure 13.



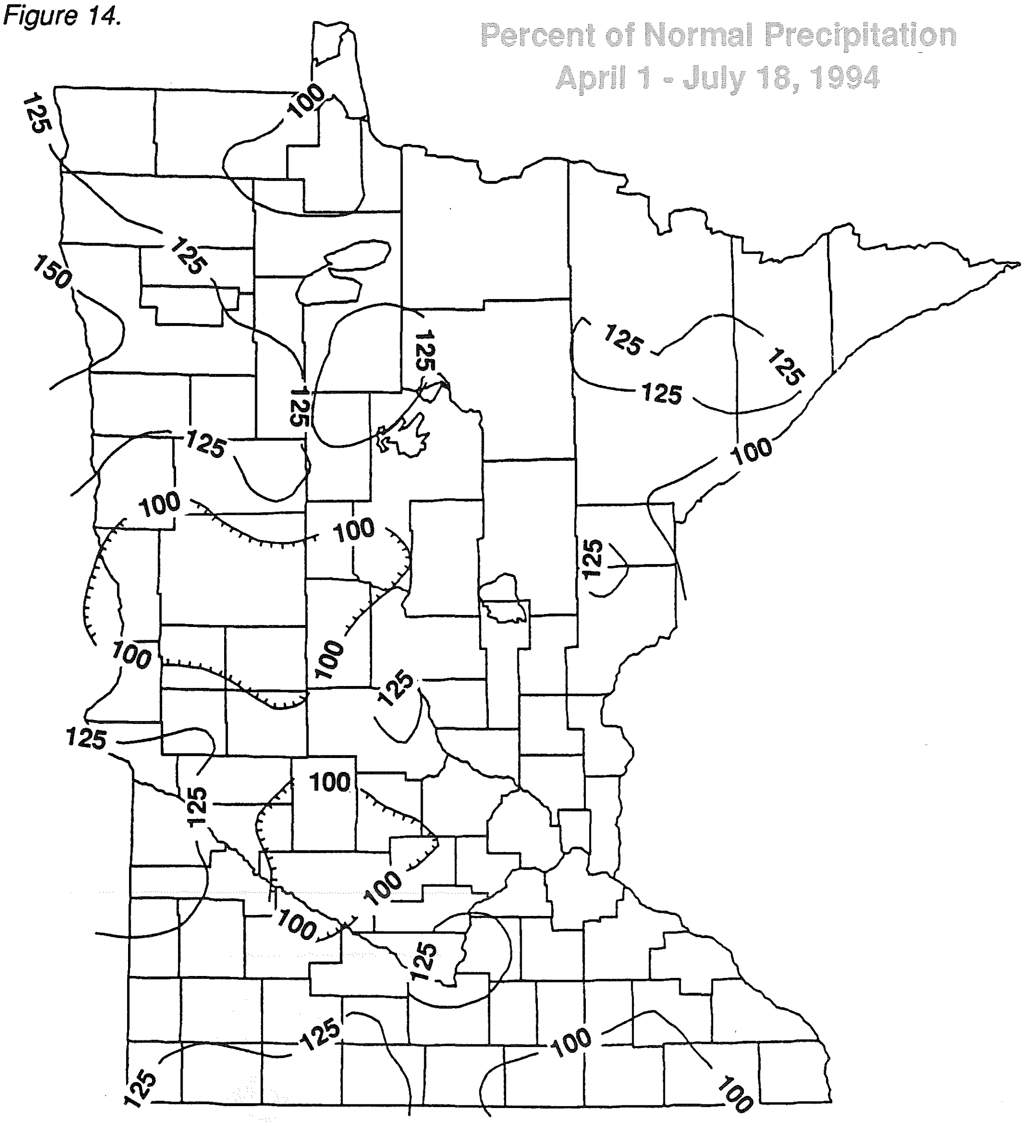
The summer of 1994 marked a return to the type of weather typical for a state the size of Minnesota. Some areas of the state experienced benign, nearly ideal weather, while others suffered through unusual weather with detrimental impacts. For most of Minnesota, near normal temperatures and timely rains were the rule. Notable exceptions were the unusual wetness in the northwest and significant hail damage in west central and southwest Minnesota.

June delivered the usual pattern of 'spells' of wet and dry weather. However, in northern and southwestern Minnesota, frequent and often heavy thunderstorms pushed June precipitation totals well above normal. The most significant rainfall of the summer was an event on the Iron Range (June 16-17, Figure 13). when six or more inches of rain fell in less than 24 hours in some areas. Rainfall rates of an inch or more per hour were common. The largest rainfall total was 10.5 inches just south of Virginia.

In northwest and portions of west central Minnesota, wet weather continued into July. Heavy and recurrent rainfall drowned crops, enhanced plant disease potential and ceased haying operations across much of the area from the Red River Valley eastward. As of mid-July, many areas across the northern third of Minnesota reported precipitation totals that were well above normal for the growing season (Figure 14). The wet weather in the north, in conjunction with hydrologic imbalances caused by recent wet years, led to above average stream flows and lake levels in some areas.

Figure 14.

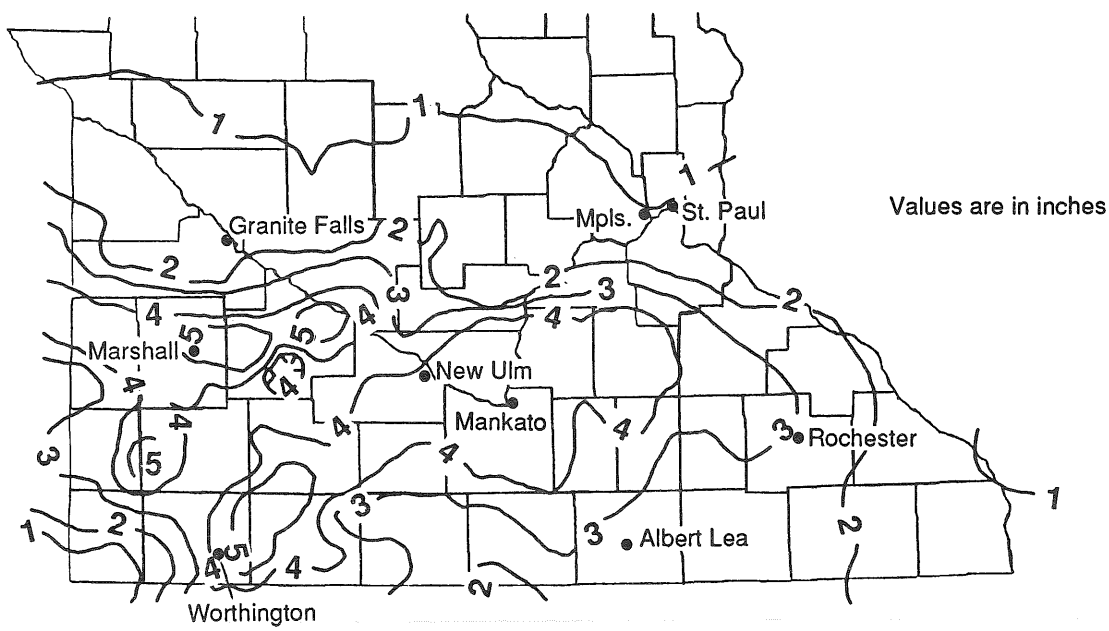
Percent of Normal Precipitation
April 1 - July 18, 1994



In August, pleasant weather mixed with cool, wet, and sometimes severe weather. The most significant rainfall event of late summer occurred on August 9 and 10 as moderate but persistent rain dropped over four inches over a large area of southern Minnesota (Figure 15). However, unlike 1993, the rain did not fall on saturated soil and did not create widespread difficulties. On August 25, a geographically isolated thunderstorm dropped over six inches of rain on portions of McLeod and Sibley Counties. As is common during the summer months, severe storms in August brought tornado, wind, lightning and hail damage to portions of the state. One particularly intense hailstorm damaged over 9000 acres of corn, soybeans, and alfalfa in LeSueur County.

Figure 15.

Heavy Rains in Southern Minnesota
August 9 - 10, 1994



'Normal' weather returned to Minnesota during the 1994 'warm' season, and there were no state-wide significant climate anomalies. While certain regions of the state experienced detrimental weather, most of Minnesota experienced nearly ideal weather, benefiting agriculture and other climate sensitive industries. Many agricultural commodities set all-time high production records.

Mild temperatures and above-normal precipitation in the northwest and southeast characterized September. A storm system produced over five inches of rain in southern and east central Minnesota on September 13-14. However, it was a pleasant month overall with mild weather accelerating crop maturity, and without the threat of frost damage.

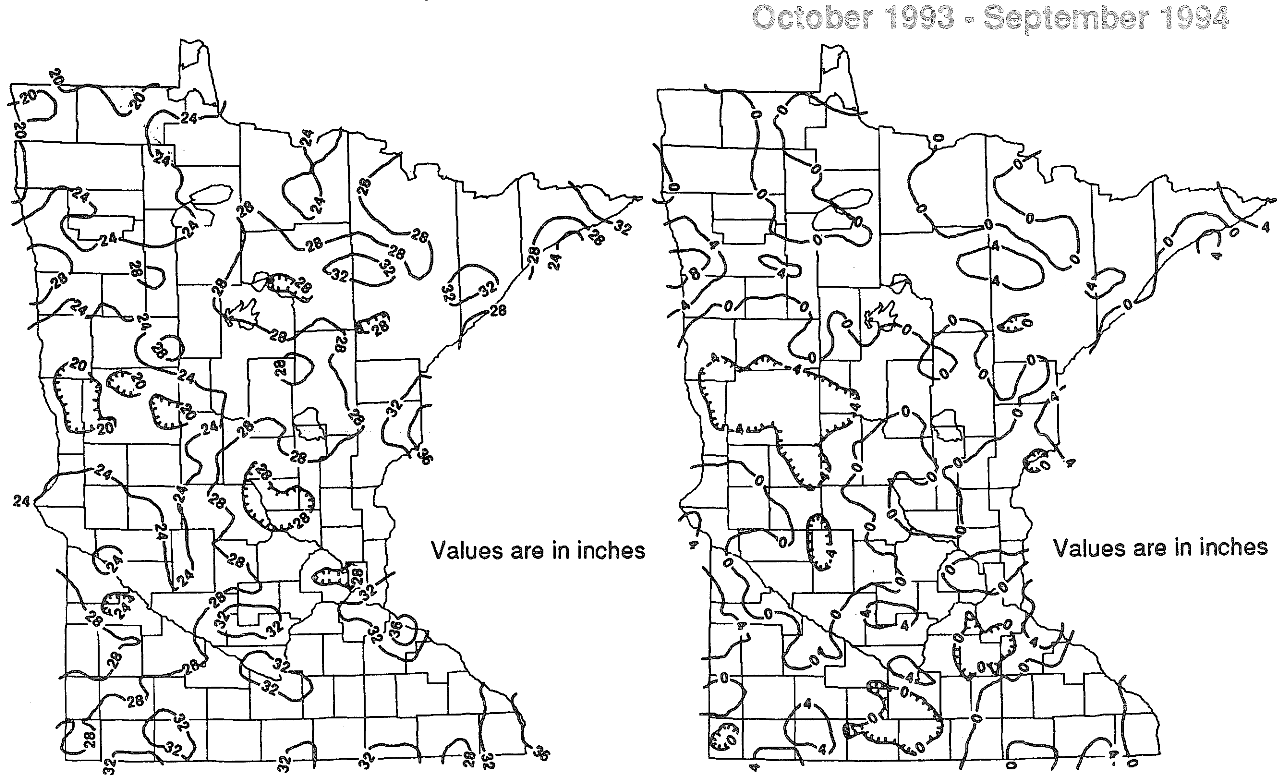
October was similar to September, alternating mild and pleasant weather with occasional wet spells. The most conspicuous weather feature of the month was the absence of a killing frost. Many locations went two to four weeks beyond the average frost date without receiving freezing temperatures.

1994 ended with precipitation totals near the long-term normal over much of Minnesota (Figure 16). Scattered areas of the state reported above normal precipitation, mainly in the northwest, while portions of west central Minnesota finished the year more than four inches below the norm. Despite the near-normal precipitation, many hydrologic systems in Minnesota remained above average, the result of the cumulative impact of the very wet early 1990's.

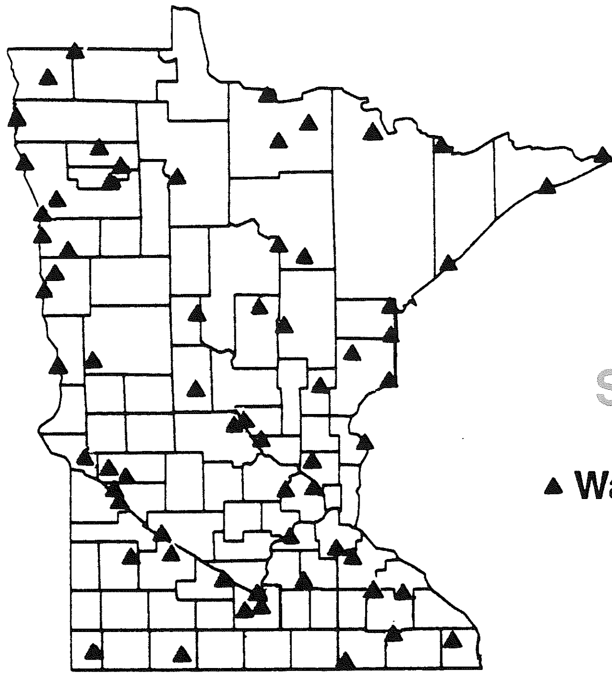
Figure 16.

Water Year Precipitation October 1993 - September 1994

Water Year Precipitation Departure from Normal October 1993 - September 1994

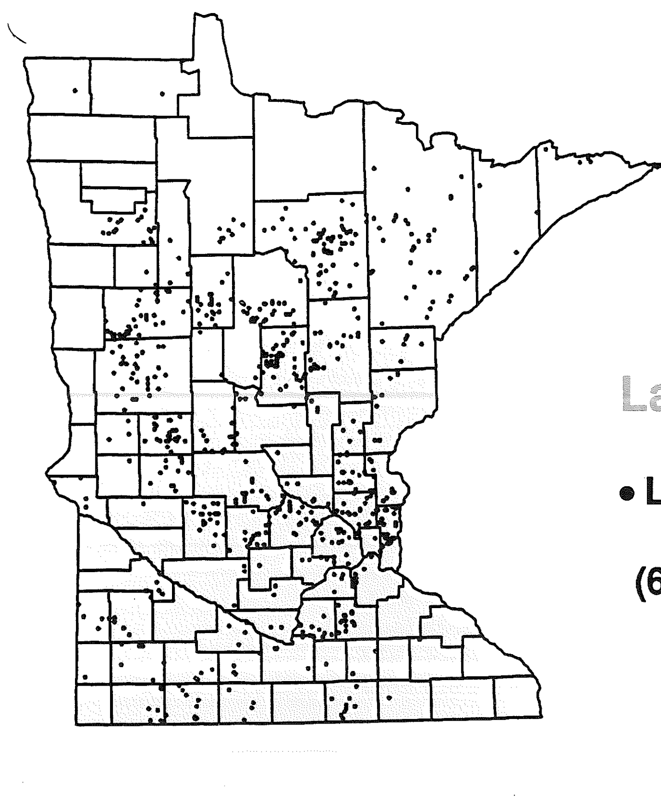


Chapter 2: SURFACE WATER



Stream Flow

▲ Watershed Gaging Station (57 Stations)



Lake Levels

• Lake Gaging Station (662 Stations)

Surface Water - Stream Flow

Introduction

The Stream Flow Unit is responsible for gathering and analyzing data related to the rivers and streams of Minnesota. Figure 1 shows the 81 major watersheds of the state and the location of many gages within those watersheds. These gages are used to gather data related to stream flow conditions which are used to establish historic high and low information as well as basic flow statistics such as exceedence values *(see sidebar).* The gages are operated by the USGS as part of their river gaging program. Funding comes from the USGS, the DNR, the National Weather Service (NWS), the U.S. Army Corps of Engineers and other public and private sources. The DNR operates numerous other gages as required by specific projects.

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

Stream Drainage Systems

There are many types of rivers and streams in Minnesota. Along the north shore of Lake Superior, and along the bluffs of the Mississippi River in the southeast are high gradient streams that have scoured channels into bedrock. In the northwest, streams are highly meandered and are situated in the bottom of an ancient glacial lake. These streams are often ditched and prone to flooding. In the south, streams are often entrenched in a well developed channel and are largely impacted by agricultural practices. In the north central portion of the state, streams can be impacted by both agricultural and forest land uses.

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

EXCEEDENCE VALUE

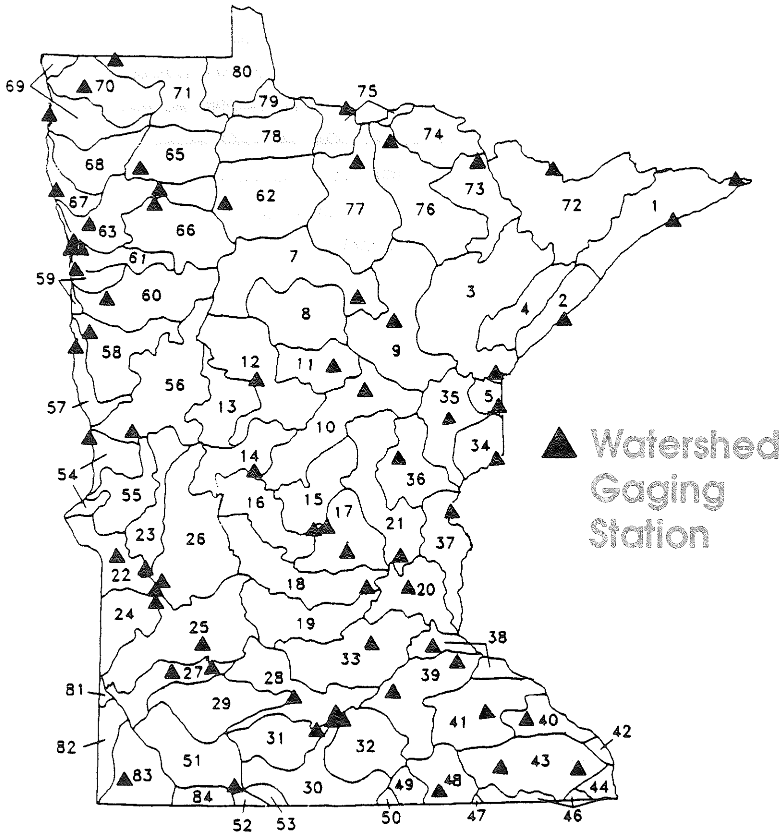
An exceedence value is a statistical parameter, based upon historical discharge records, and is the probability of stream flow *exceeding* a certain value. A 50% exceedence value (Q50) indicates that the discharge at that reporting station has been *equalled* or *exceeded* 50% of the time during the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

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

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

Figure 1.

81 Major Watersheds



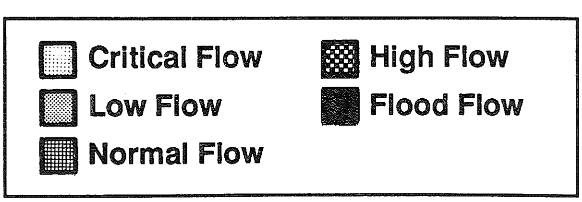
1 Lake Superior (north) ▲
2 Lake Superior (south) ▲
3 St. Louis River ▲
4 Cloquet River
5 Nemadji River ▲
*
7 Mississippi River (Headwaters, Lake Winnibigoshish) ▲
8 Leech Lake River
9 Mississippi River (Grand Rapids) ▲
10 Mississippi River (Brainerd) ▲
11 Pine River ▲
12 Crow Wing River ▲
13 Redeye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

Stream Flow Reports

A weekly report called the Minnesota Stream Flow Report is produced during the open water season (late March to October) to keep the Division of Waters staff and other concerned interests apprised of stream flow conditions throughout the state. A map that presents flow conditions in the 81 major watersheds is included with the weekly stream flow report. The map classifies each major watershed as having flow characteristics of critical, low, normal, high or flooding. A "no report" category is also used. Where no flood stage has been established, the highest monthly Q10 is used as an interim number until a flood stage can be established for that site. These categories are based on calculated flow statistics for the gage in the respective watershed. Watersheds that do not have a gage, or lack telemetry or other forms of instantaneous data access, are assigned flow categories based on a gage in an adjacent watershed with similar characteristics.

A Flood Flow Report may be generated when flows climb into the flood range. Map catagories representing flood flows are based on stages established by the National Weather Service. The purpose of the Flood Flow Report is not to forecast floods, but rather to provide information on daily stage changes and predicted stages by the National Weather Service.

A Low Flow Report may be generated when flows drop into the critical low flow range. Similar to the Flood Flow Report, the objective is to provide information to Division staff and others about flow conditions. At that time, the Division of Waters may restrict the appropriation of water to maintain adequate water for instream flow needs such as fish and wildlife, and to conserve water for higher priority uses such as municipal supply or power generation.



1993 Stream Flow Maps

On April 5, 1993, stream flow conditions in much of the Minnesota River, the Red River of the North, and their respective tributary watersheds, were in the high or flood range (Figure 2). Flows in the Upper Mississippi River, Lake Superior, and the Rainy River watersheds were in the normal range. April rains kept flows in the southern third of the state in the high to flood ranges while a lack of rain allowed flows in the Red River watersheds to recede to the normal range.

Figure 2.

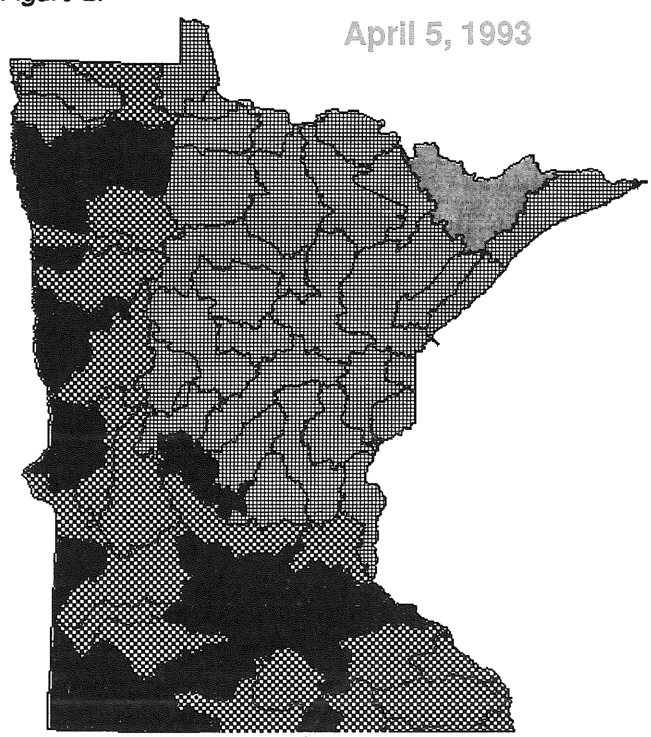
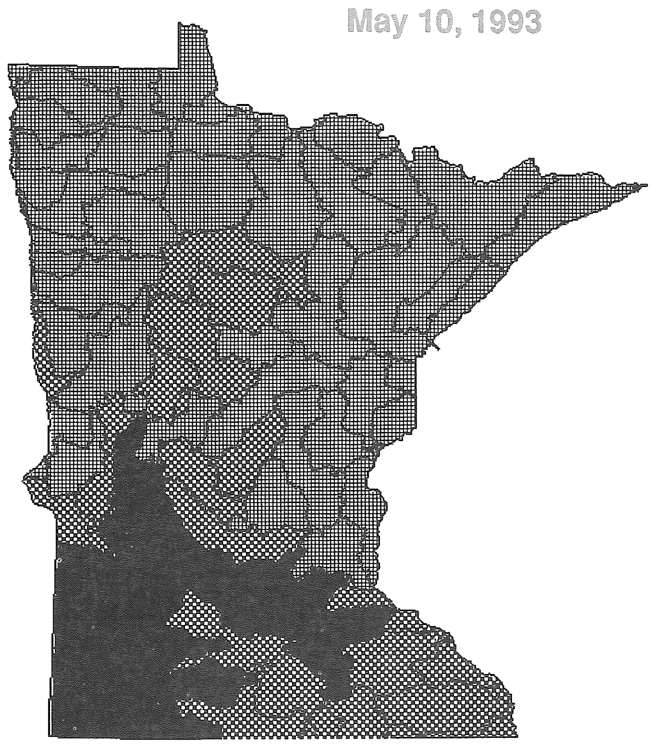


Figure 3.



In early May (Figure 3), the first of several storm systems struck southern Minnesota. The City of Marshall recorded an instantaneous discharge of 6380 cfs and a stage of 17.00 feet (local datum) on the Redwood River (both records). According to United States Geological Survey (USGS) calculations, the peak stage at Marshall was between a 200 and 500-year flood event. The same storm also caused major flooding along the Cottonwood, Watonwan, and Yellow Medicine Rivers, and numerous smaller tributaries such as Pipestone Creek. While teams from the Federal Emergency Management Agency (FEMA) did a preliminary damage assessment, rains continued in southern Minnesota. Meanwhile, a lack of rain in the Upper Mississippi, Lake Superior and Rainy River watersheds caused flows to recede to the low range. In June, rains brought flows back into the normal range for much of the north while the south experienced high flows and occasional flooding.

On June 13, 1993, the President of the United States declared nine counties in southwestern Minnesota to be federal disaster areas. However, before the disaster assessment teams could begin their work, a second and larger storm struck. The City of Marshall was hit again with precipitation totals exceeding nine inches (Figure 4). Roads, bridges and other public property that had been repaired from the May storm were again damaged. Areas that escaped damage in the first storm now experienced damage, and it became impossible for FEMA teams to determine which storm caused which damage. As a result of the new damage, the Presidential Disaster Declaration was expanded to 16 counties. Before the end

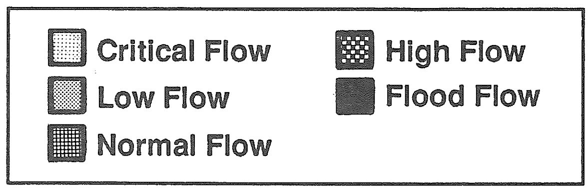
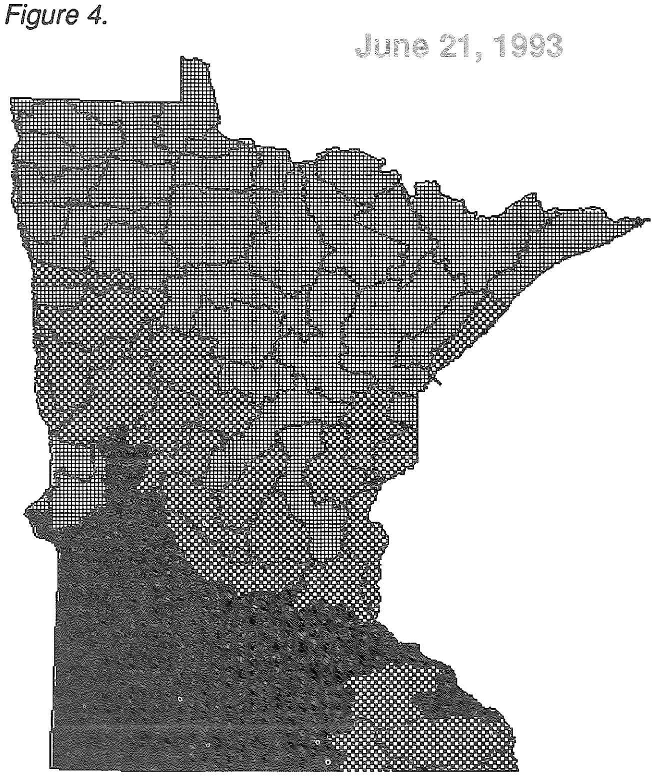


Figure 4.



of summer, 57 of Minnesota's 87 counties would be declared Federal Disaster areas and an additional 8 counties would be declared agricultural disaster areas.

For the next four weeks, heavy rains over much of southern Minnesota continued and spread to the north. Flooding occurred in the Upper Mississippi River, Lake Superior, Rainy River, and the Red River of the North watersheds. By early July, rains throughout the state brought most streams into the high range (Figure 5). Southwest Minnesota was hit on the July 4th weekend with rainfalls greater than six inches in some areas.

By mid July the continuing storms moved further north causing flash flooding in the Fargo/Moorhead area. Rivers impacted were the Red, Buffalo, Clearwater, Red Lake, Otter Tail and many small tributaries. A week later, another large storm in the East Grand Forks area caused flooding along the Buffalo, Clearwater and Wild Rice Rivers.

Figure 6.

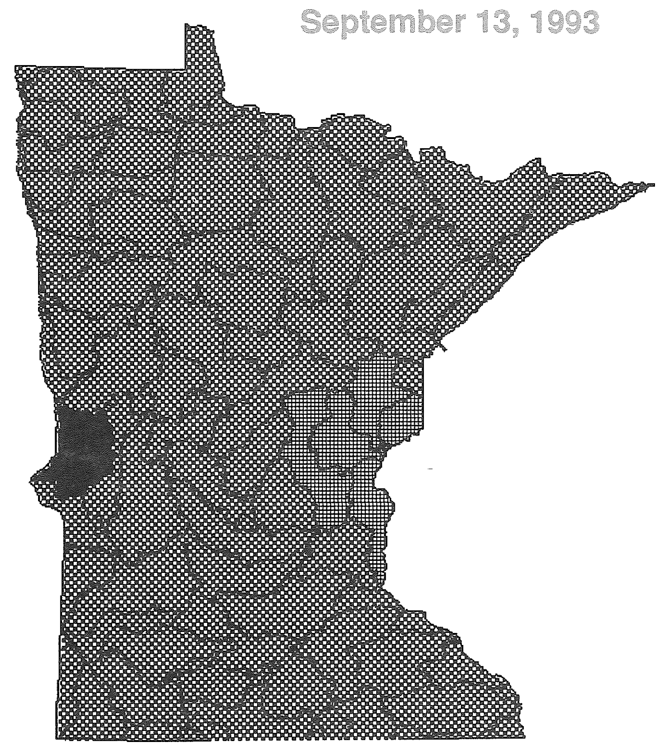
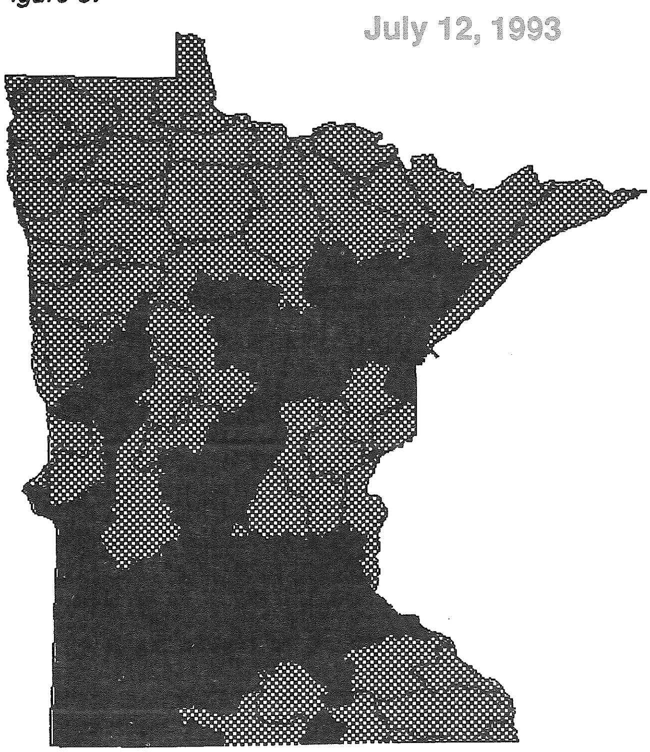


Figure 5.



Critical Flow	High Flow
Low Flow	Flood Flow
Normal Flow	

By late July, precipitation declined over much of the state which allowed streams to drop to lower levels. However, with highly saturated soils and a large volume of water in short-term storage, it only took a few inches of precipitation for streams to return to flood stages.

The Red, Two and Roseau Rivers were flooded by large rains the first week of August while the Cedar, Shell Rock and Otter Tail were flooded during the second week. During the remainder of August and September, weekly precipitation continued, but on a much lighter scale. This allowed streams in most watersheds to recede to the high flow category (Figure 6). As winter and freezeup approached, streams in much of Minnesota were at or near record levels for that time of year.

1994 Stream Flow Maps

There was significant concern in Minnesota that the high water levels left by the floods of 1993 could aggravate flooding in the spring of 1994. Fortunately, a short drought from mid-February to mid-April significantly reduced the potential for spring flooding by allowing much of the water in storage to drain out of the system (Figure 7). This increased the capacity of the system to hold whatever moisture the spring of 1994 might produce.

Critical Flow
Low Flow
Normal Flow
High Flow
Flood flow

Figure 8.

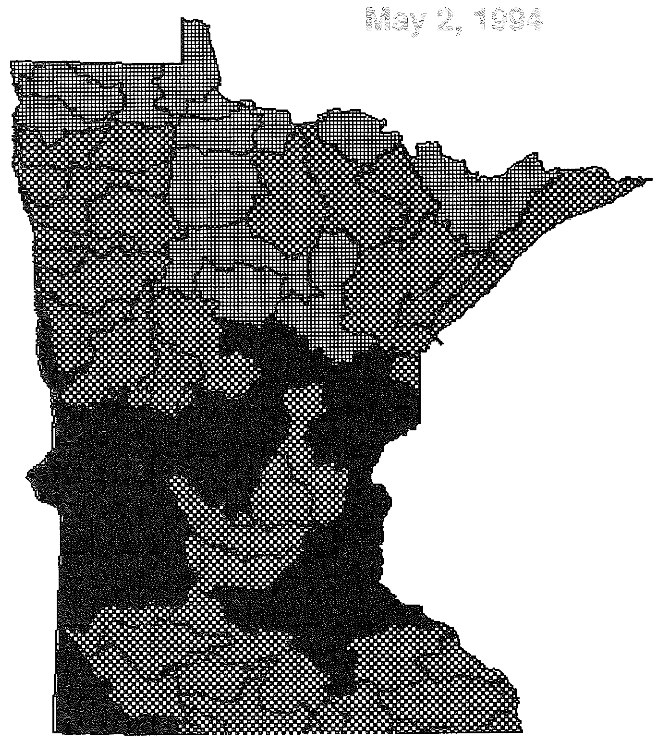
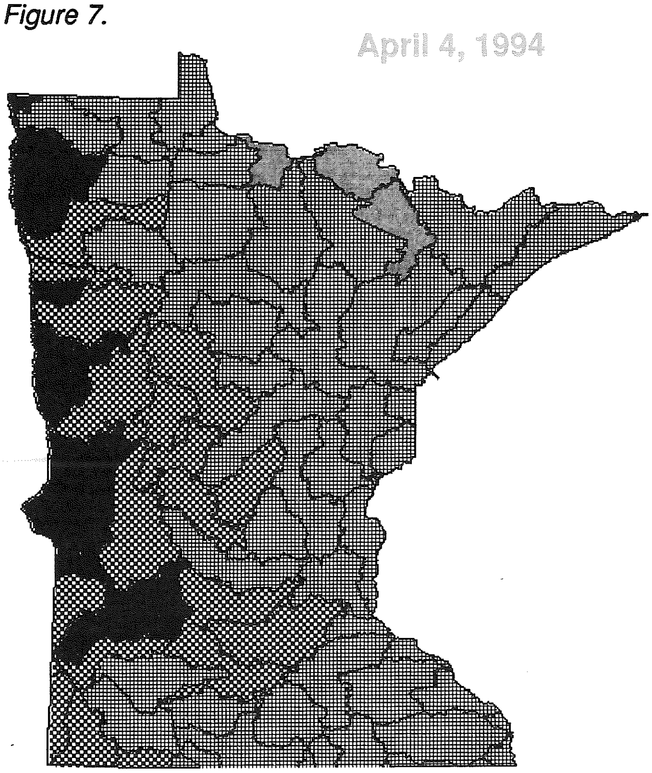


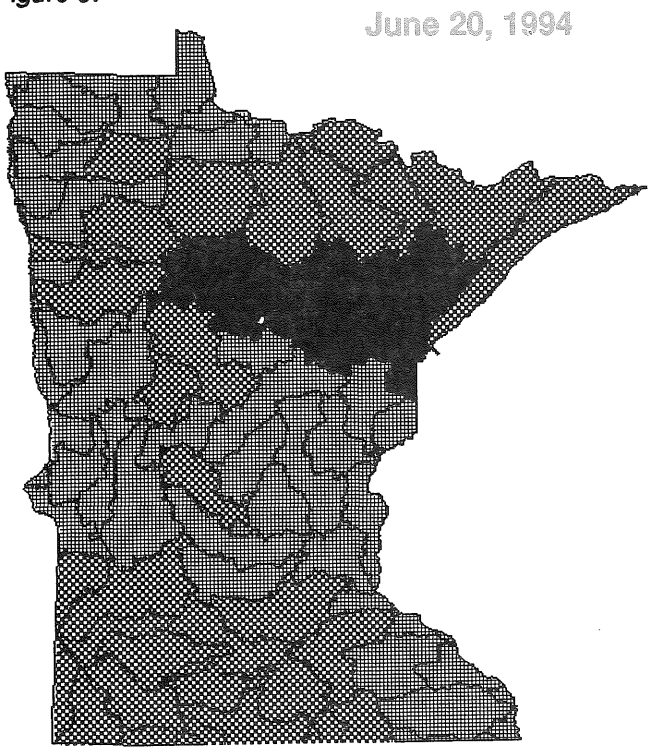
Figure 7.



In early April, flows throughout most of the state were in the normal range. Areas of high flow were limited to the western and west-central portions of the state, including parts of the Upper Minnesota, Upper Red and a few watersheds in the Upper Mississippi. Some minor flooding occurred in the headwaters of both the Minnesota and the Red River of the North, and at other points along the Red.

Stream flows throughout much of the state receded during the first two weeks of April. The last week of April brought heavy rains, a spring snow storm and minor flooding over much of the state (Figure 8).

Figure 9.



Widespread fronts produced near-normal precipitation throughout May and the first half of June. With near-normal precipitation, many of the state's streams receded to the normal range. A few watersheds, such as the St. Croix and its tributaries, the St. Louis and the Roseau River actually receded to the low flow range. A large storm in mid-June flooded parts of the Mississippi Headwaters and Lake Superior Watersheds (Figure 9).

The Upper Mississippi River remained above flood stage for the next six weeks, while the remainder of the state experienced near-normal precipitation throughout the remainder of July and August. River levels generally receded to the high or normal ranges for the remainder of the summer (Figure 10). The St. Louis River and some tributary watersheds occasionally receded to the low flow range during August.

Critical Flow
Low Flow
Normal Flow
High Flow
Flood Flow

Figure 10.

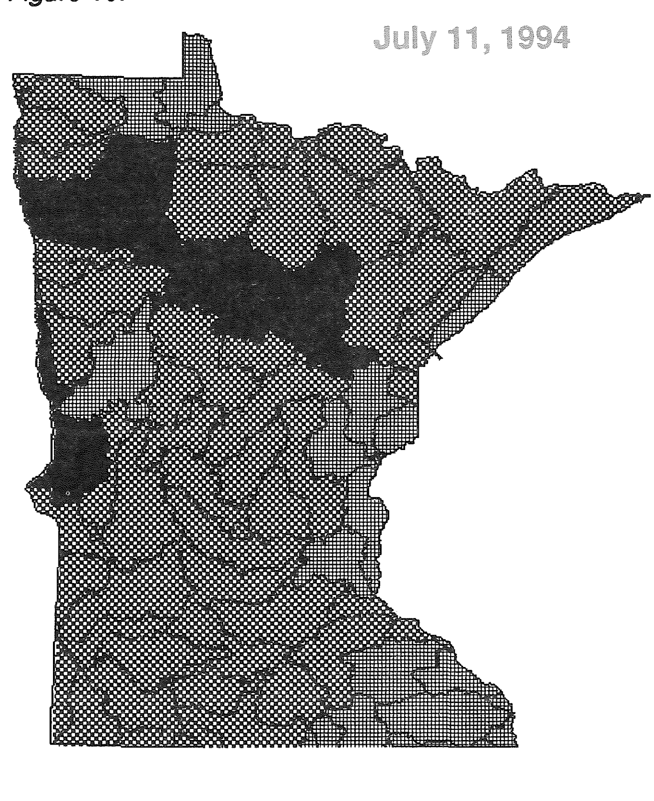
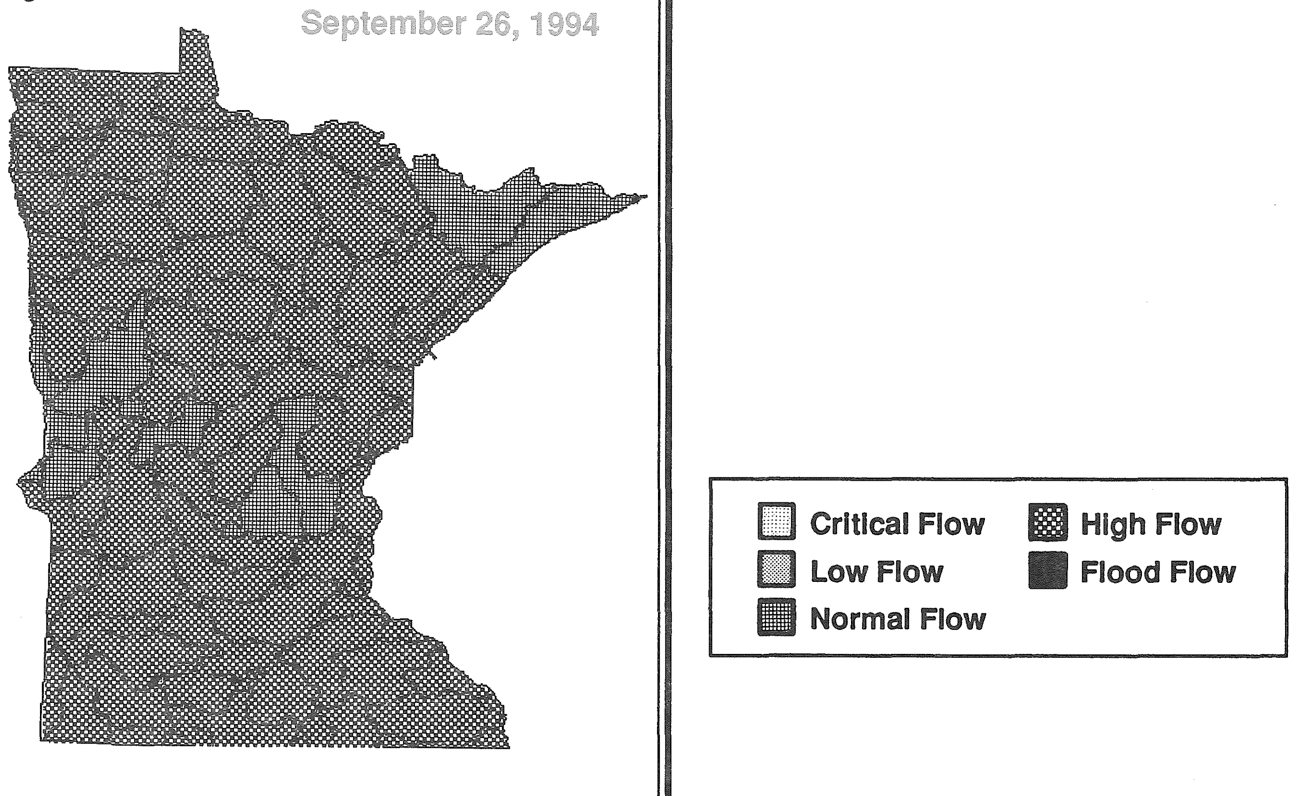


Figure 11.



In early September, the Lake Superior, Upper Mississippi and St. Croix watersheds receded to the normal range while flows in the remainder of the state remained high. A large storm in mid-September produced as much as five inches of rain in the Vermillion and Cannon River Watersheds. A second storm one week later produced 14 inches of precipitation in western Wisconsin causing some minor flooding in both the Upper St. Croix and Snake River Watersheds.

The 1994 Water Year ended much like the 1993 with stream flows for most of the state near the September 1993 levels (Figure 11). Low flows, which were common from 1987 to 1992, were rare. In fact, there has not been a stream flow in the critical flow range since August of 1992.

Hydrographs

A hydrograph is a graph showing the volume of water discharged for a specific time period. To gain further insight into the flow conditions of 1993 and 1994, hydrographs are shown for five rivers (Figure 12). Each river chosen is found in a different geomorphological environment and is impacted by different types of land use. A two-year and a ten-year hydrograph is included for each river.

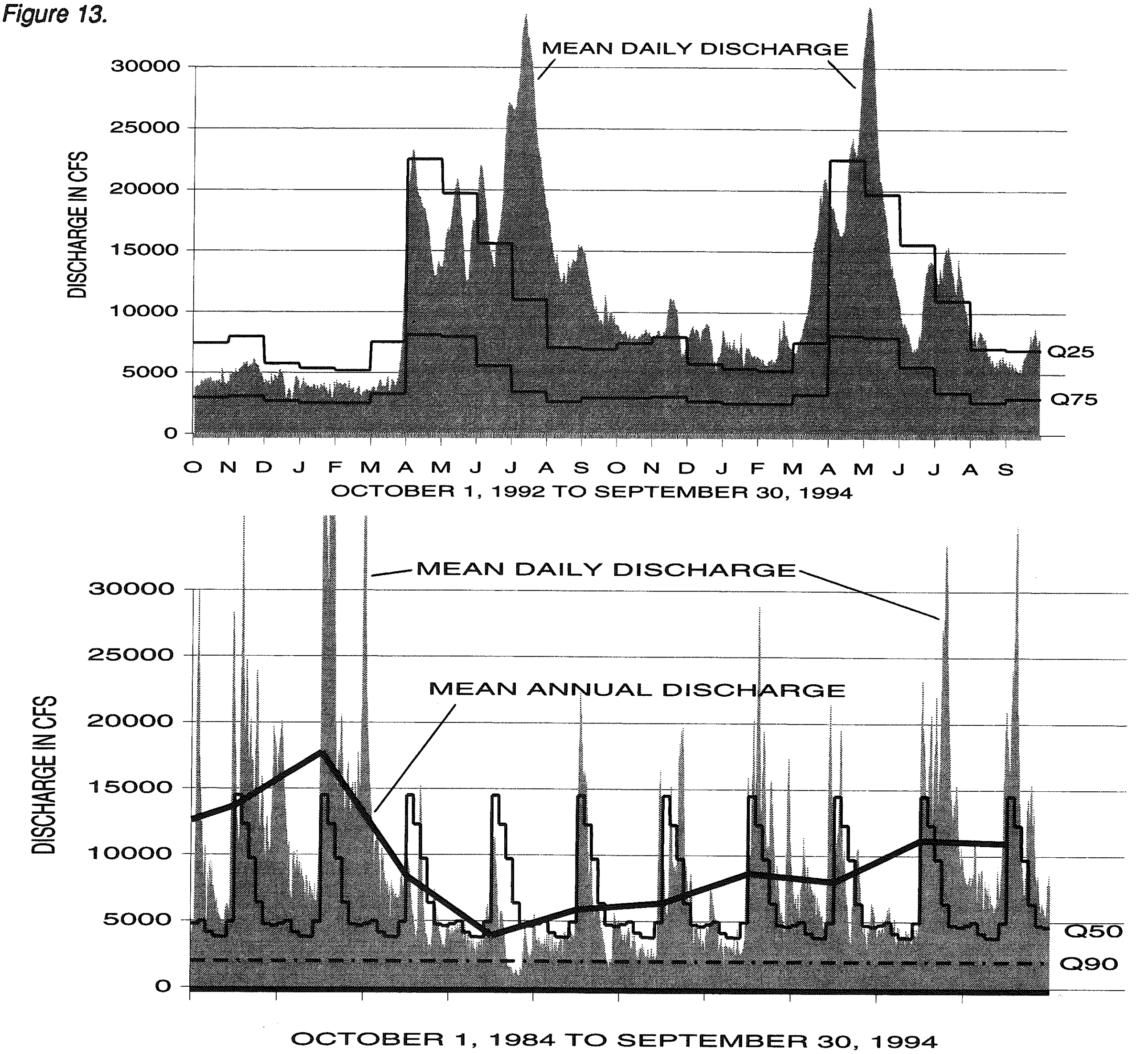
The two-year hydrographs (1993-1994) show the mean daily discharge and the monthly Q25 and Q75 exceedence levels. As stated earlier, flows greater than the monthly Q25 are considered high, below the monthly Q75 are considered low, and between the monthly Q25 and Q75 are considered normal. Flood flows are not shown on the hydrographs because of the scale. The ten-year hydrographs (1985-1994) show the mean daily discharge, the mean monthly average (Q50) and the mean average annual discharge. The mean annual discharge value is placed in the middle of the water year (usually April 2) to show one year in relation to the next. Included on the ten-year hydrograph for the Mississippi River at Anoka (Figure 13) and the St. Louis River at Scanlon (Figure 17) is the annual Q90 which represents critical flow. The Q90 is not included on the other hydrographs as the scale used makes the Q90 difficult to observe.

Associated with each set of hydrographs is a table showing the average mean annual discharge for the period of record, 1985-1994, 1993, 1994, and the years of the highest and lowest observed flow. Listed after the entire period of record is the total number of years in the record. The Pomme de Terre River period of record (1931-1994) does not equal the 59 years used for calculations, due to data gaps within the period of record.

Figure 12. River/Gage Locations

Mississippi River at Anoka

Figure 13.



Flows in the Mississippi River at Anoka were high, ranking 14th and 15th respectively, for Water Years 1993 and 1994. These compare to the early 1980's when high flows were maintained for a longer duration.

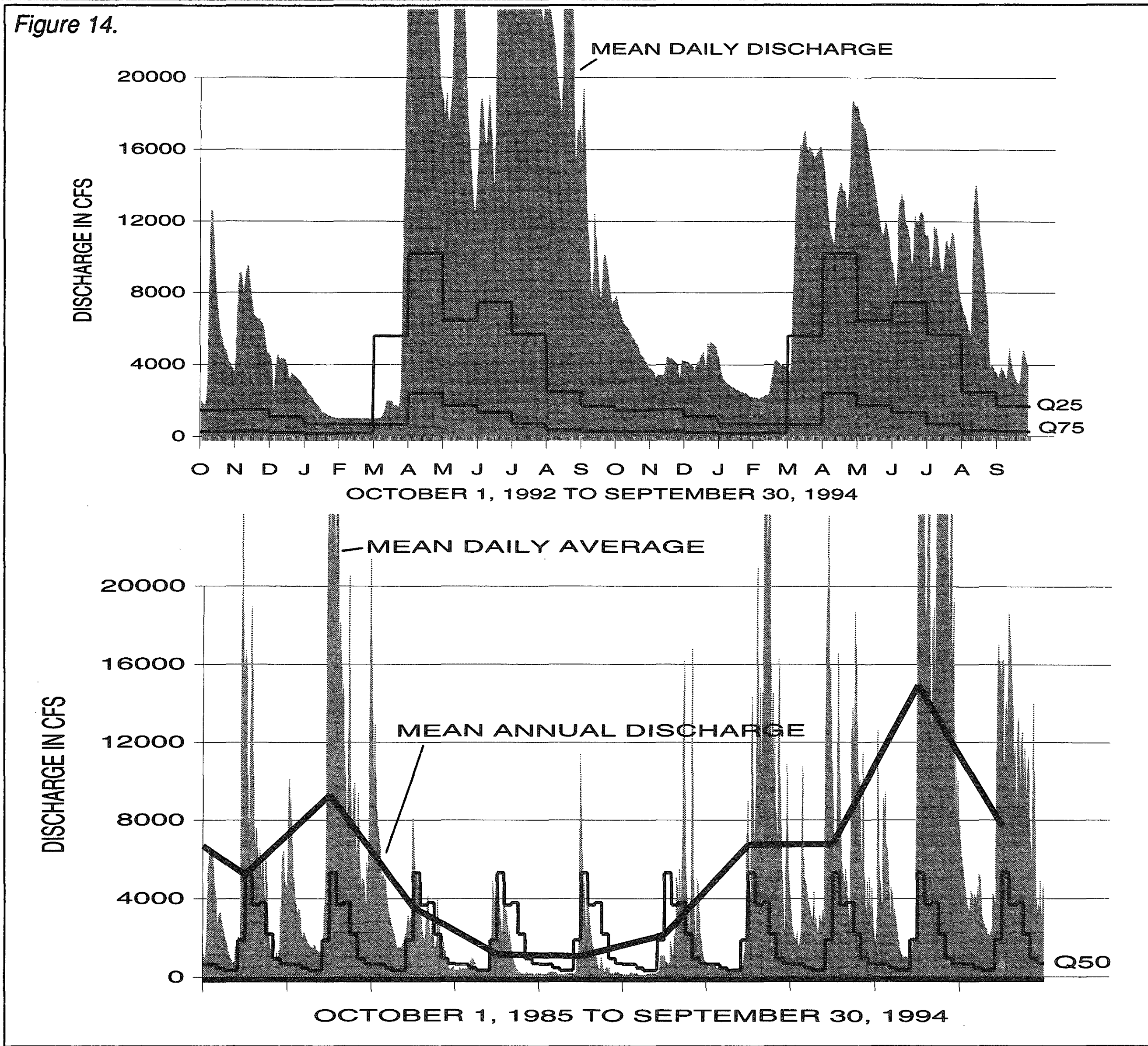
MISSISSIPPI RIVER AT ANOKA

Year(s) (Rank)	Mean Annual Discharge (cfs)	% of Normal
1931-1994 (63)	8,003	100
1985-1994	9,485	119
1993 (14)	11,160	139
1994 (15)	10,955	137
1986 (1)	17,750*	222
1934 (63)	1,603**	20

*Highest Recorded **Lowest Recorded

Minnesota River at Mankato

Figure 14.



The Minnesota River flows from west to east through predominantly agricultural lands. A record peak stage of 30.11 feet for 1993 was reached on June 26, with a corresponding discharge of 74,600 cfs. This discharge is significantly lower than the record discharge of 94,100 cfs during the spring flood of 1965. Water Year 1994 ranked 6th in total discharge for the 73 years of records.

For the 10-year period of 1985 to 1994, five years ranked in the top ten (1993, 1986, 1994, 1992, and 1991). Conversely, 1988 to 1990 have flow rankings of 58, 59 and 42 respectively. In spite of these three dry years, flows in the Minnesota River for the last ten years were 178% of normal.

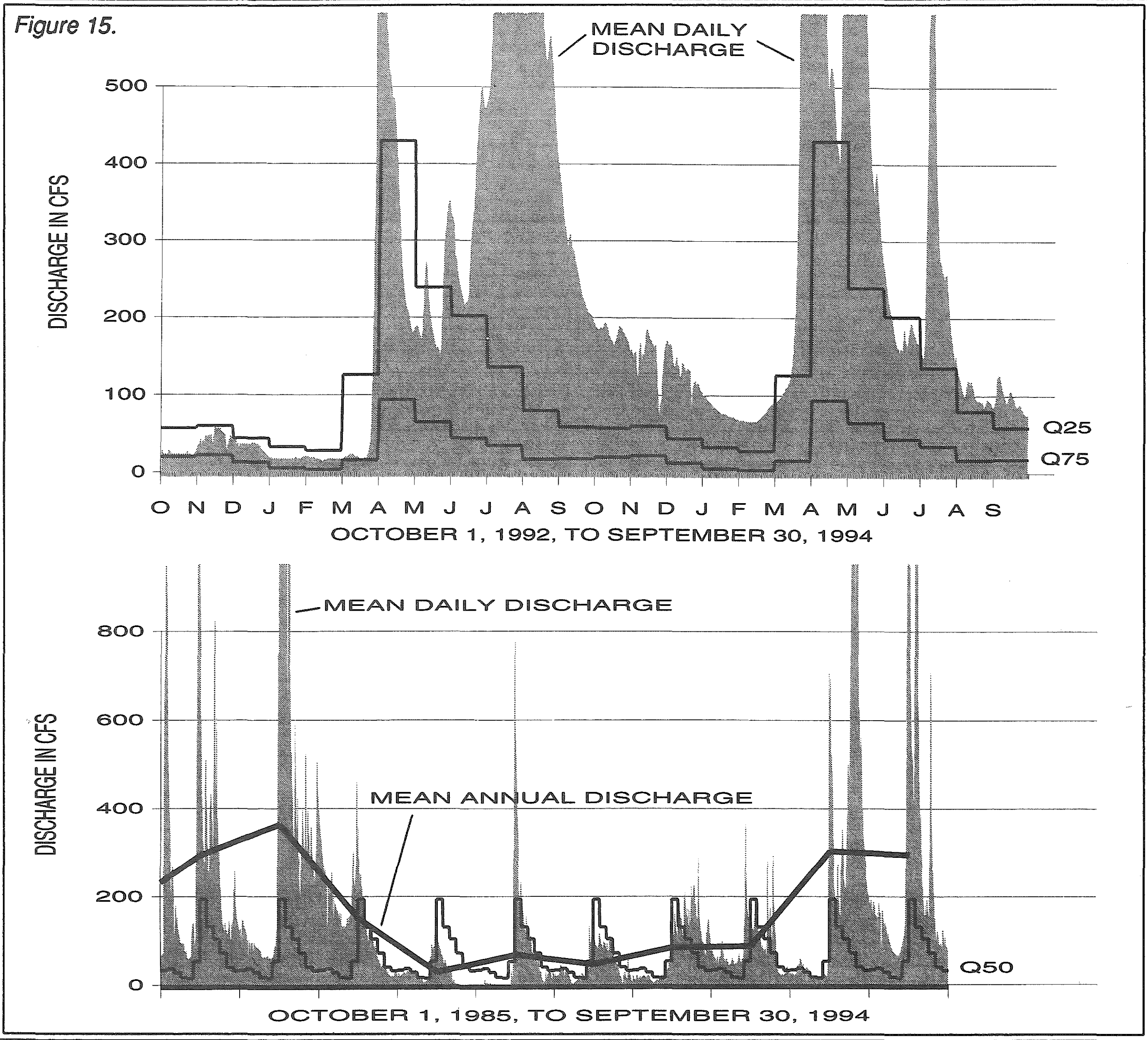
MINNESOTA RIVER AT MANKATO

Year(s) (Rank)	Mean Annual Discharge (cfs)	% of Normal
1921-1994 (73)	3,290	100
1985-1994	5,842	178
1993 (1)	14,890*	452
1994 (7)	7,655	233
1934 (73)	136**	4

* Highest Recorded ** Lowest Recorded

Pomme de Terre River at Appleton

Figure 15.



The Pomme de Terre River, in west-central Minnesota, flows due south into the Upper Minnesota River. Of the 59 years of flow records at Appleton, Water Years 1993 and 1994 rank second and third highest, respectively. Both exceeded the mean annual discharge for the entire period by over 250%.

For the ten-year period of 1985 to 1994, four years ranked in the top ten (1986,1993, 1994 and 1985). The three-year period of 1988 to 1990 had annual discharges that ranked 57th, 40th, and 50th. Overall, the 10-year average from 1985 to 1994 is 172 cfs, or almost 150% of normal.

POMME DE TERRE RIVER AT APPLETON

Year(s) (Rank)	Mean Annual Discharge (cfs)	% of Normal
1931-1994 (59)	117	100
1985-1994	172	147
1993 (2)	303	259
1994 (3)	294	252
1986 (1)	363*	327
1977 (59)	21**	19

* Highest Recorded **Lowest Recorded

Red River of the North at Grand Forks

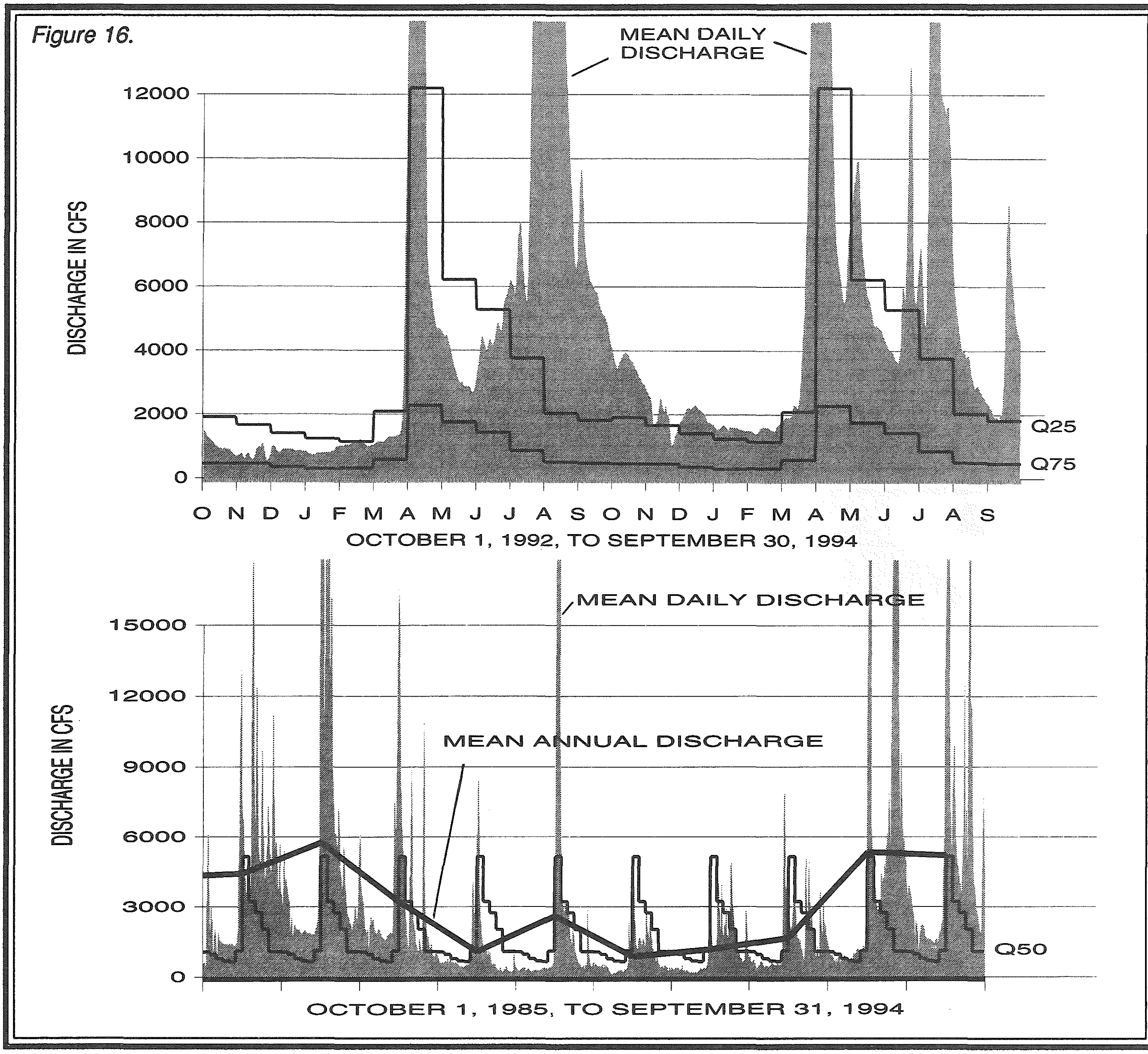


Figure 16.

Flows in the Red River of the North during Water Years 1993 and 1994 rank eighth and ninth highest, respectively, for the 90 years of records at Grand Forks. Heavy rains in 1993 filled Lake Traverse and the Whiterock Reservoir to near record stages. Flows from these reservoirs were limited at times during 1993 and 1994 to prevent downstream flooding. A significant portion of flow in 1994 was due to water stored in the reservoirs from 1993. For the ten-year period of 1985 to 1994, three years rank in the top ten (1986, 1993 and 1994). The years of 1988 to 1992 ranked 72, 39,76, 70 and 61, respectively.

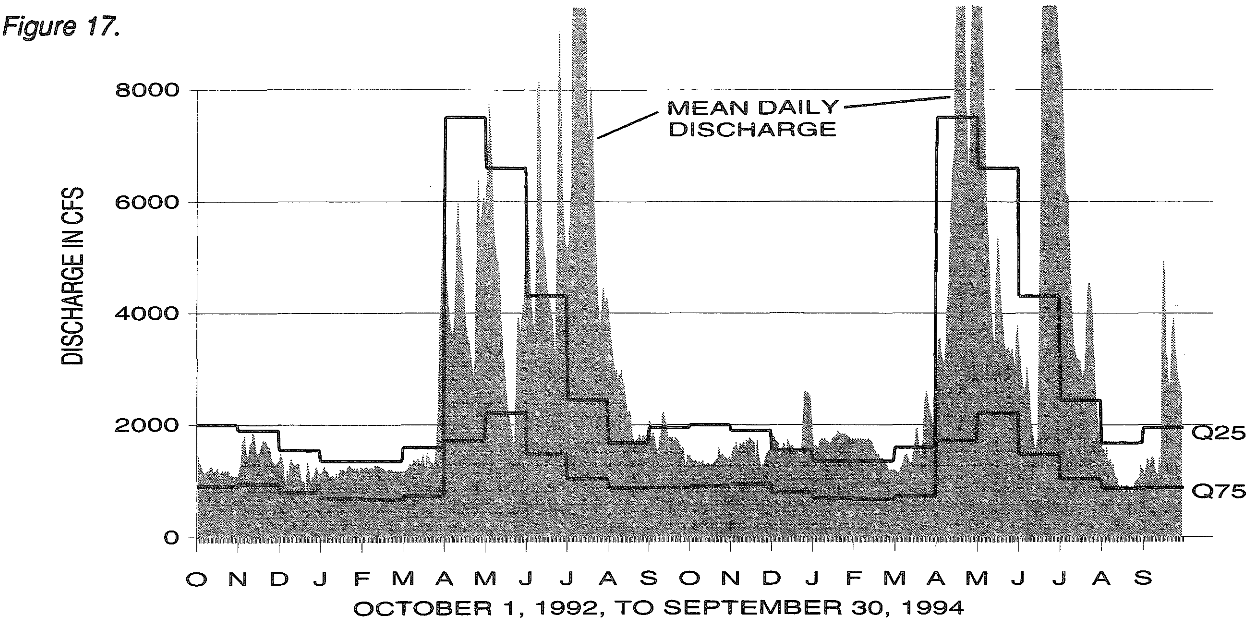
RED RIVER OF THE NORTH

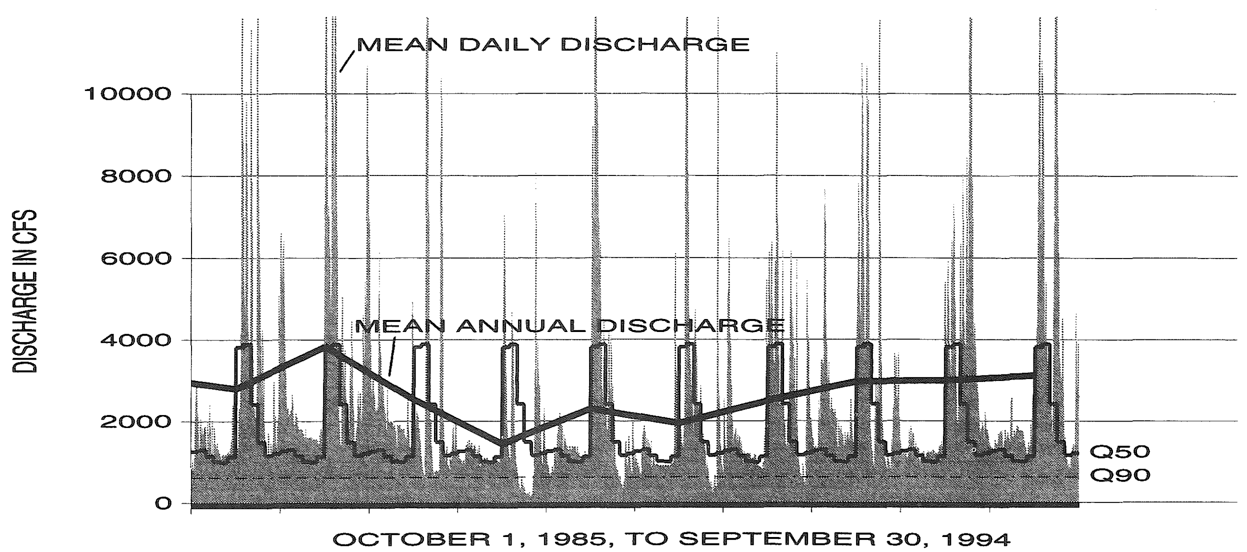
Year(s) (Rank)	Mean Annual Discharge (cfs)	% of Normal
1904-1994 (90)	2,625	100
1985-1994	3,136	119
1993 (8)	5,353	204
1994 (9)	5,202	198
1950 (1)	7,580*	289
1934 (90)	244**	10

* Highest Recorded ** Lowest Recorded

St. Louis River at Scanlon

Figure 17.





The St. Louis River in northeastern Minnesota flows through mostly forested lands. Flows in the St. Louis are affected by five reservoirs operated for hydroelectric purposes. These reservoirs may either reduce peak flows from storm events or increase low flows by draining water for power generation.

The St. Louis River was at 127% of normal discharge for both Water Year 1993 and 1994, while the average for 1985-1994 was 112% of normal.

ST. LOUIS RIVER AT SCANLON

Year(s) (Rank)	Mean Annual Discharge (cfs)	% of Normal
1908-1994 (86)	2,361	100
1985-1994	2,633	112
1993 (19)	3,007	127
1994 (20)	2,993	127
1972 (1)	4,276*	181
1924 (86)	945**	40

* Highest Recorded **Lowest Recorded

Historic Floods in Minnesota

Figure 18 is a map showing the year that the highest instantaneous discharge (cfs) was observed for each of the 81 major watersheds. The map shows that the major floods in Minnesota for most of recorded history were in 1950, 1965, 1969 and 1993. Many of the floods listed as "Other Years" occurred in 1972. The 1993 floods were caused by spring and summer rains, while the others were the result of spring rains coinciding with snowmelt.

1965 and 1969 were the years of the highest *instantaneous* discharge for much of southern Minnesota. However, 1993 was the year of the highest *annual* discharge for southern Minnesota.

Figure 19.

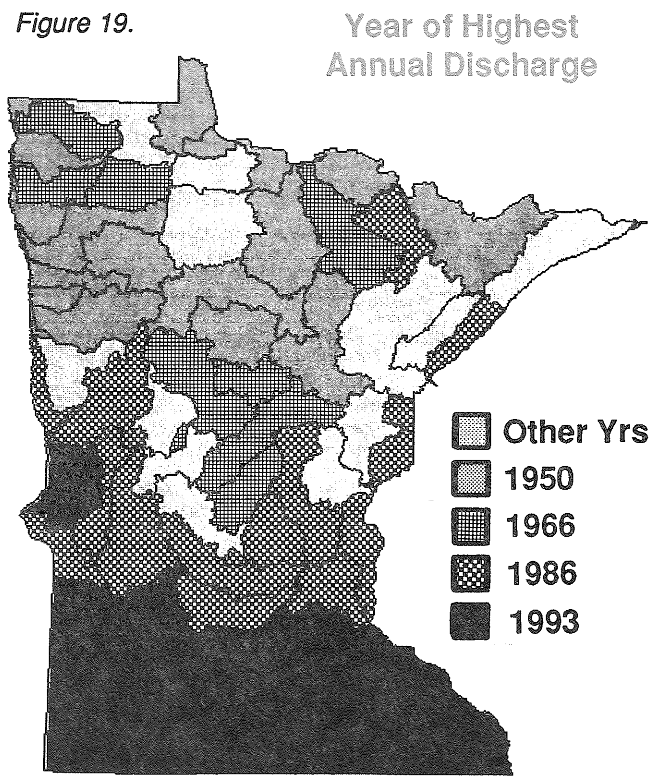


Figure 18.

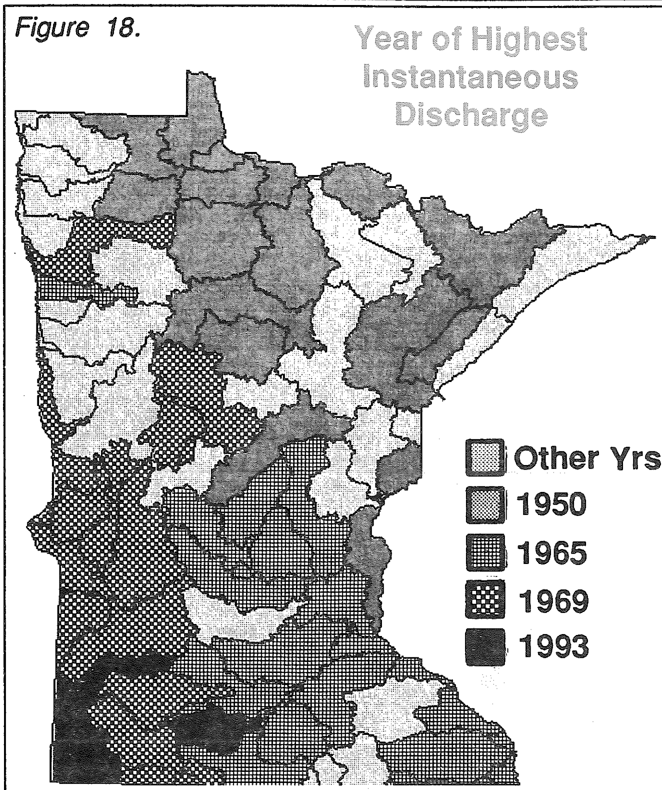
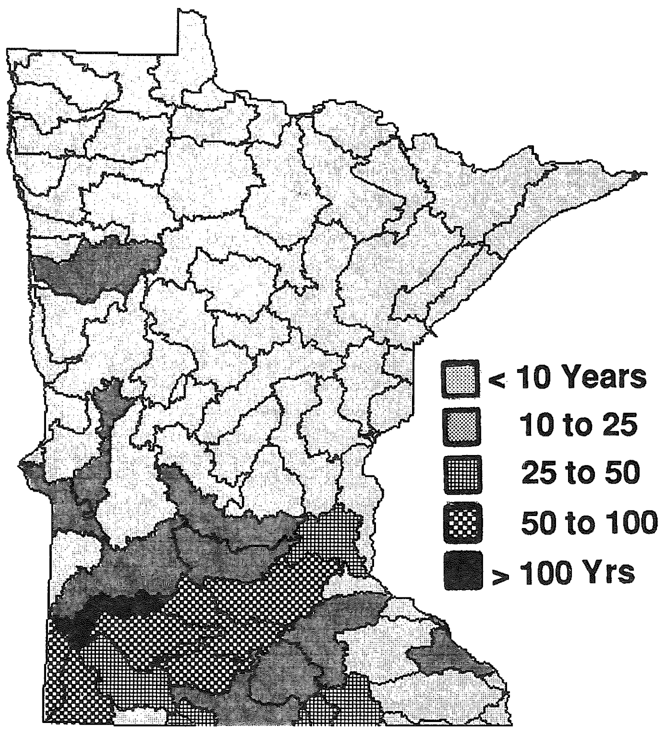


Figure 19 is a map showing the year of the highest annual discharge (total volume) for all 81 major watersheds.

Figure 20 shows the highest flood frequency attained by the largest flood event in Water Year 1993 and is based on calculations by the USGS. All 1993 peak discharges were the result of spring or summer storms and none were caused by the spring snowmelt.

The map shows that much of southern Minnesota experienced floods that were greater than a 10-year flood event. The surprising exceptions were the Zumbro and Root Rivers which experienced significant damage, even though the highest recorded discharge was less than a 10-year event.

Figure 20. 1993 Flood Frequencies



A July 1993 storm caused the Red River of the North to rise approximately 7 feet in 8 hours, yet amounted to a less than 25-year flood event. Surprisingly, with approximately 100 years of records at several gage sites, a 100-year flood event has yet to be experienced on the Red River of the North.

Flooding along the Des Moines River at Jackson was in the range of a 25 to 50-year flood event while flooding on the Watonwan and Cottonwood Rivers and the Minnesota River (at both Mankato and Jordan) were 50 to 100-year flood events. Only the Redwood River experienced a flood event with a frequency greater than 100 years. The highest peak at Marshall was between a 100 and 200-year event, while three smaller peaks on June 17, June 19, and July 5, 1993, were all 10 to 25-year flood events. The last peak at Marshall, August 16, 1993, was just under a 10 year flood event.

Figure 21. MN River Hydrograph (Jordan)

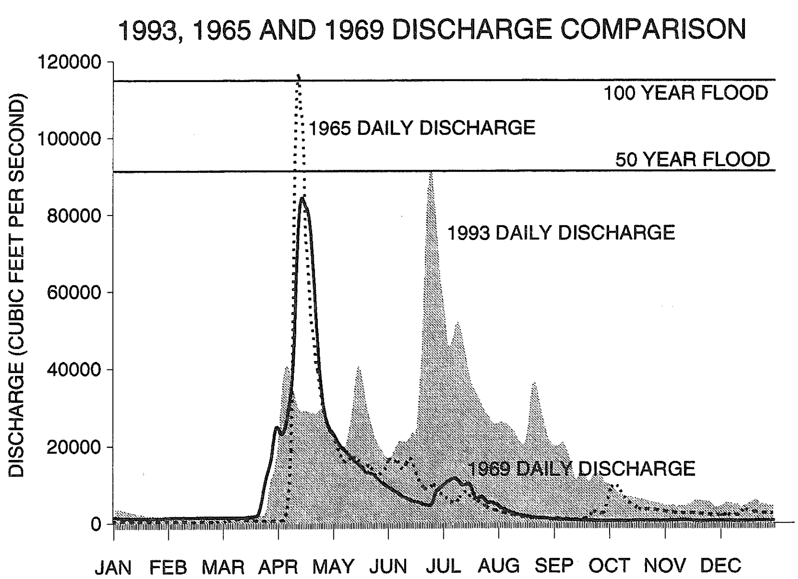


Figure 21 is a hydrograph showing discharges for the Minnesota River at Jordan during 1965, 1969 and 1993. The map shows the mean daily discharge and the expected discharge for a 50 and 100-year flood event. The area under each curve represents the total volume discharged. 1965 and 1969 were major flood years on the Minnesota. However, the combined total volume of water discharged during those two years is approximately equal to the total volume discharged during 1993.

Surface Water - Lake Levels

Introduction

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

Lake levels are actively monitored at 662 sites in Minnesota (Figure 1). Of these, 442 are monitored by citizen volunteers and 220 are monitored cooperatively with other organizations including:

- Anoka County Conservation District
- Becker County Coalition of Lake Associations
- Cambridge Area DNR Wildlife
- Chisago County
- City of Maple Grove
- Freshwater Foundation
- Kandiyohi County
- Minnesota Zoo
- Polk County SWCD
- Ramsey County
- Sauk River Watershed District
- Thirty Lakes Watershed District

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

The data that is collected is stored in a database (Lakes db©), which enables easy access to the information (see pages 34-35 for 10 selected lakes). Lakes db© software has been installed on many cooperators' computers, with staff instructed on basic storage and retrieval. In five years of operation, approximately 585,000 individual lake readings have been entered. During Water Years 1993 and 1994, over 40,000 water level readings were collected and entered.

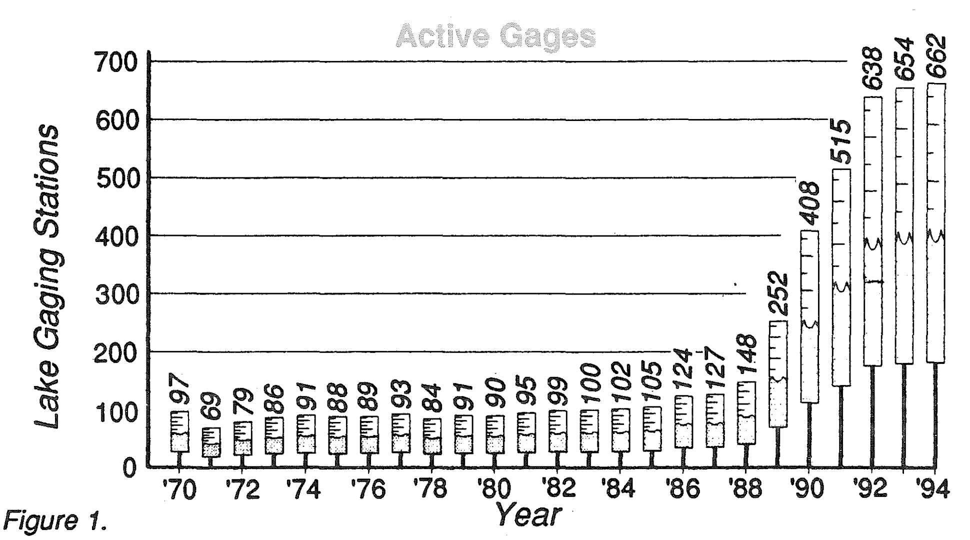
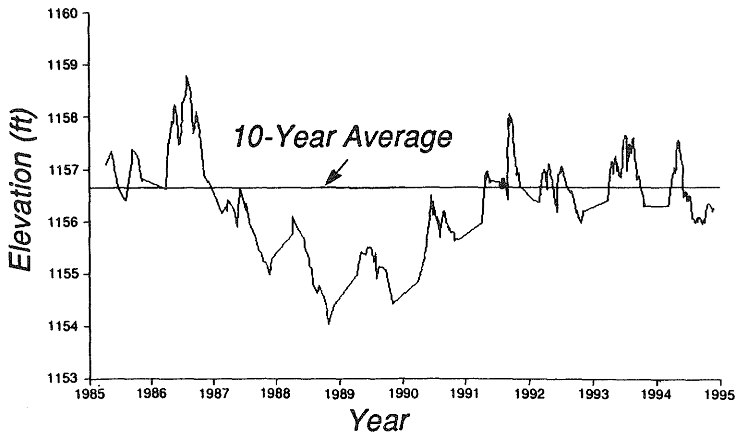
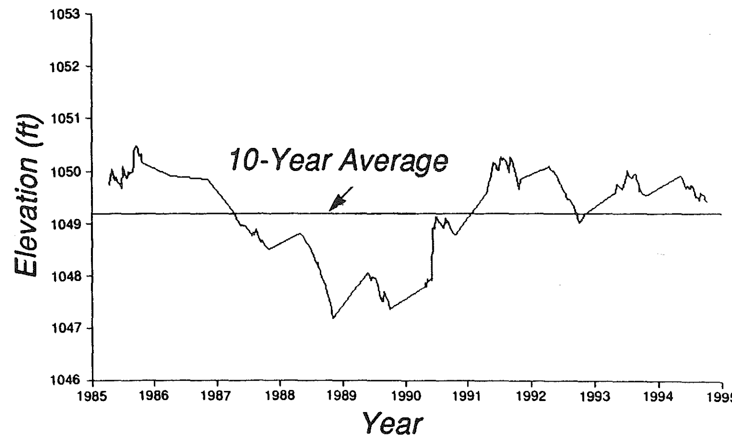


Figure 1.

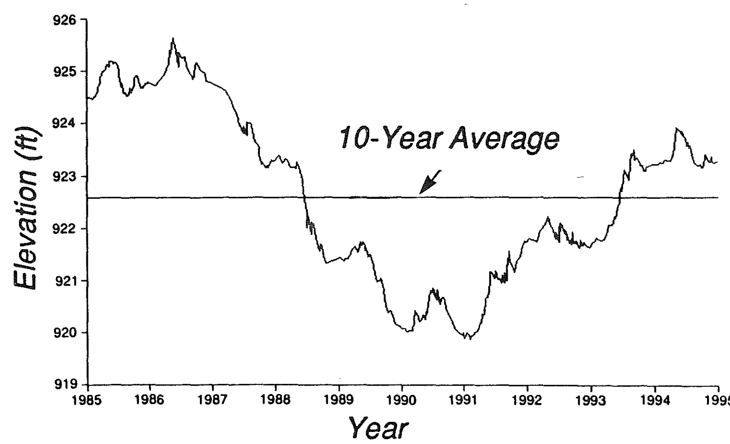
Green Lake (34-79) Kandiyohi County
Water Levels, 1985-1994



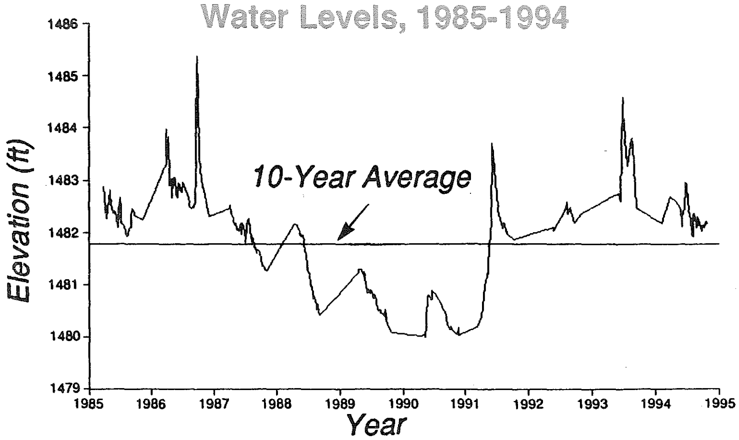
Sylvia Lake (86-289) Wright County
Water Levels, 1985-1994



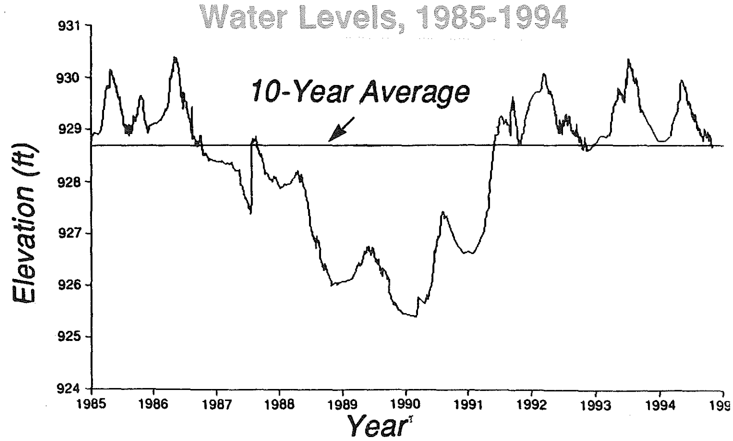
White Bear Lake (82-167) Washington County
Water Levels, 1985-1994



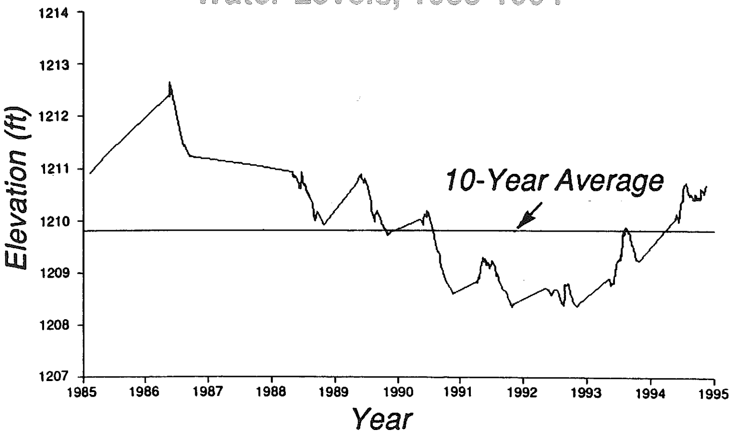
Shetek Lake (51-46) Murray County
Water Levels, 1985-1994



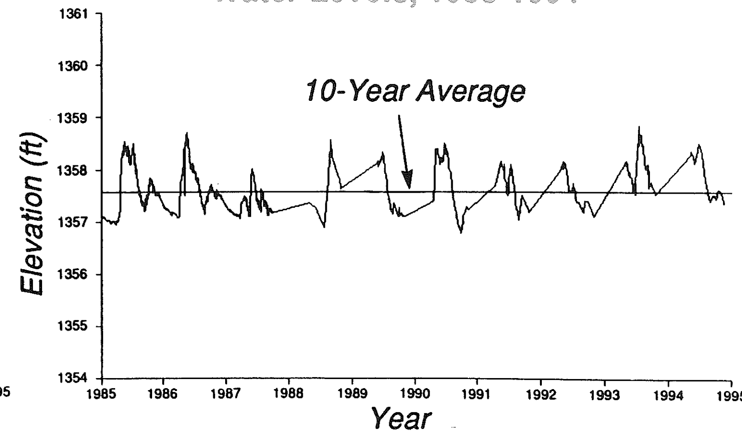
Minnetonka Lake (27-133) Hennepin County
Water Levels, 1985-1994

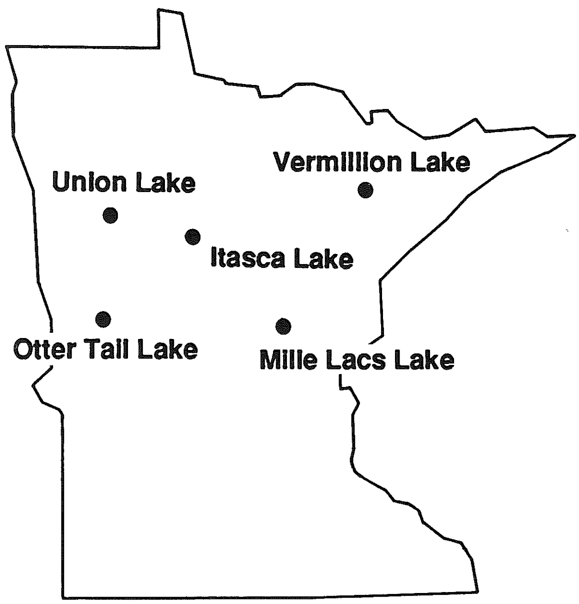


Union Lake (60-217) Polk County
Water Levels, 1985-1994

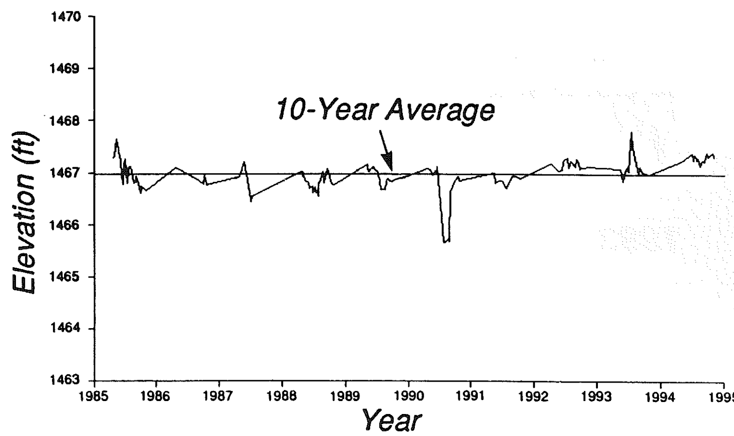


Vermillion Lake (69-378) St. Louis County
Water Levels, 1985-1994

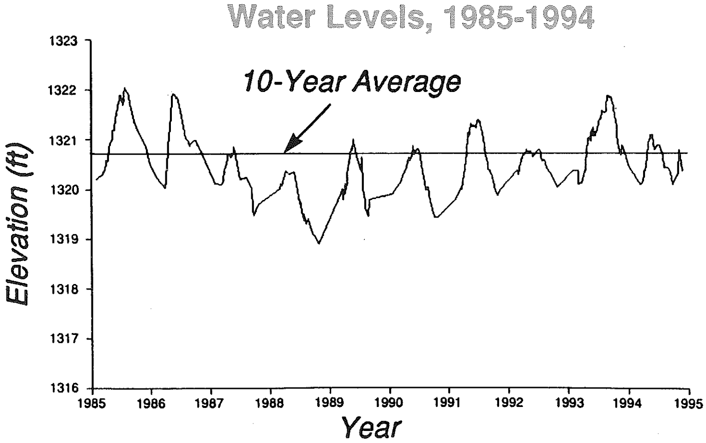




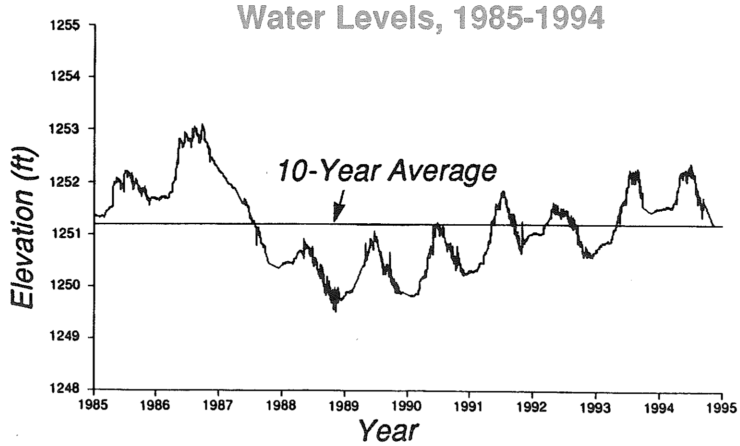
Itasca Lake (15-16) Clearwater County
Water Levels, 1985-1994



Otter Tail Lake (56-242) Otter Tail County
Water Levels, 1985-1994



Mille Lacs Lake (48-2) Mille Lacs County
Water Levels, 1985-1994



Lake Level Trends

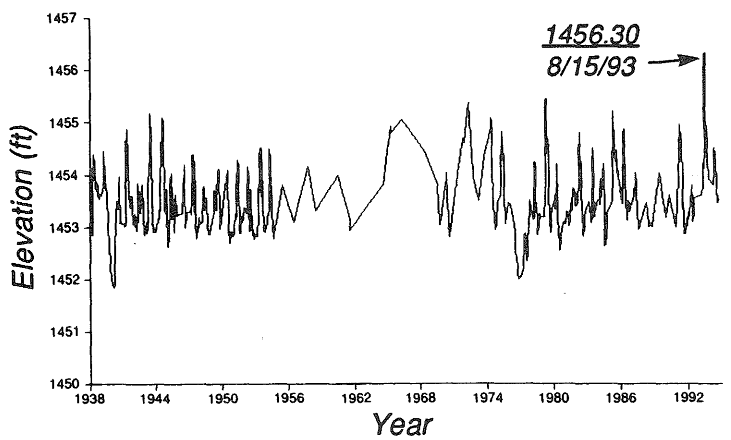
Lake level fluctuations from spring and summer rains resulted in many lakes experiencing highest recorded levels in 1993. Throughout the state, 28% of monitored lakes experienced highest recorded levels during 1993. The timing and distribution, as expected, generally followed that of rainfall patterns. The occurrence of highest levels began during spring in the south and, as summer progressed, shifted northward. These occurrences of highest recorded levels were principally located in the south and northwest, although many were recorded statewide. Level hydrographs for representative lakes are shown on pages 36 and 37, with peak levels and dates highlighted.

Lake levels during 1994 showed considerable stability, especially when compared to 1993. 1994 fluctuations were generally less than 10-year averages as can be seen in the table on pages 38-40. These relatively stable levels during 1994 are consistent with 1994 precipitation patterns and amounts.

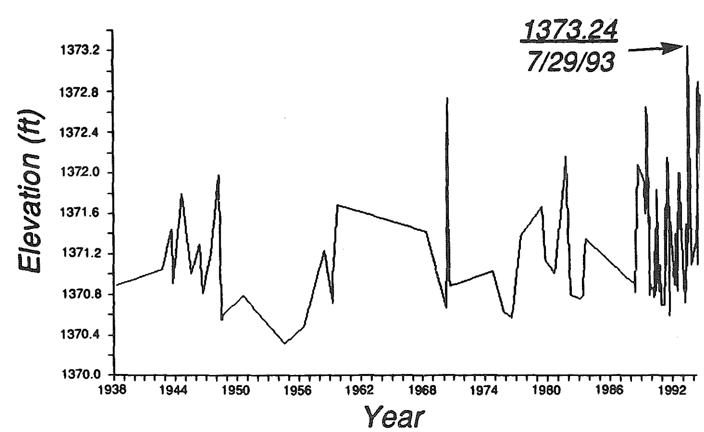
Landlocked lakes have generally reached or exceeded normal levels after experiencing extreme lows during the drought of the late 1980's. In selected cases, levels are very high, with some flood damage occurring. Multiple years of normal to above normal precipitation since the drought have contributed to generally wetter soil conditions, increased runoff rates and increased ground water levels. All of these tend to increase volume to lakes. These increases are especially noticeable on landlocked lakes.

1993 Record High Levels

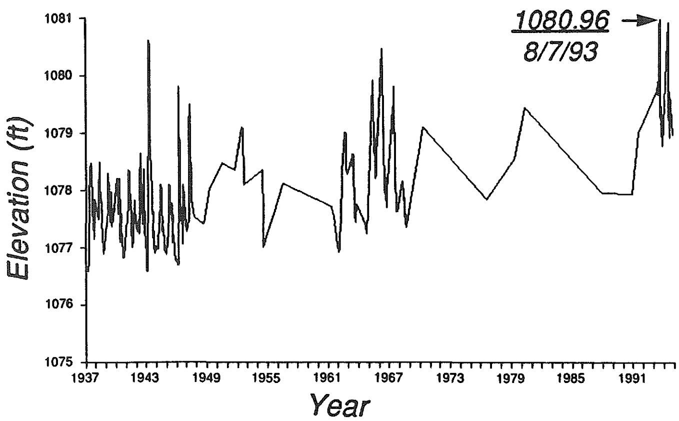
Height of Land Lake (3-195) Becker County
Water Levels, 1938-1994



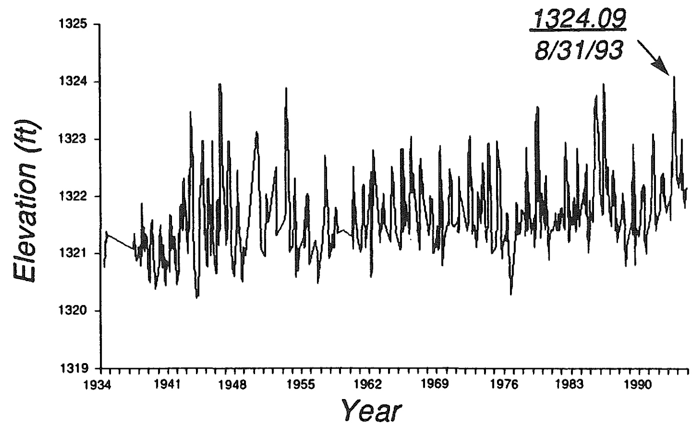
Sturgeon Lake (69-939) St. Louis County
Water Levels, 1938-1994

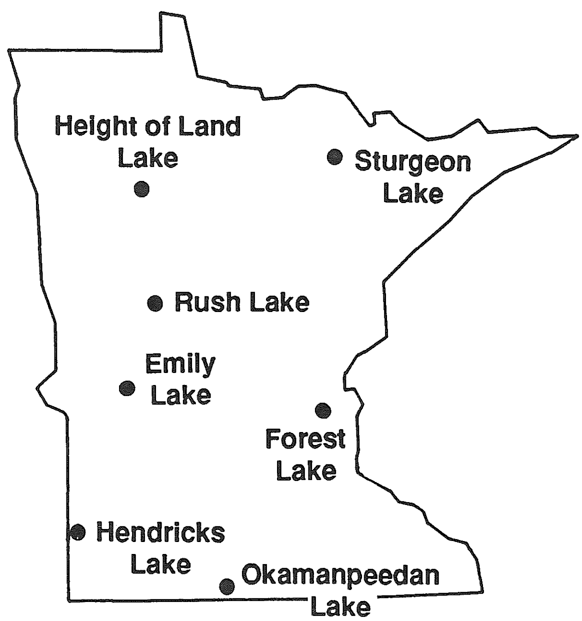


Emily Lake (61-180) Pope County
Water Levels, 1937-1994

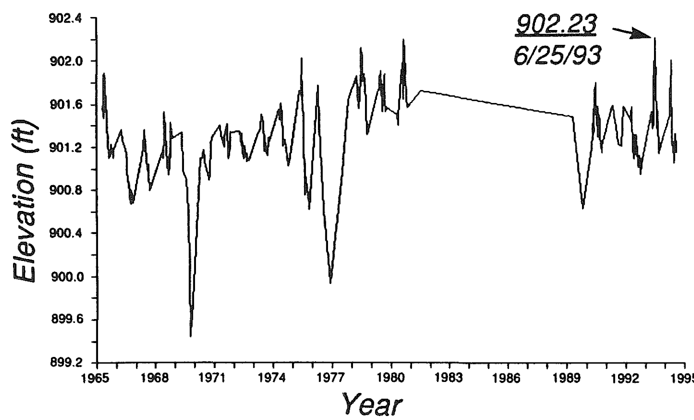


Rush Lake (56-141) Otter tail County
Water Levels, 1934-1994

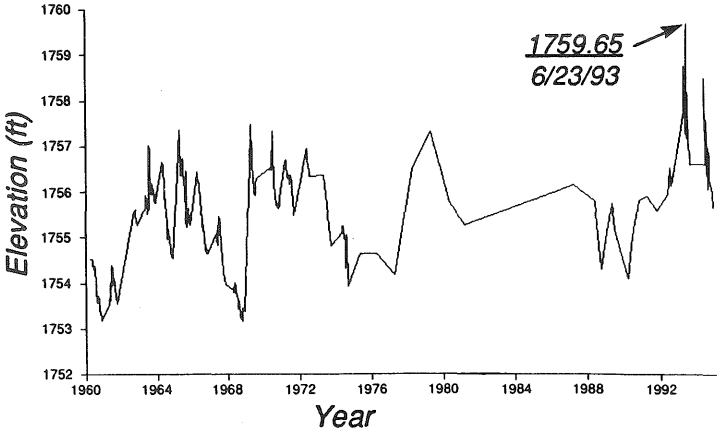




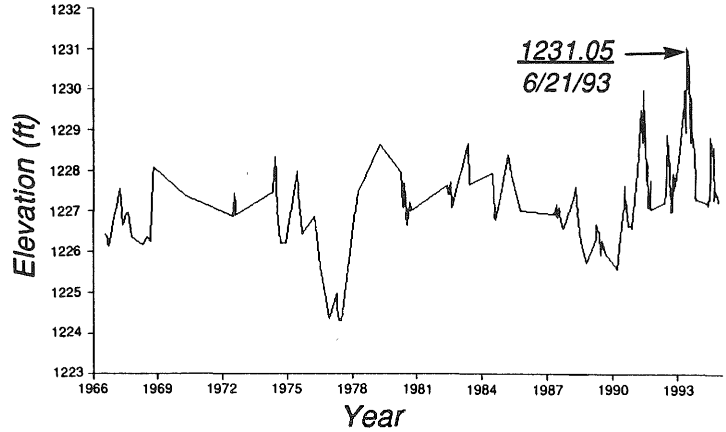
Forest Lake (82-159) Washington County
Water Levels, 1944-1994



Hendricks Lake (41-110) Lincoln County
Water Levels, 1960-1994



Okamanpeedan Lake (46-51) Martin County
Water Levels, 1966-1994



Annual Lake Level Fluctuation (feet)

LAKE NAME (LAKE ID)	1993	1994	10 -YR. AVE.
AITKIN COUNTY			
Little Pine (1-176)	1.57	1.02	0.99
Minnewawa (1-33)	0.78	0.62	0.82
Cedar (1-209)	1.48	1.26	1.65
Farm Isdland	1.88	1.05	1.02
ANOKA COUNTY			
Otter (2-3)	0.76	1.09	1.67
Baldwin (2-13)	4.57	4.42	3.07
Linwood (2-26)	0.85	0.70	0.68
Martin (2-34)	1.85	1.23	1.08
Coon (2-42)	0.74	0.80	1.10
Ham (2-53)	0.76	0.76	1.08
Spring (2-71)	2.05	1.68	1.81
George (2-91)	0.77	0.46	1.22
BECKER COUNTY			
Two Inlets (3-17)	2.94	0.72	1.34
Round (3-155)	1.60	0.46	1.18
Height of Land (3-195)	2.68	1.04	1.61
Cotton (3-286)	1.46	0.66	1.03
White Earth (3-328)	1.80	0.70	1.10
Buffalo (3-350)	2.66	0.76	1.35
Sallie (3-359)	2.19	0.86	1.36
Muskrat (3-360)	1.26	0.62	0.88
Big Cormorant (3-576)	1.10	0.66	0.93
Ida (3-582	0.74	0.60	0.98
Upper Cormorant (3-588)	1.18	0.75	0.92
BELTRAMI COUNTY			
Gallagher (4-92)	0.32	0.36	0.65
Turtle River (4-111)	1.36	1.59	1.59
Bemidji (4-130)	1.82	1.14	1.78
BIG STONE COUNTY			
Big Stone (6-152)	2.58	1.51	2.43
BLUE EARTH COUNTY			
Madison (7-44)	1.9	1.12	1.68
CARLTON COUNTY			
Chub (9-8)	0.66	0.70	0.84
CARVER COUNTY			
Lotus (10-6)	1.52	1.08	1.52
Waconia (10-59)	1.29	0.66	1.24

LAKE NAME (LAKE ID)	1993	1994	10 -YR. AVE.
CASS COUNTY			
Lower Trelipe (11-129)	1.30	1.15	1.13
Girl (11-174)	1.61	0.90	0.91
Hand (11-242)	0.49	1.08	0.81
Big Portage (11-308)	0.48	0.27	0.65
Ten Mile (11-413)	0.68	0.34	0.72
CHISAGO COUNTY			
South Lindstrom (13-28)	2.15	3.23	1.62
Green (13-41)	0.98	1.43	1.14
Rush (13-69)	1.22	1.36	1.43
North Center (13-32)	2.08	0.62	1.57
North Lindstrom (13-35)	1.94	0.69	1.57
Comfort (13-53)	2.02	1.51	1.45
CLEARWATER COUNTY			
Itasca (15-16)	0.94	0.26	0.81
COOK COUNTY			
Flour (16-147)	0.46	0.73	0.60
Poplar (16-239)	0.65	0.95	1.04
COTTONWOOD COUNTY			
Cottonwood (17-22)	1.68	0.47	2.07
CROW WING COUNTY			
Olander (18-91)	1.04	1.07	1.24
Rabbit (18-93)	0.95	1.32	0.90
South Long (18-136)	1.60	1.56	1.12
Ross (18-165)	3.05	1.10	1.41
Edward (18-305)	0.66	0.77	0.71
Pelican (18-308)	0.62	0.62	0.86
North Long (18-372)	0.69	0.73	0.82
Hubert (18-375)	0.87	0.42	0.81
DAKOTA COUNTY			
Marion (19-26)	2.02	1.26	1.96
DOUGLAS COUNTY			
Victoria (21-54)	1.32	0.90	1.16
Carlos (21-57)	0.65	1.04	1.00
Miltona (21-83)	0.80	0.92	1.00
Moses (21-245)	2.77	1.02	1.25
Lobster (21-144)	1.40	1.60	1.02

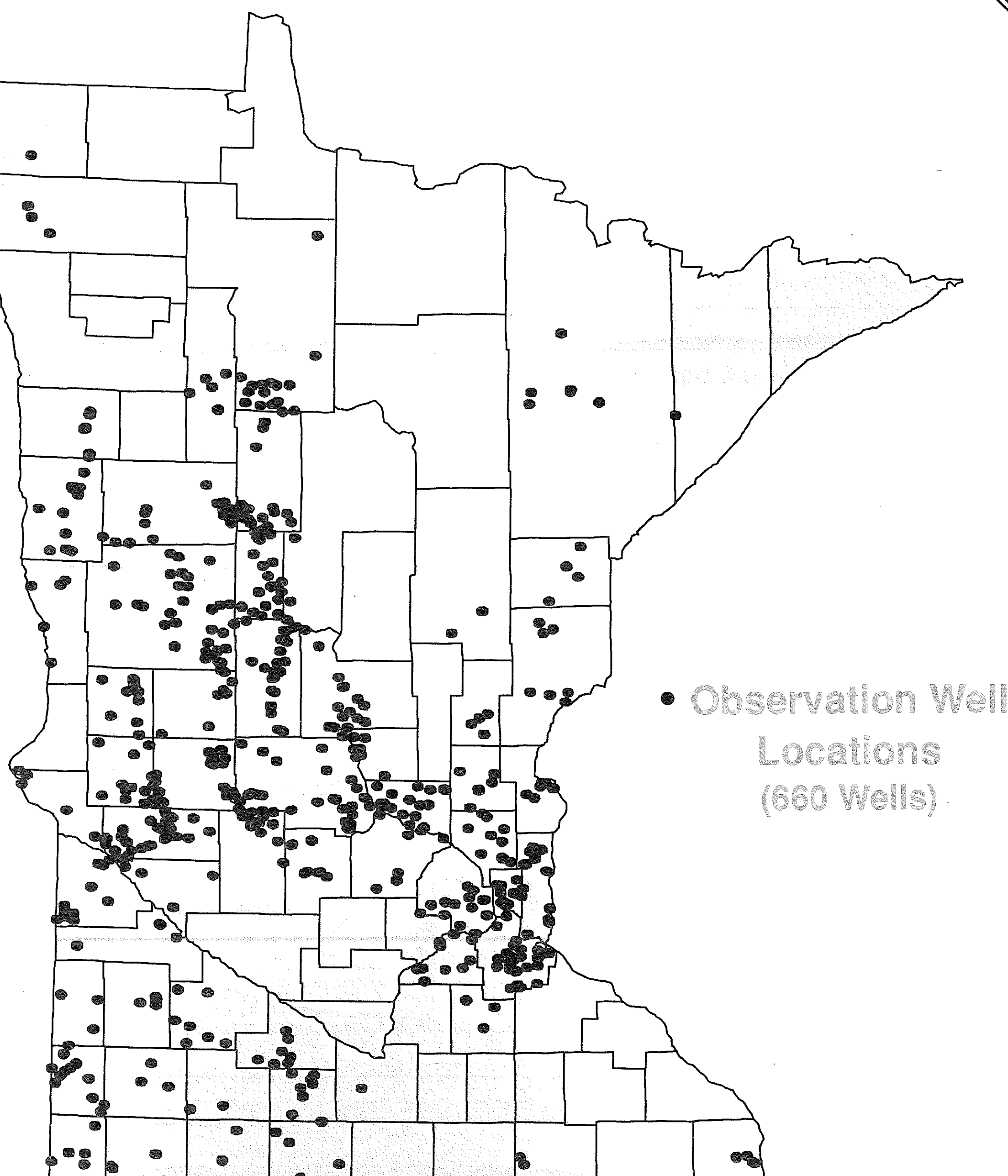
LAKE NAME (LAKE ID)	1993	1994	10 -YR. AVE.
HENNEPIN COUNTY			
Eagle/Pike (27-111)	0.78	0.96	0.98
Rice (27-116)	1.00	1.28	1.08
Fish (27-118)	1.10	1.09	1.11
Cedar Island (27-119)	0.54	0.92	1.03
Schmidt (27-121)	0.45	0.62	0.91
Minnetonka (27-133)	1.62	1.28	1.49
Independence (27-176)	1.82	2.27	1.71
HUBBARD COUNTY			
Belle Taine (29-146)	1.20	0.48	1.24
Plantagenet (29-156)	1.70	0.90	1.41
Long (29-161)	0.40	0.42	0.47
Potato (29-243)	0.50	0.38	0.63
ISANTI COUNTY			
Skogman (30-22)	1.36	0.86	1.21
ITASCA COUNTY			
Split Hand (31-353)	1.94	1.10	1.61
Siseebakwet (31-554)	0.58	0.50	0.73
Long (31-570)	1.22	1.19	1.03
Loon (31-571)	0.78	1.10	1.20
Bowstring (31-813)	1.94	1.74	1.56
Dora (31-882)	2.38	2.52	1.87
JACKSON COUNTY			
Loon (32-20)	1.54	1.86	1.36
Heron N Marsh (32-57-1)	8.74	4.02	3.94
Heron N Heron (32-57-5)	5.81	4.88	3.31
Heron S Heron (32-57-7)	6.80	4.85	3.60
KANDIYOHI COUNTY			
Calhoun (34-62)	1.24	1.47	1.32
Green (34-79)	1.36	1.62	1.40
Big Kandiyohi (34-86)	3.15	1.45	1.67
Mud (34-158)	1.14	0.80	1.31
Eagle (34-171)	1.38	1.04	1.58
Skataas (34-196)	0.60	0.86	1.35
Andrew (34-206)	1.61	1.46	1.50
LE SUEUR COUNTY			
West Jefferson (40-92-2)	1.61	0.70	1.45
Washington (40-117)	2.24	0.60	1.49
LINCOLN COUNTY			
Benton (41-43)	1.90	1.30	1.41
Hendricks (41-110)	3.05	2.80	1.53
MARTIN COUNTY			
Okamanpeedan (46-51)	3.75	1.70	1.97

LAKE NAME (LAKE ID)	1993	1994	10 -YR. AVE.
MILLE LACS COUNTY			
Mille Lacs (48-2)	1.59	1.17	1.34
Shakopee (48-12)	1.96	0.85	1.23
MORRISON COUNTY			
Sullivan (49-16)	2.12	0.86	1.31
Alexander (49-79)	1.33	0.62	0.89
MURRAY COUNTY			
Shetek (51-46)	2.10	1.05	1.86
NOBLES COUNTY			
Ocheda (53-24)	2.08	1.36	1.67
OTTER TAIL COUNTY			
Big Pine (56-130)	2.93	1.76	1.65
Rush (56-141)	2.50	1.20	1.58
Little Pine (56-142)	1.78	0.90	1.03
West Leaf (56-114)	0.86	0.81	0.92
Otter Tail (56-242)	1.80	1.00	1.48
Star (56-385)	1.11	1.32	0.87
Long (56-388)	1.06	0.90	0.82
Pickerel (56-475)	0.88	0.50	0.64
Lizzie (56-760)	1.66	0.90	1.16
Pelican (56-786)	1.40	0.92	1.35
Prairie (56-915)	0.45	0.44	0.85
PINE COUNTY			
Island (58-62)	1.84	1.31	1.47
Sturgeon (58-67)	0.66	0.48	0.81
Grindstone (58-123)	1.05	1.16	1.14
Pokegema (58-142)	2.08	2.98	3.25
POLK COUNTY			
Sandhill (60-69)	0.57	0.52	0.95
Union (60-217)	1.11	0.75	1.05
Maple (60-305)	0.39	0.45	0.95
POPE COUNTY			
Minnewaska (61-130)	1.34	1.40	1.15
Emily (61-180)	2.50	2.00	1.79
RAMSEY COUNTY			
East Silver (62-1)	0.87	1.19	1.68
Bald Eagle (62-2)	0.74	0.95	1.26
Gervais (62-7)	1.70	1.47	2.24
Round (62-9)	1.04	1.03	2.19
Wakefield (62-11)	0.84	1.39	2.56
Phalen (62-13)	2.72	2.38	3.79
Beaver (62-16)	1.16	1.14	2.02
Birch (62-24)	1.20	1.21	1.37
McCarron's (62-54)	0.87	0.52	1.17

LAKE NAME (LAKE ID)	1993	1994	10 -YR. AVE.
RAMSEY COUNTY (cont.)			
Como (62-55)	1.37	1.30	1.75
Owasso (62-56)	0.72	1.20	1.22
Josephine (62-57)	0.79	0.83	1.27
Turtle (62-61)	1.29	0.93	1.04
Long (62-67)	2.74	1.81	1.70
Pike (62-69)	1.46	0.60	1.32
Valentine (62-71)	2.09	1.29	1.79
Snail (62-73)	2.56	1.67	1.66
Island (62-75)	1.17	1.34	1.43
Johanna (62-78)	1.13	0.90	2.10
Wabasso (62-82)	1.02	1.36	1.51
West Silver (62-83)	1.36	0.82	1.72
ST. LOUIS COUNTY			
Pequaywan (69-11)	1.60	0.52	0.73
Vermillion (69-378)	1.30	1.15	1.62
Embarass (69-496)	2.30	4.50	2.31
Esquagama (69-565)	2.30	4.70	2.55
St. Mary's (69-651)	1.34	1.05	1.25
Ely (69-660)	0.57	0.72	0.87
Dark (69-790)	1.80	1.74	1.66
Pelican (69-841)	0.46	0.62	1.18
Sturgeon (69-939)	2.53	1.85	1.33
SCOTT COUNTY			
Upper Prior (70-72)	2.60	1.21	2.70
STEARNS COUNTY			
Grand (73-55)	0.39	0.82	1.01
Big Fish (73-106)	0.79	0.66	0.84
Two Rivers (73-138)	4.29	1.85	2.54
Rice (73-196)	3.11	2.84	2.84
Koronis (73-200)	1.92	1.68	1.76
TODD COUNTY			
Big Birch (77-84)	0.98	0.78	1.04
Little Birch (77-89)	0.70	0.76	1.13
Sauk (77-150)	1.40	1.50	1.56
Osakis (77-215)	1.79	2.17	1.44
WASHINGTON COUNTY			
Square (82-46)	0.54	0.20	0.55
Horseshoe (82-74)	0.55	3.16	1.96
Demontreville (82-101)	1.01	0.94	1.70
Jane (82-104)	0.63	0.62	1.76
Elmo (82-106)	1.21	0.55	1.32
Sunfish (82-107)	2.46	1.20	2.00
Eagle Point (82-109)	2.85	1.28	2.30
Downs (82-110)	3.36	1.55	2.67
Long (82-118)	4.20	2.78	3.50
Forest (82-159)	1.08	0.96	0.79
Clear (82-163)	1.98	1.11	1.25
White Bear (82-167)	1.78	0.78	1.20
WATONWAN COUNTY			
St. James (83-43)	3.48	0.62	1.80
WRIGHT COUNTY			
Charlotte (86-11)	1.86	1.24	1.36
Pulaski (86-53)	2.15	1.37	1.60
Maple (86-134)	0.54	0.86	1.37
Indian (86-223)	1.20	1.02	1.53
Sylvia (86-289)	0.47	0.50	0.82
YELLOW MEDICINE COUNTY			
Tyson (87-19)	1.72	0.68	0.96
AVERAGES:	**1.61**	**1.22**	**1.44**

Chapter 3
GROUND WATER

Number of Active Observation Wells in Water Year 1994

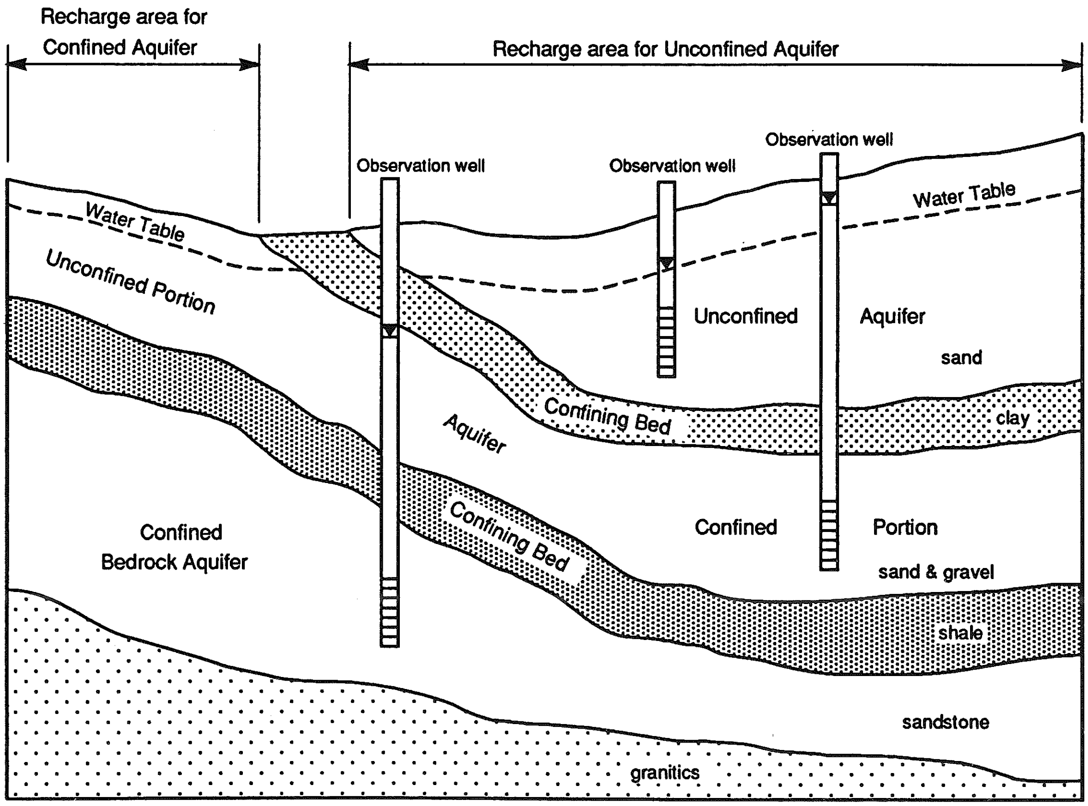


Ground Water

Introduction

Monitoring of ground water levels in Minnesota began in 1942 and, starting in 1947, was expanded by a cooperative program between the DNR and the United States Geological Survey (USGS). By the end of Water Year 1994, approximately 660 water level observation wells (obwells) had been established statewide. Soil and Water Conservation Districts (SWCD) and the USGS monitor these wells for the DNR. The DNR obwell network was developed to record background water levels in areas of present or expected ground water use. The data are used to assess ground water resources, interpret impacts of pumping and climate, plan for water conservation, evaluate local water complaints and otherwise support resource management programs.

Figure 1. Hypothetical Unconfined and Confined Aquifer Systems



Aquifers

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

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

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

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

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

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

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

Statewide Summary

The remainder of this chapter discusses the ground water levels in unconfined and confined aquifers during Water Years 1993 (WY93) and 1994 (WY94). This discussion focuses on two aspects: water levels for these two years and their comparison to long-term averages, and water level trends over several years for two major bedrock aquifer systems in the metropolitan area. To achieve meaningful comparisons and trend analysis, representative obwells were chosen from the network based on their length of record and their geographical location.

During WY94, the DNR monitored water levels in approximately 660 wells throughout the state. Figures 2, 3 and 4 show the locations of these wells, identifying those that were placed in unconfined aquifers, in buried artesian aquifers and in bedrock aquifers.

Figure 3.

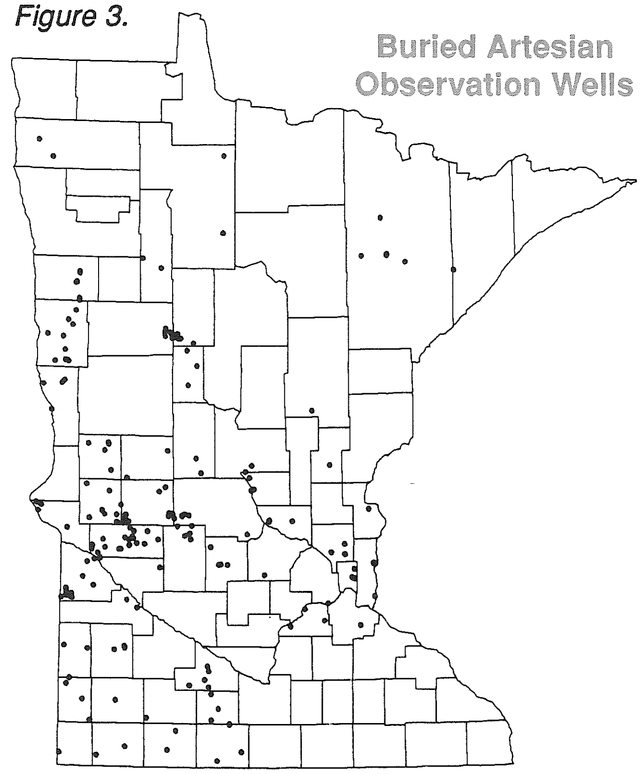
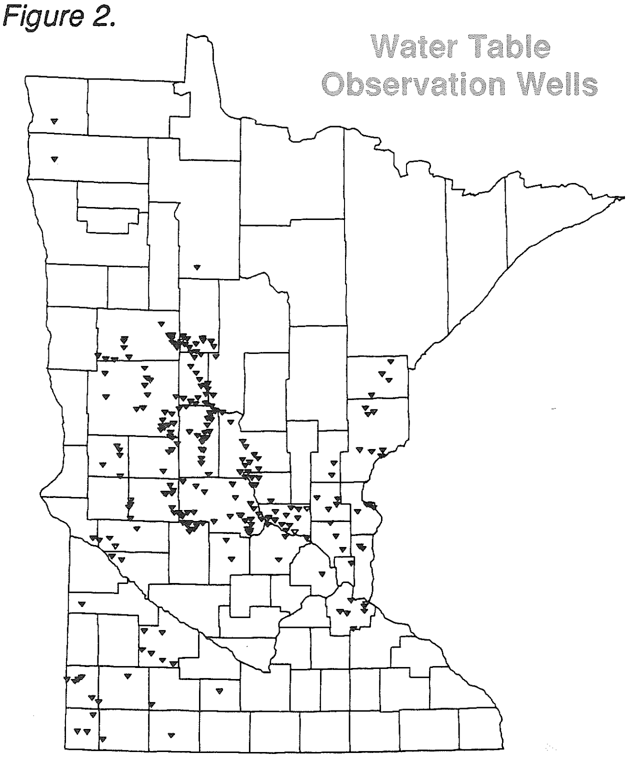


Figure 2.



WY93 and WY94 Comparisons

For the selected representative obwells, water levels within each water year are compared. These levels are also compared to the historical average. Where data was available, water levels were analyzed twice per water year, usually in March and July. These months were chosen because they most likely show the aquifer's condition following the winter before the heavy summer use period begins and again in the middle of the summer season before the onset of fall rains. Where data was not available for one or both of these months, comparisons for other months were made. These exceptions are noted in the x-axis labels of the following graphs.

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

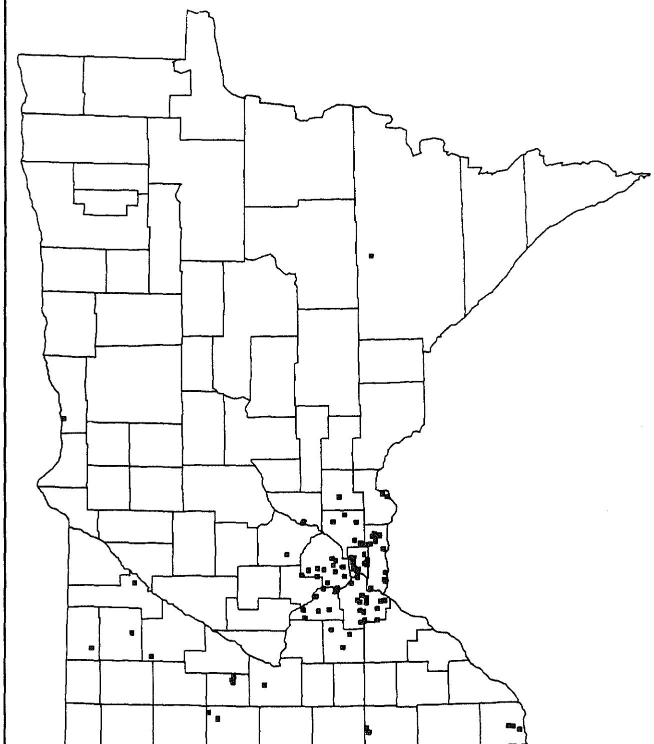
Unconfined Aquifers

Figure 5 shows water levels during the months of March and July for WY93 and WY94, as well as the long-term monthly average, for selected water table wells throughout Minnesota. In all instances, the average March reading is less than that for July. While drainage from the aquifer continues throughout the winter, recharge is restricted. In general, wi r precipitation is stored as snowpack and frozen soil prevents or slows the infiltration and percolation of spring snow melt. By the end of winter, the aquifers are at a low point. As the soil thaws and spring rains occur, the aquifers are recharged resulting in the higher July water levels. As noted earlier, these unconfined aquifers respond rapidly to climatic events.

For the month of March, water levels in WY94 were higher than in WY93. It is noted in the Climatology chapter of this publication that spring of 1993 was marked by cold temperatures and late melting of a normal snowpack. Spring of 1994 came early with the melting of a heavy snowpack over soil with very little frost. These 1994 conditions allowed for an early recharge of unconfined ground water.

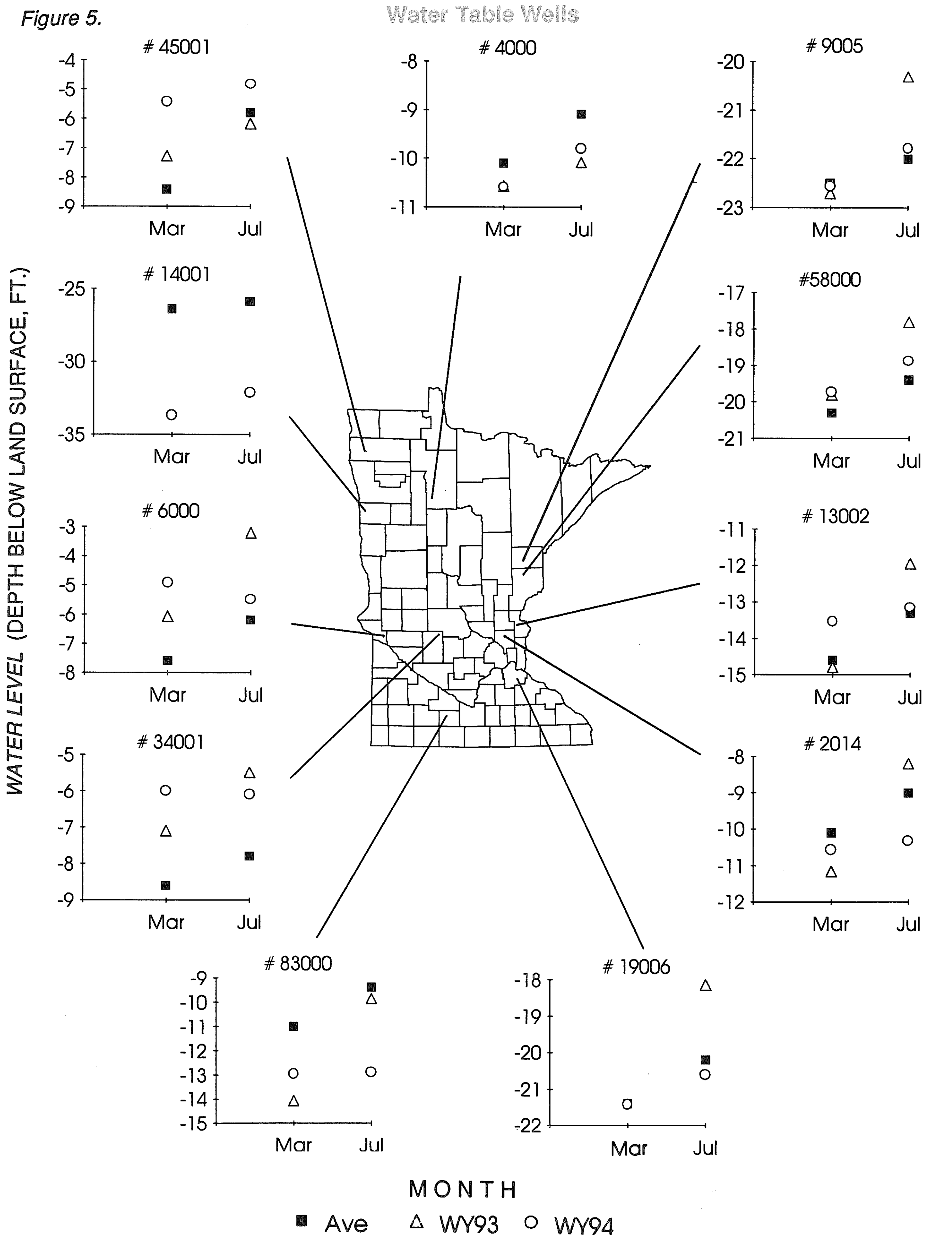
For July, however, WY94 levels were below those for the previous year. The Climatology chapter indicates that May to August, 1993, was among the wettest periods on record, accounting for the higher water table.

Figure 4. Bedrock Observation Wells



Comparison of water year readings with long-term averages shows varying patterns: for some wells the readings are above the average, in others they are below. Grouping the wells by large geographic regions does not indicate any trends. Lack of a regional pattern may result from the individual characteristics of isolated unconfined aquifers.

Figure 5.


Water Table Wells
WATER LEVEL (DEPTH BELOW LAND SURFACE, FT.)
45001
4000
9005
14001
#58000
6000
13002
34001
2014
83000
19006
Mar
Jul
MONTH
Ave
WY93
WY94

Confined Aquifers - Buried Artesian

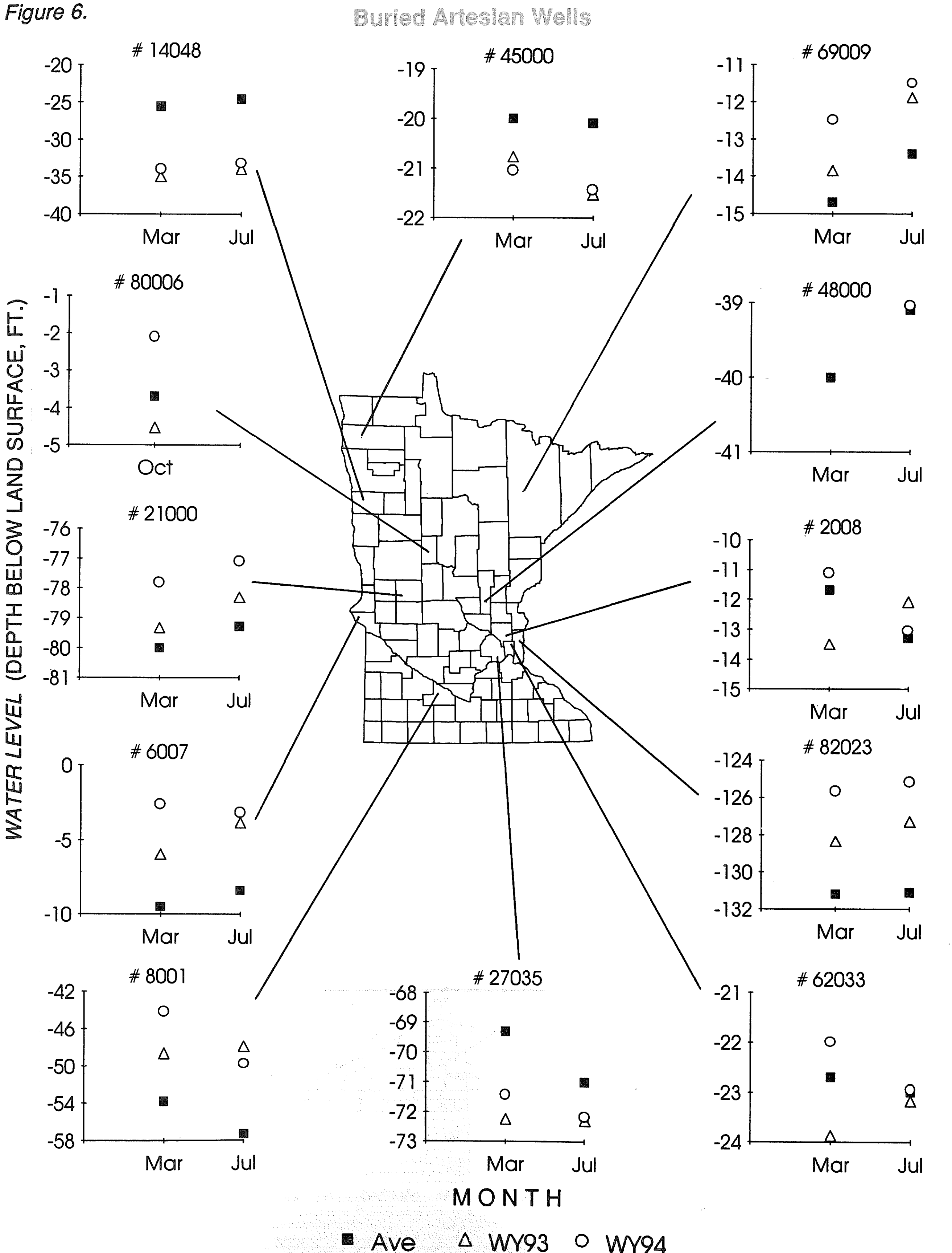
Seasonal water levels in confined buried artesian aquifers are compared to historic averages in Figure 6. Under confined conditions, these aquifers generally respond less quickly to seasonal inputs from snow melt and precipitation. However, buried artesian aquifers are often near the surface with their extent poorly defined and they may be connected with adjacent unconfined aquifers. As a result, individual responses of buried artesian aquifers to recharge may be difficult to predict.

Average water levels for most wells do not show a seasonal trend. Two wells, however, (69009 in St. Louis County and 48000 in Mille Lacs County) do show a rise in water level following winter. Levels in well 27035 in Hennepin County fall during the summer, possibly an effect of increased water use in the Minneapolis/St. Paul metropolitan area during that season. Similarly, for well 8001 in the City of Sleepy Eye, lower water levels in July may result from increased summer pumpage for both municipal and industrial purposes.

In general, water levels in March were higher in WY94 than WY93. This same pattern was evident in July, but the differences between 1993 and 1994 are smaller and, in many cases, unimportant.

The observed water levels in WY93 and WY94 were higher than the average in some wells and lower than average in others. It is difficult to identify a trend, but the levels in the northwest were below average; levels across a central band of Minnesota and including the northeast were above average; and, around the metropolitan area, no pattern was evident. The one south-central well had higher than average levels.

Figure 6.


Buried Artesian Wells
14048
45000
69009
80006
48000
21000
2008
6007
82023
8001
27035
62033
WATER LEVEL (DEPTH BELOW LAND SURFACE, FT.)
Mar
Jul
Oct
MONTH
Ave
WY93
WY94

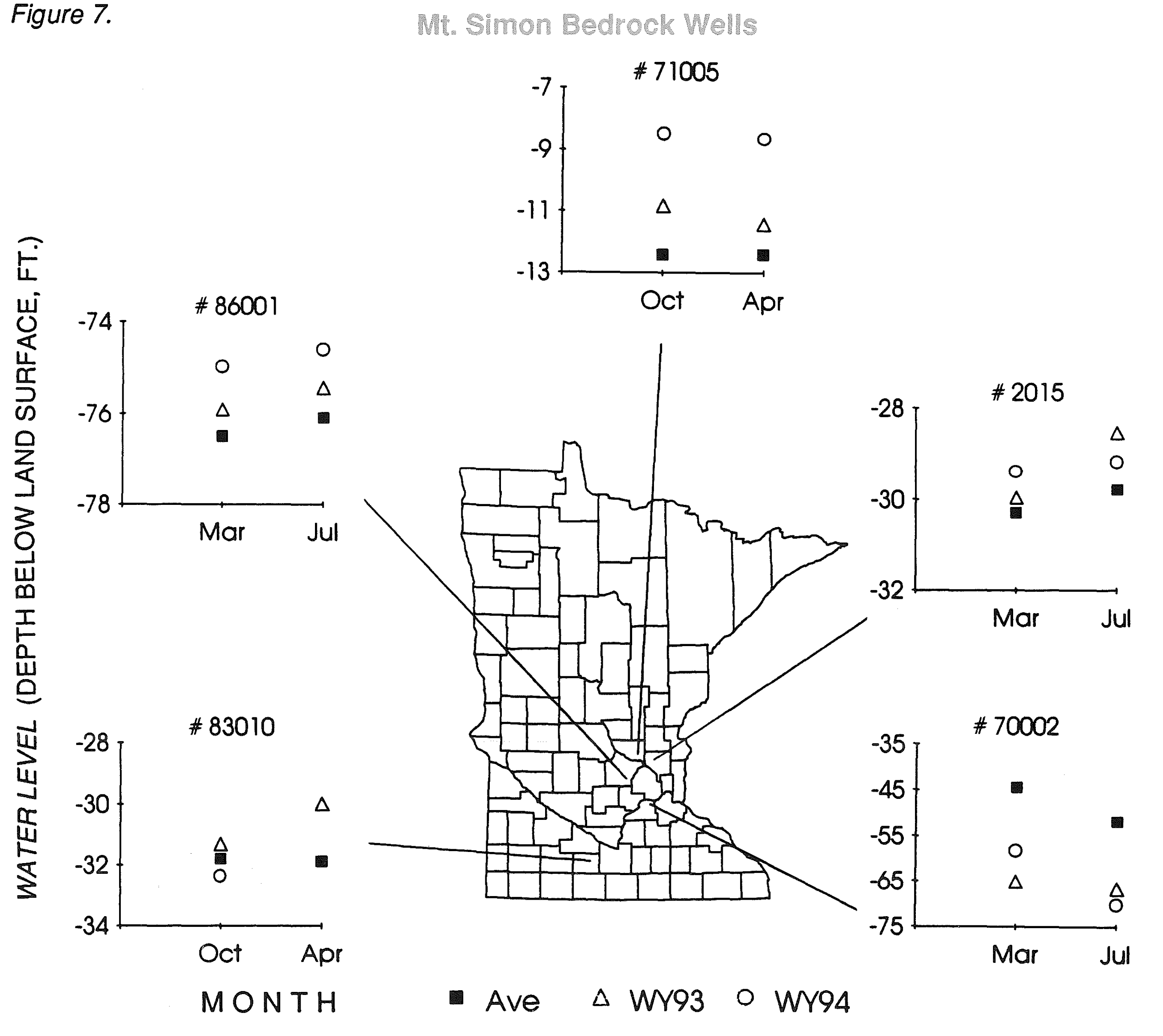
Confined Bedrock - Mt. Simon Aquifer

As illustrated in Figure 7, two of the measured Mt. Simon wells show no seasonal differences in average water level between October and April. Of the remaining three Mt. Simon wells, two (86001 and 2015) show a slight rise in level following winter while the third (70002) indicates a drop in summer. This last well may be influenced by increased summer pumping from nearby municipal wells.

Water levels in the Mt. Simon aquifer were generally higher in WY94 than in WY93. In the two sets of measurements where this was not the case, the levels were similar.

Water levels in WY93 and WY94 were above average except for one well (70002) in Scott County. Municipal pumping since the mid-eighties from another aquifer seems to affect this aquifer and consequently has skewed the average reading.

Figure 7.



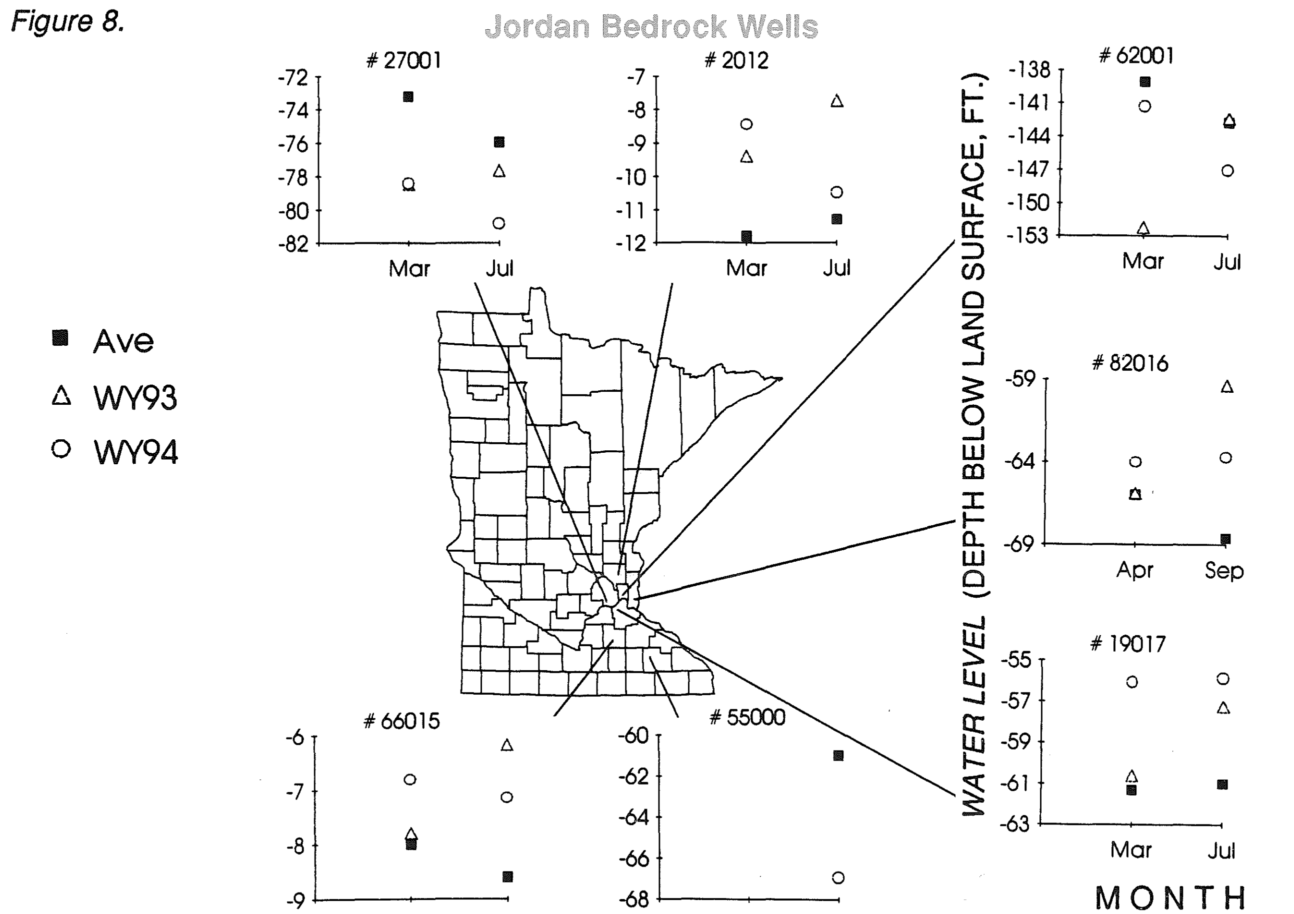
Confined Bedrock - Prairie du Chien- Jordan Aquifer

Water level comparisons for the Prairie du Chien-Jordan aquifer system (hereafter referred to as Jordan) are shown in Figure 8. Average water levels indicate a seasonal difference with the July level lower than in March. This is a result of seasonal pumping and is discussed in the Water Level Trend section which follows.

Water levels in March tended to be higher in WY94 than in WY93. The situation is reversed in July, however. This may be the result of WY93 being much wetter, particularly in the spring and early summer, creating less demand for private and municipal pumping.

For the most part, water levels in WY93 and WY94 were above the historical average. In wells 27001 and 62001, where this is not the case, water level averages incorporate an earlier period of time when water levels were higher. In more recent years these levels have steadily maintained a lower level, presumably as the result of increased municipal pumping. Therefore, WY93 and WY94 readings are shown compared to an average which is skewed toward a higher water level; when compared to averages reflecting the more current trend, WY93 and WY94 water levels were about average for 27001 and above average for 62001. Well 55000 has just reentered the Obwell Network and consequently has very little data to report for the water years in discussion. Long-term records for this well also indicate a skewed average water level similar to that for 27001 and 62001.

Figure 8.

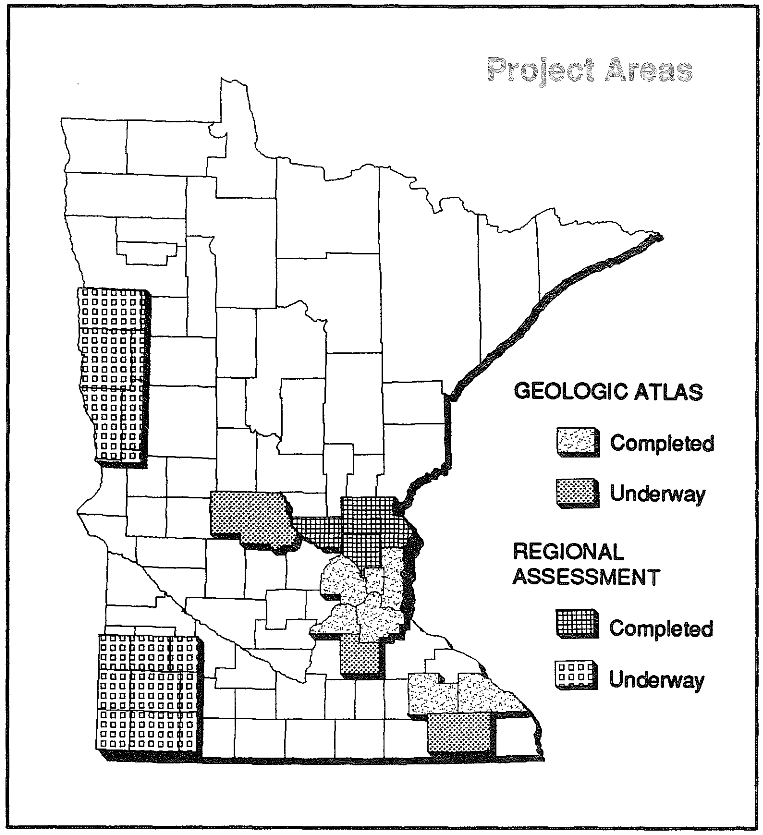


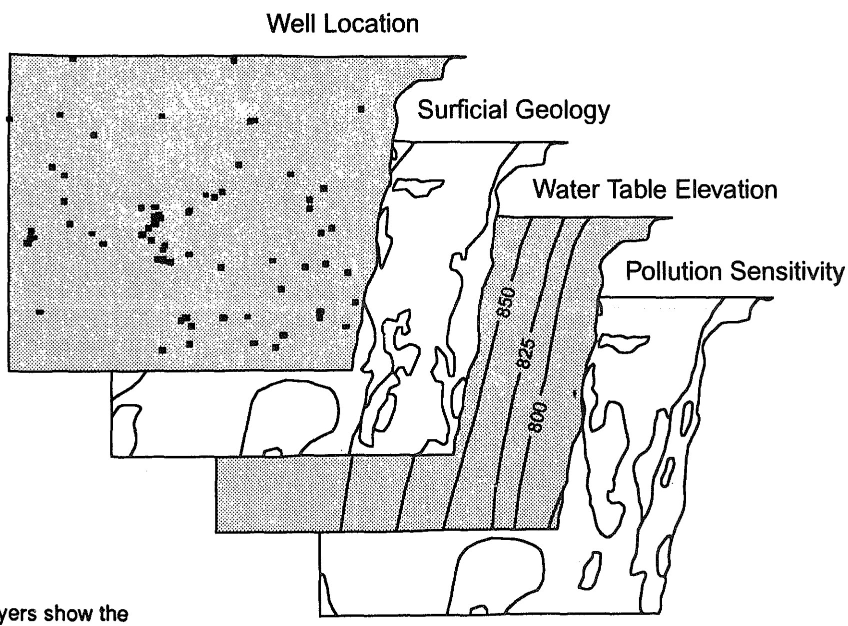
County Geologic Atlas and Regional Hydrogeologic Assessment Program

Ground Water Data Use

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

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





Layers show the extreme NE corner of Chisago County, from *Anoka Sand Plain Regional Hydrogeologic Assessment, 1993*

GIS-Based Mapping

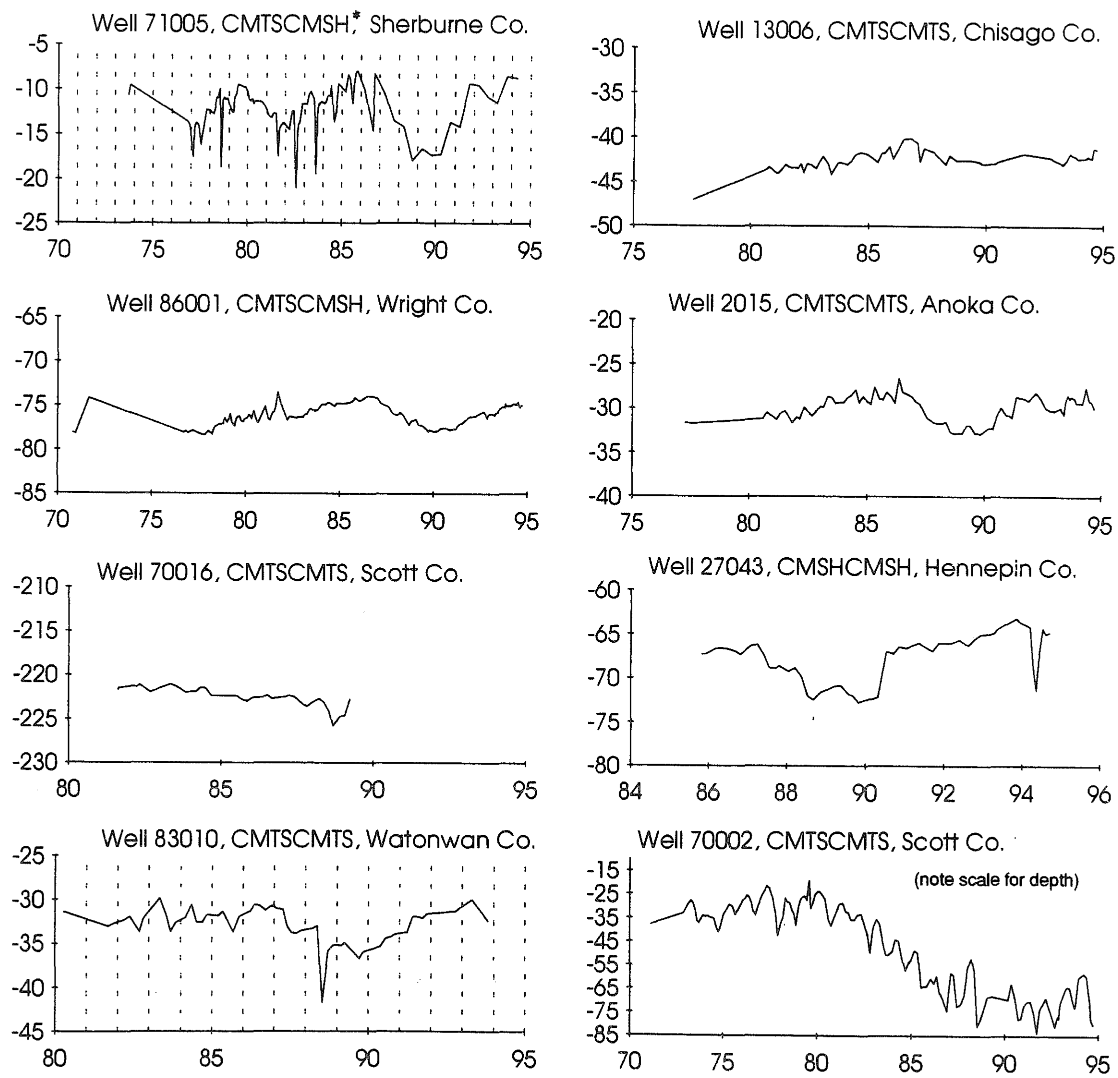
The information collected is organized, displayed and analysed using Geographic Information System (GIS) technology, a computer-based tool for manipulating spatial information. Beginning in 1993, all atlas and regional assessment reports were developed using GIS.

Water Level Trends

In and around the seven-county metropolitan area, pumping and development pressure continues to grow for two major aquifer systems: the Jordan and the Mt. Simon. At present, the Jordan supplies water for nearly all of the municipal and private high capacity water users in the metro area. The Mt. Simon lies deeper than the Jordan, and is more protected from contamination sources. While this aquifer was used in the past for purposes such as air conditioning, its use is now restricted to situations where no other potable water source is available. However, interest and speculation continue about the possibility of using water from this aquifer.

With the heavy demand upon the Jordan and the possibility of using the Mt. Simon, questions are raised regarding the condition of these aquifers and whether or not they are in danger of depletion. The following brief analysis addresses these questions.

Figure 9. Mt. Simon Bedrock Aquifer: Water Level Depths (feet) Over Past Years



* Aquifer Code: first 4 letters indicate the aquifer at the top of the well screen; second 4, the aquifer at the bottom of the screen.

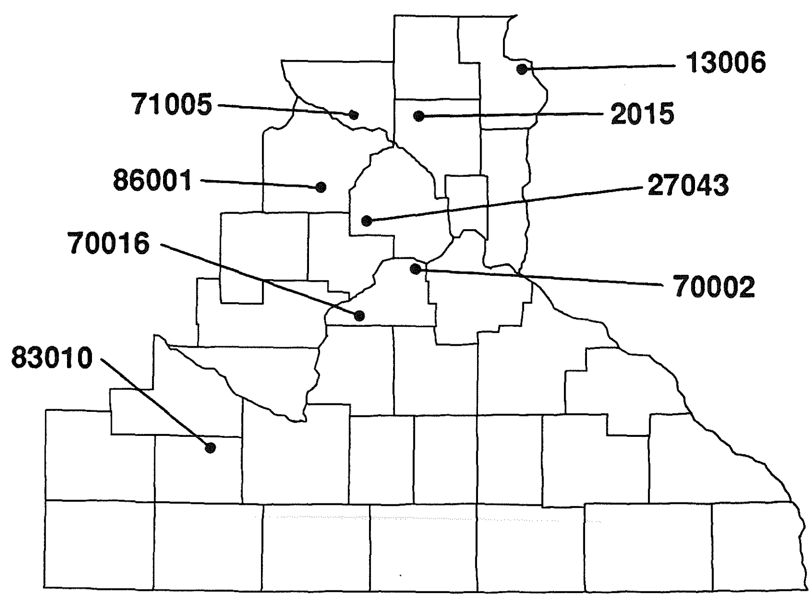
Mt. Simon Aquifer System

Hydrographs illustrating water levels for the period of record in several Mt. Simon wells are shown in Figure 9. These wells were selected for their long measurement record and because they represent the major area of use for this aquifer system in Minnesota (Figure 10).

While there is some cyclical variation, all of the wells except one exhibit a steady water level. The exception is well 70002 in Scott County. This well appears to be impacted by municipal pumping from another aquifer system which began in the mid-eighties. As a result, the water level dropped approximately 40 feet in the Mt. Simon but, since 1989, has remained fairly steady.

The cyclical variations reflect decreased recharge during the dry period between 1986 and 1988 followed by a steady recovery in the years since.

Figure 10. Location of Mt. Simon Aquifer Trend Analysis Wells in Southeast Minnesota



Jordan Aquifer System

Figure 11 shows the locations of Jordan aquifer wells selected for this analysis. As with the Mt. Simon wells, these were selected for their long measurement record and because they are distributed throughout the area underlain by this aquifer system.

Historic water levels for the selected wells in the Jordan aquifer system are shown in Figures 12a and 12b. In general, water levels in the Jordan aquifer do not appear to be declining throughout the Minneapolis/St. Paul metropolitan area. There are, however, a few locations where water level declines are observed. Wells 27010 and 27001 in Hennepin County and 19030 in Dakota County have experienced declining water levels. The fact that these wells are showing decline is interesting for the fact that they are all in the same vicinity of, and lie in a line on both sides of, several major water users.

The trend for water levels in well 62009, Ramsey County, is not clear. Very little data exists prior to 1980, but what does exist, suggests that water level decline may also be occurring there.

A cyclical pattern, similar to that of the Mt. Simon aquifer, is also evident in many of the Jordan wells, especially 27011, 62030, 66015 and 82029. Another characteristic often observed in pumped aquifers is seasonal drawdown as summer pumping increases to meet increased seasonal demands. This pattern can be seen in many of the Jordan well hydrographs and is highlighted in several hydrographs by including ***vertical dashed lines*** to delineate individual years. For example, hydrographs for wells 27039 and 19005 show downward spikes in the middle of each year, the result of summer drawdown.

Figure 11. Location of Jordan Aquifer Trend Analysis Wells in Southeast Minnesota

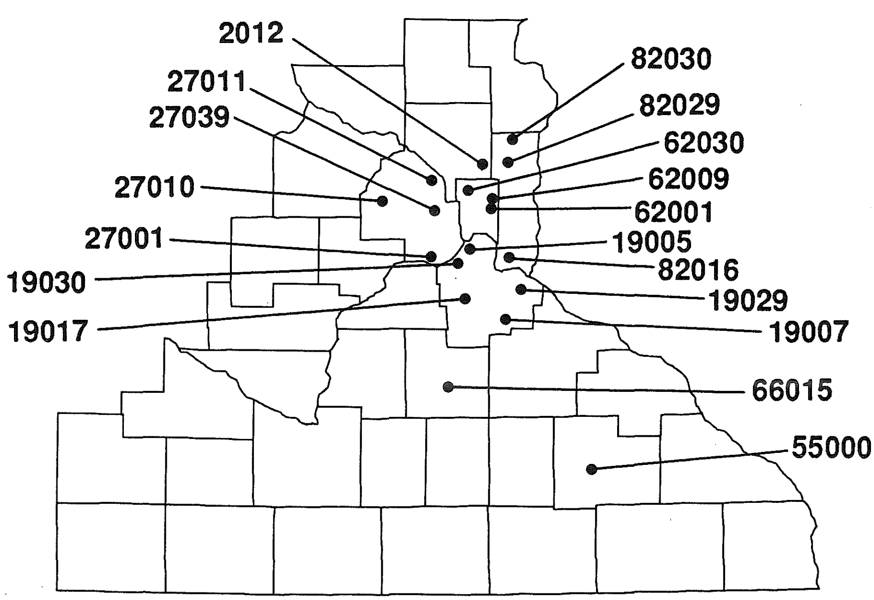
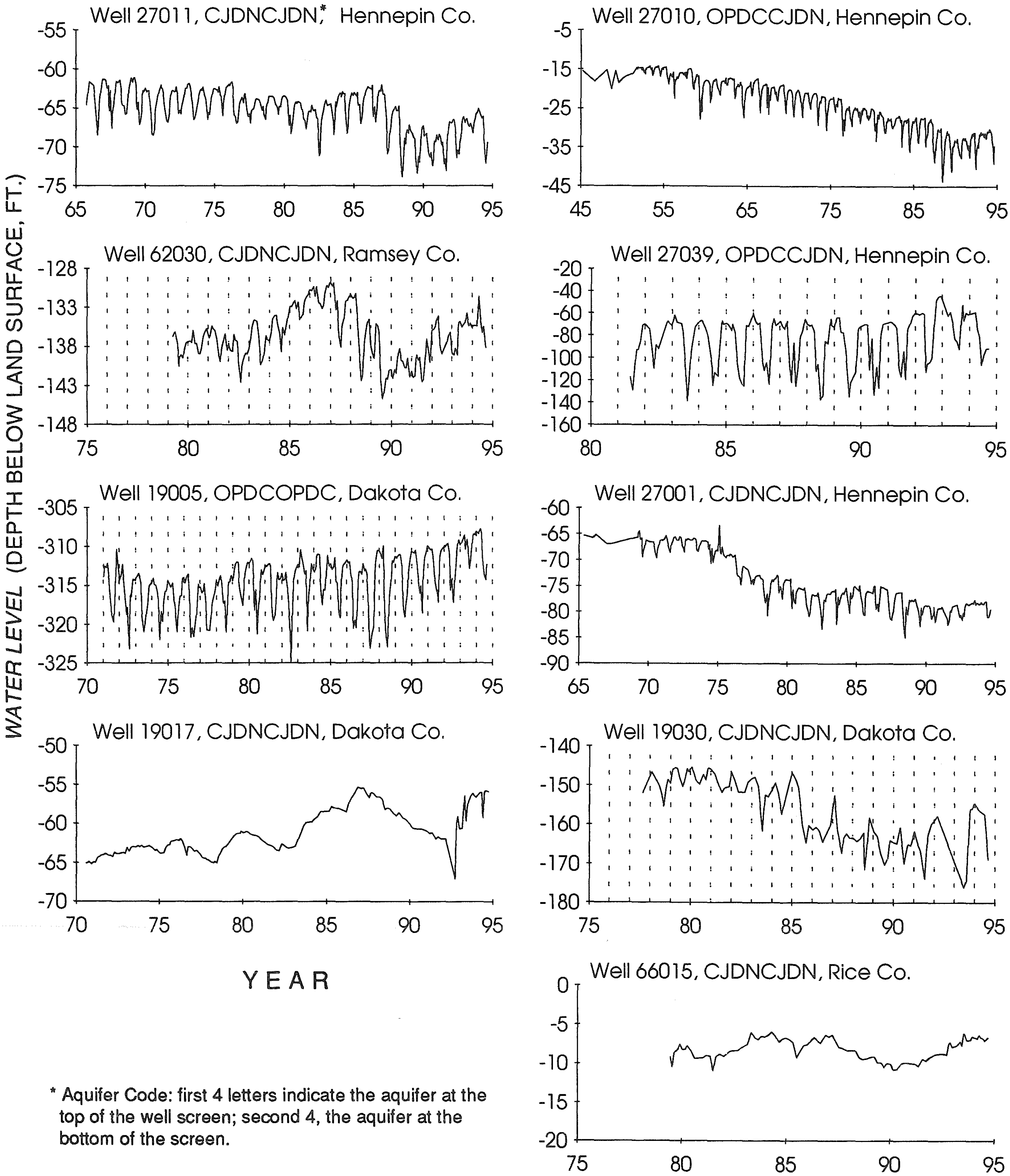
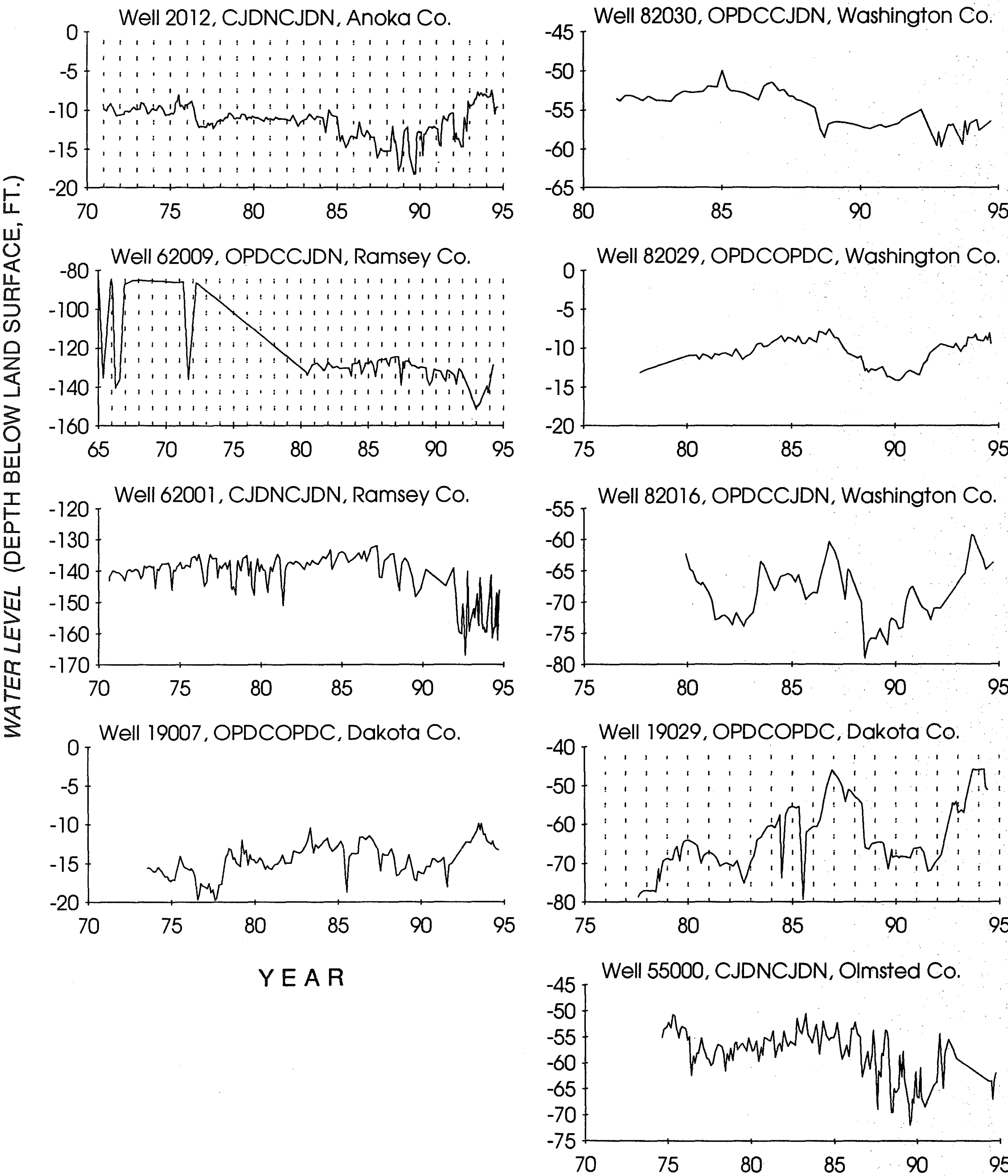


Figure 12a. Jordan Bedrock Aquifer: Water Level Depths (feet) Over Past Years



* Aquifer Code: first 4 letters indicate the aquifer at the top of the well screen; second 4, the aquifer at the bottom of the screen.

Figure 12b. Jordan Bedrock Aquifer: Water Level Depths (feet) Over Past Years



Obwell Network Expansion

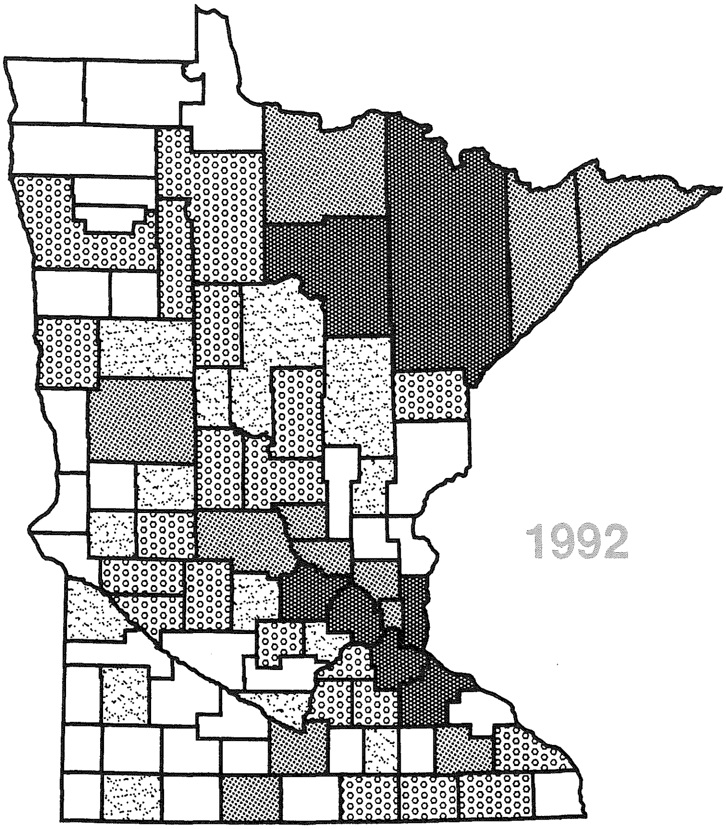
The Obwell Network continues to be expanded to gain more widespread coverage of ground water resources throughout Minnesota. In Water Year 1995, an additional 13 county Soil and Water Conservation Districts have been added as observers. The number of obwells being monitored has increased to approximately 740. Cook County, representing an area of the state with few observation wells, is investigating potential observation wells for the purpose of joining the network. Wells in the Mt. Simon aquifer which are scheduled to be sealed are being evaluated for inclusion in the network.

Summary

Early spring water levels for WY94 were generally higher than those for WY93. By summer the situation had reversed, possibly due to the greater than average rainfall in WY93. Depending on the well, water levels in both years were either above or below the historic average, with no regional or statewide pattern observed.

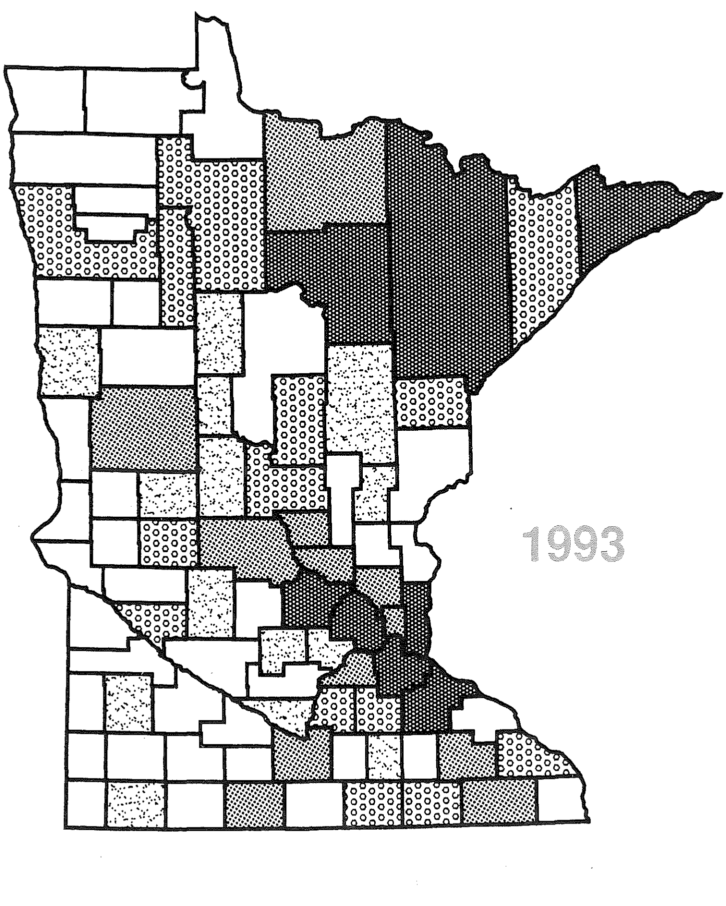
Long-term water level trends in the Mt. Simon aquifer system generally do not show any decline. The one instance of decline is probably associated with nearby high capacity pumping. For the Prairie du Chien-Jordan aquifer system, historic water levels generally show no decline. However, a localized area within the metropolitan region does show declining water levels, presumably the result of high pumping rates.

Chapter 4: WATER USE



1992

Reported Water Withdrawals by County



1993

Billions of Gallons (BG)

- < 1 BG
- 1 BG - 2 BG
- 2 BG - 5 BG
- 5 BG - 50 BG
- > 50 BG

Water Use

Introduction

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

As a condition of each permit, the holder must report the volume withdrawn for the previous year to within 10% accuracy. The data collected is used for many purposes, such as documenting water rights, understanding the hydrology of aquifers from which water is withdrawn, and evaluating existing water supplies by monitoring use and the impact of that use. The data is reported on a calendar year basis. This chapter summarizes the reported water use data for calendar years 1992 and 1993.

Major Water Use Categories

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

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

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

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

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

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

Statewide Water Use Comparison for 1992 and 1993

Total water use for calendar years 1992 and 1993 remained relatively stable, however, some categories changed significantly. The reported use in 1993 was 1106 billion gallons (BG), down slightly from 1133 BG in 1992. There were other changes in use patterns as well, which will be discussed further in the text. Figure 1 is a comparison of the two years showing use by major category and the percent change from the previous year.

A comparison of surface water versus ground water use for 1992 shows that the majority of appropriations are for surface water (Figure 2). 82% of withdrawals in Minnesota are from surface water sources, compared to 80% nationally (USGS data). However, if the non-consumptive use for most power generation is removed, use of ground water and surface water are more even (non-consumptive use means water that is immediately returned to its source after use). Over 99% of withdrawals in Minnesota (and nationally) are used for power generation and power plant cooling. This relationship remains substantially constant from year to year.

Surface water use increased slightly from 1992 to 1993, primarily for power generation. The large decrease in ground water use was largely due to the extremely wet, cool conditions in 1993 and subsequent reduced crop and lawn irrigation.

Figure 1. Comparison of Changes in Water Use by Category from 1992-93 Billions of Gallons (BG)

Major Use Category	1992 BG	1992 % of Total	1993 BG	1993 % of Total	Use Change (BG)	% Change
Power Generation	679	60	722	65	+ 43	+ 6%
Public Supply	175	15	164	15	- 11	- 6%
Industrial Processing	158	14	127	11	- 31	- 20%
Irrigation	63	6	30	3	-33	- 52%
Other	58	5	63	6	+5	+ 9%
	1133	100	1106	100	- 27	

Figure 2. Comparison of Surface Water and Ground Water Use by Category for 1992

Major Use	*Surface Water Use (BG)*	*Ground Water Use (BG)*	*% from Surface Water*	*% from Ground Water*
Power Generation	678	1	»99%	«1%
Public Supply	64	111	37%	63%
Industrial Processing	131	27	83%	17%
Irrigation	17	46	27%	73%
Other	41	17	71%	29%
	931 BG SW Use *82% of Annual Use*	***202 BG GW Use*** *18% Of Annual Use*		

Public Water Supply

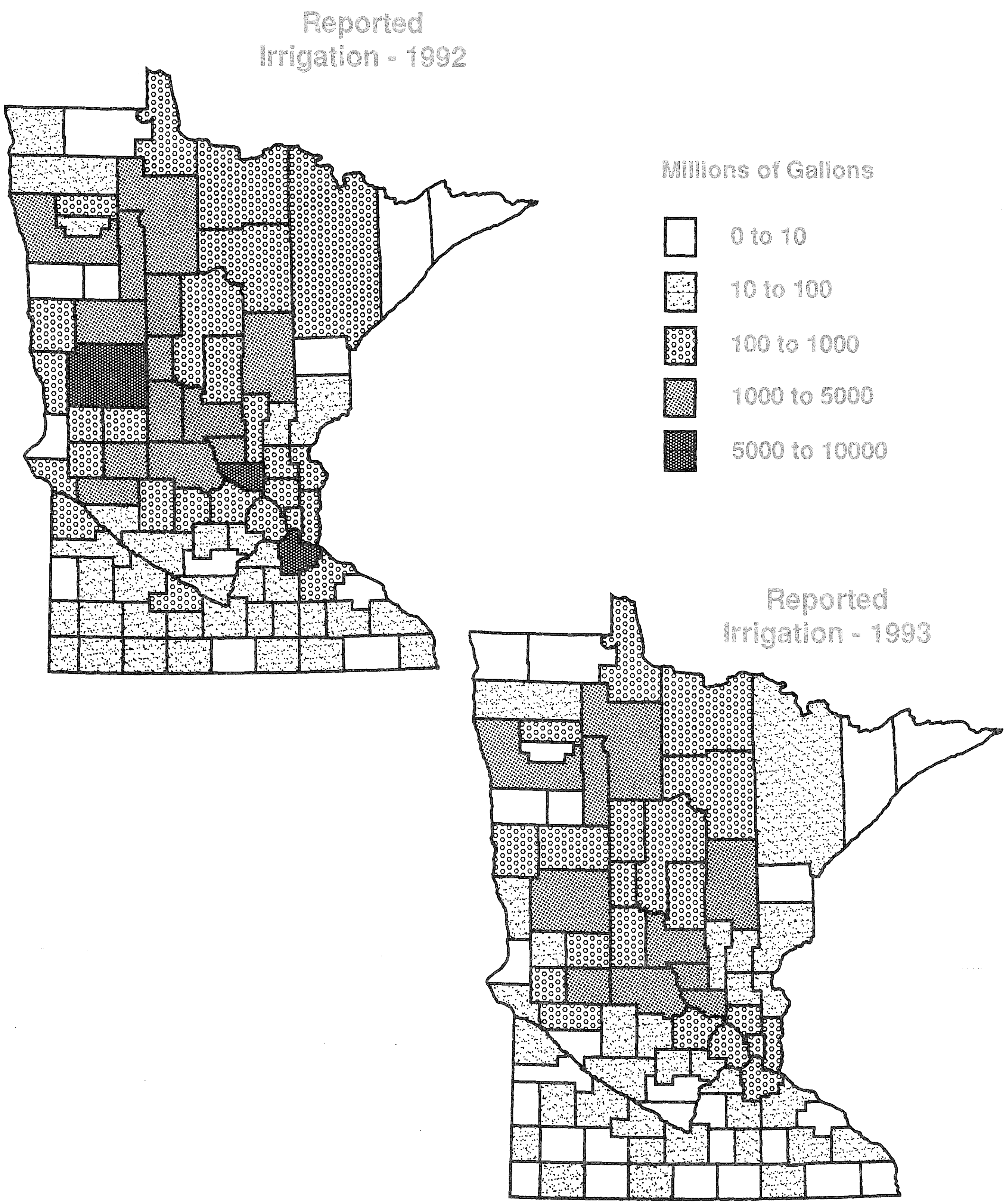
Growth in public water supply from ground water sources has remained approximately the same for the past five years. Ground water tends to be more reliable than many surface water sources and can be more cost effective in areas of population growth. In 1950 ground water accounted for only 34% of public water supply use. By 1970 it had climbed to nearly 50%. Today 65% of public water supply use comes from ground water, compared to 39% nationally (USGS data, 1986-1990). That change may be stabilizing, however.

Overall public supply use should begin to level out more as well. A 1993 law requires all public water suppliers serving more than 1000 people to submit water emergency and conservation plans to the DNR for approval by January 1996. In addition, before increased appropriations or new wells are granted, public water suppliers must now submit demand reduction measures to the DNR for approval. These must include conservation rate structures and public education, e.g., retrofitting of showers and toilets with water-saving devices. We will be following these changes through increased data tracking and analysis.

Irrigation

Water use for irrigation has dropped considerably since the drought of the late 1980's. 1992 irrigation use totalled 63BG, down 40% from the 1988 high of 103 BG. As noted, 1993 use dropped even farther due to heavy rains and cool temperatures, to only 30 BG.

Irrigation accounts for only a small percentage of total water use in Minnesota. However, it is significant in that it is almost entirely consumptive use, the majority from


Reported
Irrigation - 1992
Millions of Gallons
0 to 10
10 to 100
100 to 1000
1000 to 5000
5000 to 10000
Reported
Irrigation - 1993

ground water sources. In a wet year such as 1993, irrigation accounted for 11.3% of total ground water withdrawals. In a dry year, it can exceed 30% of all ground water use. Ground water is the source of 73% of irrigation withdrawals in Minnesota (1992), compared to only 38% nationally (USGS data).

Sherburne and Otter Tail Counties reported the most water use for irrigation in 1992, using 69 BG and 68 BG respectively. Mahnomen and Norman Counties, in the northwest part of the state, use very little water for irrigation. Neither county reported any irrigation use in 1992. Use in counties which irrigate primarily wild rice, such as Clearwater and Aitkin, is more constant from year to year due to their special needs and use of impoundments or paddy systems. As a result, surface water use for irrigation does not change significantly as most wild rice irrigation utilizes surface water sources during spring runoff when water levels are typically high.

Power Generation

Power generation was the primary use for 7 of the 10 counties with the greatest total use in 1992 (Figure 3). Power generation in those counties accounted for 57% of all use in Minnesota for the year. Power generation in Goodhue and Wright Counties alone accounted for 29% of all reported use in that year, largely due to nuclear power plant cooling. Most of this is surface water (withdrawn from rivers) and is almost entirely returned to its source after use.

Figure 3. Appropriation by the 10 Counties with the Greatest Use in CY 1992 *

County	Surface Water	Ground Water	Total	Primary Use
1) Goodhue	180	3	183	Power Generation
2) Wright	144	2	146	Power Generation
3) Washington	102	9	111	Power Generation
4) Hennepin	51	35	86	Power Generation
5) St. Louis	78	1	79	Power Generation
6) Dakota	51	20	71	Power Generation
7) Itasca	56	1	57	Power Generation
8) Ramsey	32	17	49	Power Generation
9) Anoka	40	9	49	Waterworks
10) Cook	41	<1	41	Mining
	775 BG *83% of SW Use*	*97 BG* *48% of GW Use*	*872 BG* *77% of total use*	

* CY 1992 is shown as it is more representative of a typical year

Industrial Processing

Counties whose primary water use in 1993 was for industrial processing include Cook (54.1 BG, mine processing), Koochiching (16.7 BG, paper and pulp processing), Carlton (3.7 BG, paper and pulp processing), Benton (3.4 BG, general industrial), and Lake (3 BG, mine processing). These figures were similar for 1992, with the exception of Lake County, which experienced a dramatic decrease in mine processing.

Other Uses

Other uses include such things as air conditioning, water level maintenance, fisheries use and temporary dewatering for construction. These uses represent only a small piece of Minnesota water use, accounting for approximately 5% per year.

Summary

Total use from 1992 to 1993 remained relatively constant, although ground water use dropped by 19%, due primarily to a reduction in irrigation that year. Power generation continues to account for the majority of use, totalling 722 BG of the 1106 BG for 1993 (>65%). Surface water still accounts for over 80% of all appropriations.

Several efforts are underway which should result in changes in water use trends. These include a redefined priority system to help reduce lower priority uses, the gradual elimination of once-through systems, elimination of ground water use to augment lake levels and the public supply system requirements for emergency and conservation planning described previously (page 63).

Comparison of Minnesota with U.S. data*

Minnesota ranked:

- 35th in total water use
- 20th in ground water use
- 30th in surface water use
- 5th in water use for mining

Percentage of Total Use by Category

	U.S	MN
Power Generation	47	63
Public Supply	9	15
Industrial	6	12
Irrigation	34	5
Other	4	5

* These numbers compare the latest 5-year data (1986-90) from the USGS with Minnesota 1990 data

Reported Water Use 1992 and 1993 (Millions of Gallons)

	1992		1993	
1) POWER GENERATION				
NUCLEAR POWER				
surface	287614.842		290680.605	
ground	0.000		0.000	
OTHER POWER				
surface	390331.684		430228.852	
ground	1054.837		1077.953	
Subtotals	679001.363	60% of total	721987.410	65% of total
surface	677946.526		720909.457	
ground	1054.837		1077.953	
2) PUBLIC SUPPLY				
MUNICIPAL WATER WORKS				
surface	63751.064		58955.542	
ground	107699.845		101342.940	
PRIVATE WATER WORKS				
surface	1.967		2.649	
ground	923.793		836.237	
COMMERCIAL & INSTITUTIONAL				
surface	0.000		0.000	
ground	2438.416		2108.659	
COOPERATIVE WATERWORKS				
surface	0.000		0.000	
ground	130.143		143.050	
FIRE PROTECTION				
surface	0.000		0.000	
ground	30.951		568.356	
STATEPARKS, WAYSIDES, REST AREAS				
surface	0.000		0.000	
ground	23.984		25.099	
Subtotals	175000.163	15% of total	163982.532	15% of total
surface	63753.031		58958.191	
ground	111247.132		105024.341	

	1992		1993	
3) IRRIGATION				
GOLF COURSE IRRIGATION				
surface	716.857		415.101	
ground	3300.231		2383.936	
CEMETERY IRRIGATION				
surface	0.000		0.000	
ground	39.966		18.234	
LANDSCAPING IRRIGATION				
surface	37.368		30.165	
ground	271.155		209.033	
SOD IRRIGATION				
surface	8.787		4.331	
ground	57.219		18.238	
NURSERY IRRIGATION				
surface	22.044		25.962	
ground	275.147		198.448	
ORCHARD IRRIGATION				
surface	5.428		0.083	
ground	2.552		0.000	
NON CROP IRRIGATION				
surface	27.533		11.541	
ground	31.375		1.435	
MAJOR CROP IRRIGATION				
surface	4991.262		797.871	
ground	42073.480		15751.973	
WILD RICE IRRIGATION				
surfac	11357.958		10310.261	
ground	0.000		0.000	
Subtotals	63218.362	6% of total	30176.612	3% of total
surface	17167.237		11595.315	
ground	46051.125		18581.297	

	1992		1993	
4) INDUSTRIAL PROCESSING				
AGRICULTURAL PROCESSING				
surface	443.532		645.085	
ground	11656.014		10481.511	
PULP & PAPER PROCESSING				
surface	44405.133		26411.433	
ground	892.705		812.114	
MINE PROCESSING				
surface	68525.405		68020.603	
ground	33.508		31.759	
SAND & GRAVEL WASHING				
surface	2224.375		2523.086	
ground	715.451		786.730	
SEWAGE TREATMENT				
surface	1.526		1.139	
ground	1073.889		1202.833	
PETROLEUM OR CHEMICAL PROCESSING				
surface	0.000		489.716	
ground	3082.505		3009.322	
METAL PROCESSING				
surface	0.000		0.000	
ground	847.777		843.727	
NON-METAL PROCESSING				
surface	1.910		0.737	
ground	929.277		843.902	
OTHER INDUSTRIAL PROCESSING				
surface	15497.914		5078.200	
ground	8113.256		5450.801	
Subtotals	158444.177	14% of total	126632.698	11% of total
surface	131099.795		103169.999	
ground	27344.382		23462.699	

5) OTHER

	1992	1993
COMMERCIAL BUILDING AIR COND. (A/C)		
surface	0.000	0.000
ground	293.800	171.123
INSTITUTIONS; SCHOOLS, HOSPITALS (A/C)		
surface	0.000	0.000
ground	3.760	2.921
HEAT PUMPS		
surface	7.397	7.304
ground	0.000	0.000
COOLANT PUMPS		
surface	808.976	628.597
ground	95.897	116.047
DISTRICT HEAT		
surface	0.000	0.000
ground	59.023	60.579
ONCE THROUGH HEATING OR A/C		
surface	0.000	0.000
ground	5559.211	5384.331
OTHER A/C		
surface	89.700	155.500
ground	1.900	1.200
TEMPORARY CONSTRUCTION NON-DEWATERING		
surface	1616.813	11.575
ground	3.000	8.555
TEMPORARY CONSTRUCTION DEWATERING		
surface	412.921	354.670
ground	1541.970	994.096
TEMPORARY PIPELINE AND TANK TESTING		
surface	21.529	8.155
ground	13.060	20.360
OTHER TEMPORARY		
surface	0.000	0.000
ground	0.000	30.432
BASIN (LAKE) LEVEL MAINTENANCE		
surface	1485.737	2397.185
ground	263.672	143.470

	1992		1993	
MINE DEWATERING				
surface	16747.030		21210.740	
ground	0.000		0.000	
QUARRY DEWATERING				
surface	10762.126		11497.442	
ground	0.000		0.000	
SAND/GRAVEL PIT DEWATERING				
surface	279.881		181.998	
ground	0.000		0.000	
TILE DRAINAGE & PUMPED SUMPS				
surface	153.554		179.343	
ground	0.000		0.000	
OTHER WATER LEVEL MAINTENANCE				
surface	2010.494		2964.900	
ground	1454.200		313.300	
POLLUTION CONFINEMENT				
surface	0.144		0.000	
ground	6183.246		7076.619	
HATCHERIES & FISHERIES				
surface	5704.227		6964.836	
ground	904.784		996.589	
SNOW MAKING				
surface	86.213		95.293	
ground	201.000		285.165	
PEAT FIRE CONTROL				
surface	0.000		0.000	
ground	1.201		0.823	
OTHER SPECIAL CATAGORIES				
surface	490.869		496.000	
ground	22.900		50.100	
Subtotals	57508.635	5% of total	62972.548	6% of total
surface	40747.911		47158.038	
ground	16760.724		15814.510	

GRAND TOTALS OF REPORTED WATER USE 1992 - 1993 (Millions of Gallons)

	1992	1993
TOTALS	1133172.700	1105751.800
surface	930714.500	941791.000
ground	202458.200	163960.800

Reported Water Use by County 1992 - 1993 (Millions of Gallons)

REPORTED PUMPAGE

	County	1992 Surface	1992 Ground	1992 Total	1993 Surface	1993 Ground	1993 Total	Primary Use(s)	% of 1993Total
1	AITKIN	1682.059	123.898	1805.957	1539.621	155.002	1694.623	Wild Rice Irrigation	89
2	ANOKA	39500.201	9432.787	48932.988	33961.739	8375.329	42337.068	Municipal Waterworks	96
3	BECKER	15.577	1591.901	1635.478	5.247	947.202	952.449	Municipal Waterworks	54
								Major Crop Irrigation	34
								Wild Rice Irrigation	66
4	BELTRAMI	1589.191	663.971	2253.162	1554.449	683.975	2238.424	Municipal Waterworks	23
								Industrial Processing	65
5	BENTON	3513.545	2669.623	6183.168	3410.440	1785.117	5195.557	Major Crop Irrigation	22
								Municipal Waterworks	65
6	BIG STONE	24.101	404.502	428.603	7.693	254.943	262.636	Major Crop Irrigation	27
								Steam Power Once Through	59
7	BLUE EARTH	6403.352	4044.170	10447.522	5323.685	4092.943	9416.628	Municipal Waterworks	20
8	BROWN	147.683	517.628	665.311	128.726	357.230	485.956	Municipal Waterworks	57
								Mine Dewatering	19
9	CARLTON	3082.633	518.654	3601.287	3923.974	656.065	4580.039	Pulp & Paper Processing	81
10	CARVER	8.608	1910.101	1918.709	25.193	1832.699	1857.892	Municipal Waterworks	81
								Hatcheries & Fisheries	32
11	CASS	145.114	910.018	1055.132	61.996	687.128	749.124	Municipal Waterworks	29
12	CHIPPEWA	2121.894	338.703	2460.597	3525.229	338.703	3859.302	Steam Power Cooling	90
13	CHISAGO	78.564	740.321	818.885	58.261	656.919	715.180	Municipal Waterworks	71
14	CLAY	1038.520	1193.904	2232.424	921.295	1069.212	1990.507	Municipal Waterworks	82
15	CLEARWATER	4690.640	131.360	4822.000	3859.836	113.234	3973.070	Wild Rice Irrigation	96
16	COOK	41295.082	3.991	41299.073	54231.033	4.337	54235.370	Mine Processing	≈100
17	COTTONWOOD	69.615	722.860	792.475	88.127	728.788	816.915	Municipal Waterworks	60
								Pulp & Paper Processing	47
18	CROW WING	1372.213	1453.867	2826.080	1239.336	1219.836	2459.172	Municipal Waterworks	36
19	DAKOTA	50870.133	20276.098	71146.231	64133.779	14079.926	78213.705	Steam Power Cooling	78
20	DODGE	17.546	332.591	350.137	9.150	316.555	325.705	Municipal Waterworks	97
21	DOUGLAS	107.754	1070.700	1178.454	182.429	931.573	1114.002	Municipal Waterworks	51
								Hatcheries & Fisheries	21
22	FARIBAULT	0.000	743.381	743.381	0.000	617.240	617.240	Municipal Waterworks	76
23	FILLMORE	3470.898	518.687	3989.585	4552.087	561.442	5113.529	Hatcheries & Fisheries	89
								Municipal Waterworks	63
24	FREEBORN	36.963	2735.391	2772.354	1.578	2389.050	2390.628	Agricultural Processing	37
25	GOODHUE	180366.374	2675.493	183041.867	186809.563	2191.024	189000.587	Nuclear Power Plant	91
26	GRANT	0.000	518.595	518.595	0.000	247.220	247.220	Municipal Waterworks	67
								Major Crop Irrigation	28
27	HENNEPIN	51479.798	34856.843	86336.641	59446.971	31511.231	90958.202	Steam Power Cooling	63
								Municipal Waterworks	25
28	HOUSTON	278.200	525.208	803.408	329.621	538.896	868.517	Hatcheries & Fisheries	44
								Municipal Waterworks	42
29	HUBBARD	14.825	2596.306	2611.131	10.122	1500.176	1510.298	Major Crop Irrigation	56
								Agricultural Processing	20
30	ISANTI	1.260	608.305	609.565	1.525	517.181	518.706	Municipal Waterworks	54
31	ITASCA	56416.237	807.855	57224.092	70509.717	786.811	71296.528	Agricultural Processing	27
								Steam Power Cooling	85
32	JACKSON	157.445	249.039	406.484	24.483	246.213	270.696		
33	KANABEC	4.723	174.603	179.326	14.865	135.469	150.334	Municipal Waterworks	87
34	KANDIYOHI	482.765	1915.957	2398.722	493.652	1452.992	1946.644	Municipal Waterworks	82
								Municipal Waterworks	67
35	KITTSON	141.193	254.562	395.755	299.039	185.488	484.527	Hatcheries & Fisheries	24
								Agricultural Processing	62
36	KOOCHICHING	21110.779	40.514	21151.293	17161.149	42.175	17203.324	Cooperative Waterworks	29
37	LAC QUI PARLE	26.552	1073.531	1100.083	2.167	964.915	967.082		
								Pulp & Paper Processing	97
38	LAKE	42161.086	0.107	42161.193	3713.790	0.110	3713.900	Agricultural Processing	64
								Municipal Waterworks	29
39	LAKE of							Mine Processing	82
	the WOODS	279.057	84.797	363.854	267.709	88.822	356.531	Wild Rice Irrigation	75
40	LE SUEUR	2825.871	1077.259	3903.130	2684.942	829.336	3514.278	Municipal Waterworks	25
								Mine Dewatering	44
								Sand & Gravel Washing	26

Reported Water Use by County 1992 - 1993 (Millions of Gallons)

REPORTED PUMPAGE

	County	1992 Surface	1992 Ground	1992 Total	1993 Surface	1993 Ground	1993 Total	Primary Use(s)	% of 1993 Total
41	LINCOLN	5.118	450.069	455.187	2.585	402.688	405.273	Municipal Waterworks	99
42	LYON	2.585	1347.875	1431.726	79.169	1379.480	1458.649	Municipal Waterworks	92
43	McLEOD	144.052	2123.759	2267.811	135.319	1723.051	1858.370	Municipal Waterworks	54
								Agricultural Processing	34
44	MAHNOMEN		84.677	84.677	0	93.996	93.996	Municipal Waterworks	100
45	MARSHALL	54.542	179.500	234.042	38.812	203.134	241.946	Municipal Waterworks	94
46	MARTIN	10152.090	425.131	10577.221	8936.630	195.842	9132.472	Steam Power Cooling	92
47	MEEKER	119.416	990.994	1110.410	76.306	675.765	752.071	Municipal Waterworks	64
48	MILLE LACS	14.216	489.024	503.240	36.479	454.200	490.679	Municipal Waterworks	78
								Major Crop Irrigation	63
49	MORRISON	126.857	3226.351	3353.208	52.603	2045.511	2098.114	Municipal Waterworks	28
50	MOWER	24.837	2167.928	2192.765	1.111	2113.426	2114.537	Municipal Waterworks	58
								Agricultural Processing	40
51	MURRAY	12.532	195.852	208.384	21.809	200.541	222.350	Municipal Waterworks	90
52	NICOLLET	115.088	1843.772	1958.860	51.315	1868.988	1920.303	Municipal Waterworks	90
53	NOBLES	58.604	1014.610	1073.214	102.566	1061.116	1163.682	Municipal Waterworks	91
54	NORMAN	10.440	141.603	152.043	0.000	142.889	142.889	Municipal Waterworks	99
55	OLMSTED	67.452	5484.831	5552.283	112.666	5182.163	5294.829	Municipal Waterworks	82
56	OTTER TAIL	7509.062	7555.309	15064.371	15399.141	3119.211	18518.352	Steam Power Cooling	78
								Wild Rice Irrigation	81
57	PENNINGTON	778.286	23.945	802.231	818.422	24.643	843.065	Municipal Waterworks	48
58	PINE	7.002	443.899	450.901	2.604	412.862	415.466	Municipal Waterworks	89
59	PIPESTONE	1.957	404.905	406.862	1.996	406.595	408.591	Municipal Waterworks	96
								Wild Rice Irrigation	47
60	POLK	4155.622	636.813	4792.435	4412.456	583.106	4995.562	Municipal Waterworks	45
61	POPE	58.641	3940.555	3999.196	46.035	2150.041	2196.076	Major Crop Irrigation	90
								Steam Power Cooling	56
62	RAMSEY	31828.927	17582.177	49411.104	31910.679	17422.574	49333.253	Municipal Waterworks	23
63	RED LAKE	47.557	196.886	244.443	14.193	172.208	186.401	Municipal Waterworks	90
64	REDWOOD	71.412	463.986	535.398	201.204	429.843	631.047	Municipal Waterworks	65
								Mine Dewatering	24
65	RENVILLE	26.501	464.328	490.829	16.413	451.484	467.897	Municipal Waterworks	88
66	RICE	103.214	2147.334	2250.548	103.886	2082.538	2186.424	Municipal Waterworks	85
67	ROCK	20.715	785.270	805.985	18.720	810.621	829.341	Municipal Waterworks	95
68	ROSEAU		320.139	320.139		319.659	319.659	Municipal Waterworks	100
69	ST. LOUIS	77681.165	1660.037	79341.202	96209.293	1557.520	97766.813	Steam Power Cooling	54
								Mine Dewatering	19
								Quarry Dewatering	52
70	SCOTT	1917.346	2929.451	4846.797	3074.544	2776.203	5850.747	Municipal Waterworks	32
71	SHERBURNE	26072.458	7628.960	33701.418	28116.418	3828.575	31944.993	Steam Power Cooling	79
72	SIBLEY	17.625	489.934	507.559	13.504	479.329	492.833	Municipal Waterworks	85
73	STEARNS	3238.052	6664.637	9902.689	2836.498	3860.206	6696.704	Municipal Waterworks	57
								Major Crop Irrigation	20
74	STEELE	331.783	1647.530	1979.313	390.142	1647.530	1918.321	Municipal Waterworks	74
75	STEVENS	79.026	1323.269	1402.295	89.071	595.947	685.018	Municipal Waterworks	46
76	SWIFT	14.220	2781.395	2795.615	0.000	641.258	641.258	Major Crop Irrigation	59
								Municipal Waterworks	40
77	TODD	180.081	2089.861	2269.942	45.138	1143.074	1188.212	Major Crop Irrigation	57
								Municipal Waterworks	35
78	TRAVERSE	2.045	153.860	155.905	1.588	146.809	148.397	Municipal Waterworks	99
79	WABASHA	8.543	968.864	977.407	8.337	866.420	874.757	Municipal Waterworks	78
								Major Crop Irrigation	68
80	WADENA	363.726	1563.930	1927.656	126.212	894.691	1020.903	Municipal Waterworks	31
81	WASECA	29.377	827.386	856.763	29.100	742.717	771.817	Municipal Waterworks	95
82	WASHINGTON	101621.975	10035.063	111657.038	103577.205	9477.654	113054.859	Steam Power Cooling	87
83	WATONWAN	6.601	809.247	815.848	2.502	739.939	742.441	Municipal Waterworks	98
84	WILKIN	101.391	243.176	344.567	34.940	187.364	222.304	Municipal Waterworks	77
								Major Crop Irrigation	22
85	WINONA	1072.984	2594.209	3667.193	1137.661	2457.777	3595.438	Municipal Waterworks	46
								Hatcheries & Fisheries	33
86	WRIGHT	144054.256	1783.077	145837.333	119268.461	1438.920	120707.381	Nuclear Power Plant	98
87	YELLOW MEDICINE	55.292	208.537	263.829	43.311	193.000	236.311	Municipal Waterworks	76