DROUGHT OF 1988

Star Tribune May 4, 1988

High winds, dry April sparking fears of drought across state

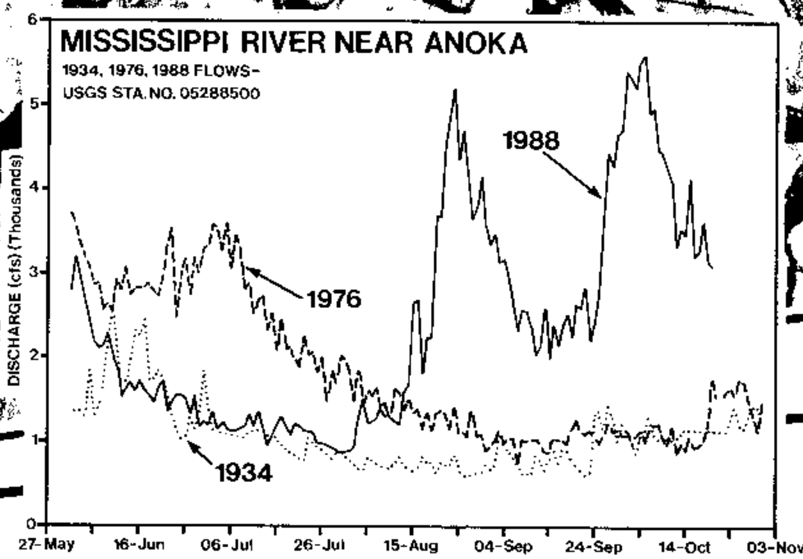
By Sharon Schmickle
and Bob Franklin
Staff Writers

High winds on the heels of a very dry April are sweeping away topsoil, igniting fields and forests and r... fears of a ...

the summer, some of central and northern Minnesota would be vulnerable to drought because the dryness goes deep into the soil, state climat... ...aid Tues-

of grass growing for lawn seed have dried up. And fields have lost tons of topsoil this week.

"It's almo...



Minnesota
DEPARTMENT OF NATURAL RESOURCES

Division of Waters

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ACKNOWLEDGEMENTS

The 1988 drought broke long-standing records; strained water use controversies; enhanced public concern about water resources; and generally challenged the energies, talents and perseverance of water managers and the public at large.

Little can be done to manage natural disasters such as the recent drought, however impacts can be managed and minimized. Although drought impacts are very damaging to some industries and the environment, it also creates the opportunity to learn and improve our future ability to manage such crises.

The opportunities presented by the 1988 drought could only be capitalized on through the close cooperation and coordination among a variety of agencies and interest groups. The following organizations deserve recognition for their performance and commitment during 1988:

- U.S. Army Corps of Engineers
- U.S. Geological Survey
- National Weather Service
- Agricultural Stabilization and Conservation Service
- Department of Agriculture
- Department of Public Safety, Division of Emergency Management
- Department of Transportation
- Pollution Control Agency
- Soil and Water Conservation Districts throughout the state
- Metropolitan Waste Control Commission
- Agricultural Extension Service - University of Minnesota
- St. Paul Public Works Department
- Minneapolis Public Works Department
- Northern States Power
- Minnesota Resort Association

The preparation of this report was truly a team effort among various Divsion of Waters staff. Contributors include:

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- Felicia White - word processing
- Jim R. Zicopula - cover design

INTRODUCTION

Certain Minnesota weather-related events are memorable:

- the Dust Bowl years of the 1930's;
- the 1940 Armistice Day blizzard;
- the 1965 and 1969 floods along the Minnesota and Mississippi Rivers and their major tributaries; and
- the July 23, 1987 "super storm" that hit the Twin Cities.

1988 will be remembered as the Year of the Drought. Daily television and radio broadcasts regarding sprinkling bans, low water levels and dry fields were constant reminders of the severity of the drought. The following facts illustrate why the summer of 1988 will also be memorable:

- June precipitation averaged 1.40 inches statewide, replacing the old record low of 1.50 inches set in 1910.
- Minnesota April through July precipitation at 6.61 inches was the second driest in the last 100 years.
- May through August average temperature at 69.7 degrees was nearly 2 degrees higher than the old record set in 1936.
- Minneapolis-St. Paul Airport had 44 days with 90 degrees or more. The old record had been 36 days in 1936.
- The Palmer Drought Index dropped below -7 in northwest Minnesota for the first time since record keeping began at the turn-of-the-century. The old record had been -6 in September 1934.
- At St. Paul, the April through July period experienced about 20 percent more solar radiation than the station's long-term average. The May through July pan evaporation was 40 percent above average.
- Groundwater levels throughout the state reached new record low levels.
- The Mississippi River at St. Paul reached low levels previously experienced only in 1934 and 1976, prompting the first total sprinkling ban in Minneapolis and St. Paul.

Definition of drought

Climatologists define drought as a period of abnormally dry and/or unusually hot weather sufficiently prolonged for the corresponding deficiency of water to cause a "serious hydrologic imbalance". More simply put, too dry and/or too hot for too long. Interpreting what is "too dry" or what is "too long" is difficult. What we do know is that when a serious hydrologic imbalance occurs in Minnesota, soil moisture reserves, groundwater supplies, lake levels and stream flows are negatively influenced. Water dependent industries, including agriculture, public utilities, forestry and tourism, are profoundly affected.

During the summer of 1988, numerous public agencies pushed aside normal work activities to concentrate on the drought. The DNR Division of Waters (DOW) spent a hectic summer coordinating the Governor's Drought Task Force; responding to citizen and media inquiries; monitoring streamflow, lake and groundwater levels; suspending surface water irrigation permits in 13 watersheds; and investigating well interference complaints. The DOW also saw the requests for "works-in-the-bed" permits increase dramatically as low water levels caused navigational access problems for many lakeshore owners.

We can say with certainty that drought will return to Minnesota, though we can't say when or how severe it will be. Five years from now we will no doubt recall that a total sprinkling ban was established in the Twin Cities, but will we remember that the ban did not begin until August 1 and lasted only 17 days? Will we remember what criteria were used to set and then rescind the sprinkling ban, or at least be able to readily obtain that information?

Report purpose

The purpose of this report is to:

- Compile a summary of what happened during the 1988 drought - weather, water levels and administrative actions;
- Collect and publish miscellaneous data which might otherwise be lost;
- Provide a word of caution - by some measures of dryness, the drought is not necessarily over; and
- Offer recommendations for future action.

This report is primarily intended as a technical document. This document is clearly not all-encompassing with regard to the drought of 1988 and its short- and long-term impacts. Other groups are examining such issues as the Minneapolis water supply, headwater reservoir operation and water appropriation priorities.

IMPACTS

It's difficult to imagine anyone in Minnesota not affected by the drought of 1988 - from farmers who lost most, if not all, of last year's crop, to the urban dweller affected by water use restrictions. The drought also affected power production, the forest products industry, public water supplies, and fish and wildlife dependent on adequate surface water. Tourism was one industry that generally fared well during this drought.

AGRICULTURE

The most devastating impacts of the drought were felt by the state's agriculture community. The "Catch-22" for farmers continued one more year. Despite generally high yields, farm incomes have been depressed the past several years due to low commodity prices. In 1988, commodity prices rose substantially but yields were low. In addition to lost production, the hot, dry weather and strong winds resulted in valuable topsoil being blown into road ditches, streams, lakes and other depressions.

Preliminary data from the Minnesota Agricultural Statistical Service show a dramatic decrease in production from previous years, as shown below:

Average Yields (bushels per acre)

	1983	1984	1985	1986	1987	1988
corn	84	107	115	115	122	72
soybeans	33	33	32	35	39	25
wheat	37	47	53	37	41	23
oats	57	65	70	51	57	33
barley	53	65	66	55	57	32

The loss of farm production has an obvious ripple effect on the state's economy. Particularly hard hit are the rural communities throughout Minnesota's farm belt. An estimate submitted with the Governor's request for federal disaster assistance put the loss to the state's economy at $1.2 billion.

Not all farms were affected equally. The Minneapolis Star Tribune (10/23/88) reported on the vastly different experiences of two farmers in Dodge County. One of the farmers ended with average yields of 50 bushels of corn and 14 bushels of soybeans per acre. These yields were substantially lower than 1987 yields of 120 bushels of corn and 42 bushels of soybeans per acre. Meanwhile, a neighbor just 10 miles away had one of the best harvests in 40 years. A late season snowstorm and perfectly timed rainfall (7 inches over 4 days) in early July resulted in corn yields of 165 bushels per acre.

FOREST RESOURCES

The state's forest resources also suffered from the drought. An estimated 66,000 acres of trees were planted in Minnesota during 1987 and 1988. DNR Division of Forestry estimates that 47 percent, or 31,000 acres, were affected by the drought. The largest amount of drought-affected trees are located on Conservation Reserve Program (CRP) acres in central Minnesota. Eighty percent of the estimated 3.5 million Christmas trees planted in 1987 and 1988 are lost.

Applied herbicides were ineffective for controlling competing vegetation and the severely depleted soil moisture has placed additional stress on surviving seedlings. Therefore the 1987 - 1988 seedlings are much more susceptible to insect and disease damage; the full impact of which may not be known for years to come.

In addition to seedlings, many thousands of mature trees in both forested and urban areas are being lost due to a lack of moisture. These losses are expected to continue for three to five years beyond the end of the drought. Even if the drought ends, most of the trees will have been weakened and will remain highly susceptible to insect and disease damage for several more years.

POWER PRODUCTION

The drought created problems for thermoelectric power generating plants as well. The Northern States Power (NSP) plant at Monticello suffered periodic power production losses of as much as 160 megawatts due to cooling problems. These losses were caused by a combination of water quality, water temperature and streamflow deficiences. During the peak power demand period, NSP purchased approximately 25 percent of the electrical demand, costing their customers a total of $422,000.

NSP officials concluded that the extent of the 1988 limitations caused by regulatory limitations of cooling water withdrawals from the Mississippi River were tolerable. However, any condition, whether physical or regulatory, that would cause the shutdown of both Monticello and Sherco under 1988 peak demand conditions would create power shortages for customers and could cause severe electrical equipment damage.

PUBLIC WATER SUPPLY

The vast majority of Minnesota communities rely on groundwater to supply domestic needs. Since groundwater levels were not as dramatically affected as surface water, there were few actual shortages.

The Wayside Housing Addition in Haven Township near St. Cloud had their wells go dry. The National Guard provided emergency water supply to the community during the summer months. An investigation by the DOW's Groundwater Unit to assess the availability of additional groundwater resources concluded that there was inadequate groundwater potential to provide a reliable long-term source of domestic water. It was recommended that the Wayside Addition connect into the St. Cloud water supply system.

The city of Granite Falls obtains its domestic water supply from the Minnesota River. In anticipation of continuing diminished flow, the city requested permission from the DNR to increase storage in the city's reservoir, in effect diverting additional water from the Minnesota River. This request was denied due to downstream concerns.

The city of Stephen in extreme northwestern Minnesota was also concerned about low water levels in their water supply source, the Tamarac River. The city proceeded to purchase up to seven million gallons of water from a nearby rural water system. The Department of Public Safety, Division of Emergency Management has agreed to reimburse the city for the cost of the water, up to $17,500. The city is responsible for all construction and material costs.

The most discussed issue of public water supply concerned the Twin Cities metropolitan area. Restrictions on nonessential uses were instituted area wide. Restrictions were partly due to the distribution systems not being able to handle the demand and also due to low flow on the Mississippi River. Especially in the metropolitan area, the drought dramatically demonstrated the continuing need for conservation measures to reduce water demand and also the need for alternative water supplies.

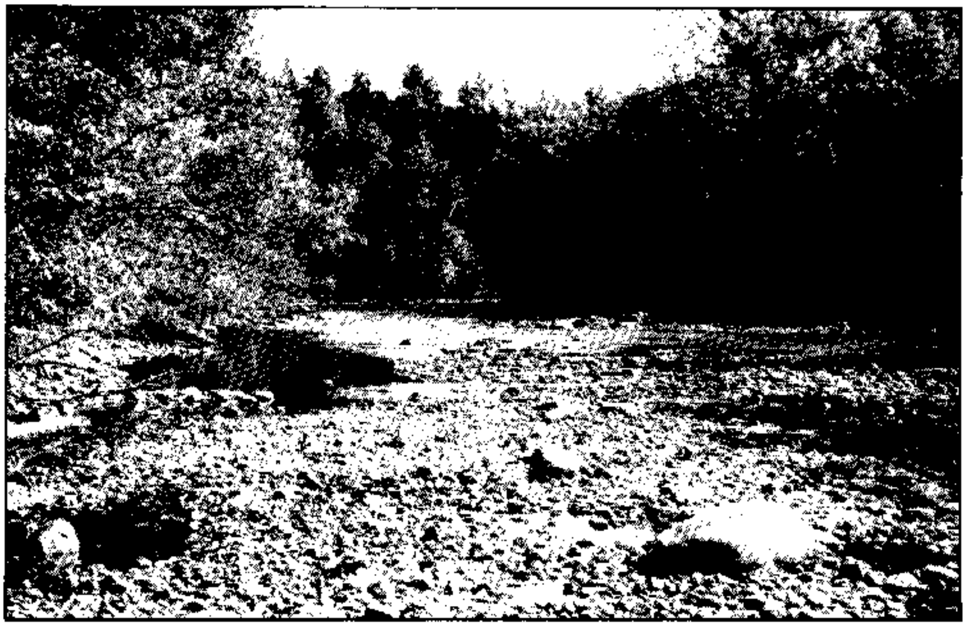
INSTREAM FLOW

The effects of the extremely low streamflow on aquatic biological resources are unclear. DNR field crews noted large areas of dry or nearly dry river channels. However, large numbers of fish were found in remaining pools indicating that at least some of the resident populations were able to migrate to refuge areas. Other fauna, such as benthic organisms, are less mobile and presumably suffered larger losses due to the dewatering of habitat (see photograph on page 6).

Much attention was paid to the low flow of the Mississippi River through the Twin Cities. Of particular concern was the water quality of the river downstream from the Metropolitan Wastewater Treatment Plant at Pigs Eye. The principal water quality standard monitored by the Pollution Control Agency is dissolved oxygen (D.O.) with a target value of greater than 5 mg/l.

During the summer of 1988, the PCA and Metropolitan Waste Control Commission conducted extensive monitoring of the Mississippi River. They concluded that the dissolved oxygen levels in the Mississippi River held up very well considering the low flow and upstream problems caused by the Minnesota River. Dissolved oxygen concentrations in the

Minnesota River ranged from 3 to 4 mg/l. On the average during the low flow period, the 5 mg/l D.O. standard was met downstream of the Metro plant, in part due to aeration of the effluent and improved operation of the treatment plant.



Pine River below the Cross Lake dam in Crow Wing County, July 1988
Photograph courtesy of Patricia Olson.

TOURISM

The drought did not appear to hurt the tourism industry. While some resorts and outfitters experienced problems due to low water levels, overall the tourism industry did better than average during 1988.

The Minnesota Office of Tourism conducted an informal survey of 44 motel/hotel, resort and campground owners. Sixty-four percent indicated that business improved over the previous summer, 11 percent indicated a decline of business while 25 percent said it stayed the same.

Many respondents mentioned that increased advertising and promotion helped increase their business. There was generally no indication as to whether the weather helped or hurt their business. The Office of Tourism concluded that the weather may have helped the motel/hotels and resorts but probably hurt campground operators.

Minnesota state parks had similar experiences. Visitors at state parks increased 12 percent over 1987. However, camping was up only 4 percent over the previous year. Large increases were noted in those parks with any type of water attraction.

CHRONOLOGY

THE WET YEARS

During the 10 year period from 1977 to 1986, Minnesota experienced some of the wettest conditions on record. The surplus was the equivalent of two additional years of normal precipitation. Then with extraordinary speed and magnitude, the climate reversed itself beginning in October of 1986. Figure 3.1 shows the 5-year precipitation departure from normal up to the end of the wet cycle.

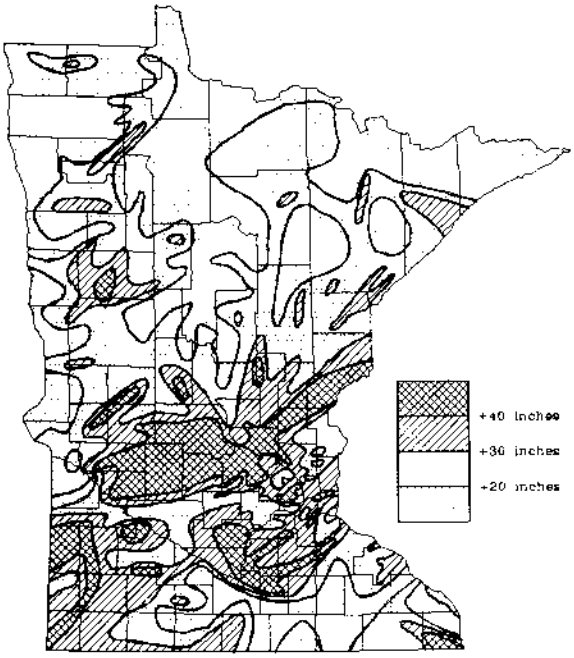


Figure 3.1
1982 - 1986 Precipitation Departure from Normal

During the mid-1980's, flooding was the major water-related concern in Minnesota. Dozens of landlocked lakes rose to high levels flooding hundreds of lakeshore homes and cabins. Lake Pulaski in Wright County, undoubtedly the most publicized, rose 5.9 feet from 1983 to a peak level in September 1986. At a cost of $1.4 million, the U. S. Army Corps of Engineers (COE) sponsored the construction of a pumping system to alleviate the high levels on Lake Pulaski. Pumping commenced on February 4, 1987 and continued for two months lowering the lake 2.8 feet to its control elevation. Lake Pulaski has since dropped an additional 3.4 feet.

Palmer Drought Severity Index

The National Weather Service Climate Analysis Center (CAC) in Washington D. C. quantifies drought using a water budgeting technique called the Palmer Drought Severity Index. This index classifies drought on a five level scale ranging from "incipient drought" (initial stages of drought) to "extreme drought". This technique allows relative comparisons from place to place and from year to year. For example, an "extreme drought" classification in northwestern Minnesota can be thought to have similar implications to an "extreme drought" in say, northern Georgia or western Kansas. The U.S. Department of Agriculture uses this index to make policy decisions regarding its various agricultural programs. As shown in Figure 3.2, the Palmer Drought Severity

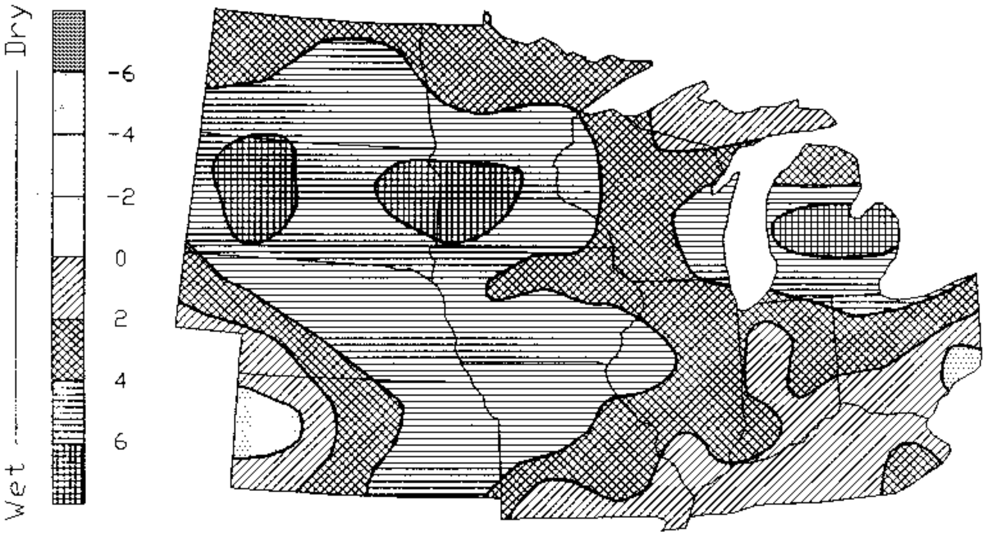


Figure 3.2
Palmer Drought Severity Index - November 1986

Index for the fall of 1986 indentified very wet conditions throughout the upper midwest.

1987

The winter of 1986-1987 was one of the warmest and driest in Minnesota's recorded history. Temperatures averaged as much as 12 degrees above normal from December through February. Many areas were virtually snow-free all winter.

Dry and warm conditions persisted through spring and early summer of 1987. Early season grass fires were more frequent than usual, lake levels dropped from the previous year's near-record high levels, and agricultural areas with sandy soils suffered from moisture stress. In early to mid-

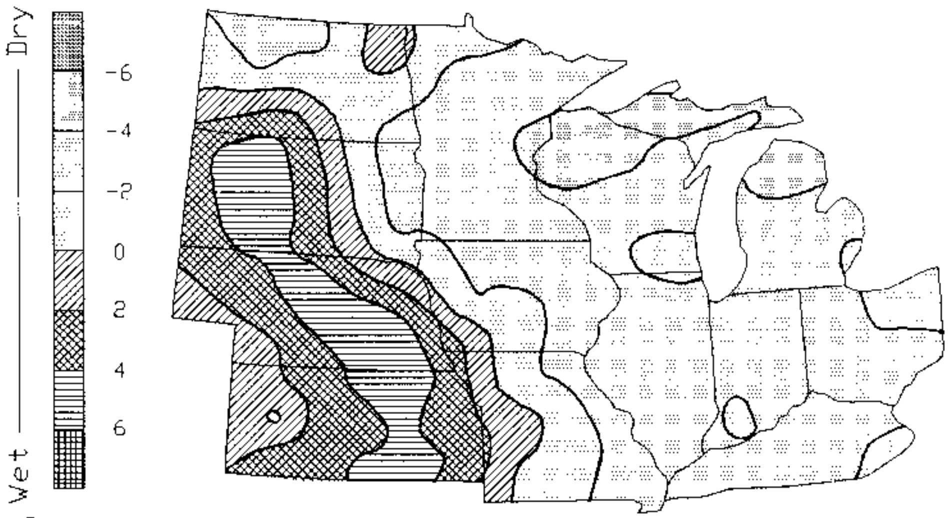


Figure 3.3
Palmer Drought Severity Index - June 1987

summer, calculated levels of drought intensity reached the extreme (or worst) category in east central Minnesota (Figure 3.3).

In July 1987, adequate to excessive rains and stored soil moisture reserves from the previous year supported high agricultural yields in most areas and helped to alleviate late season fire danger. The Twin Cities metro area experienced two spectacular yet geographically isolated rainfall events in July. The two-storm total exceeded 16 inches at some urban locations.

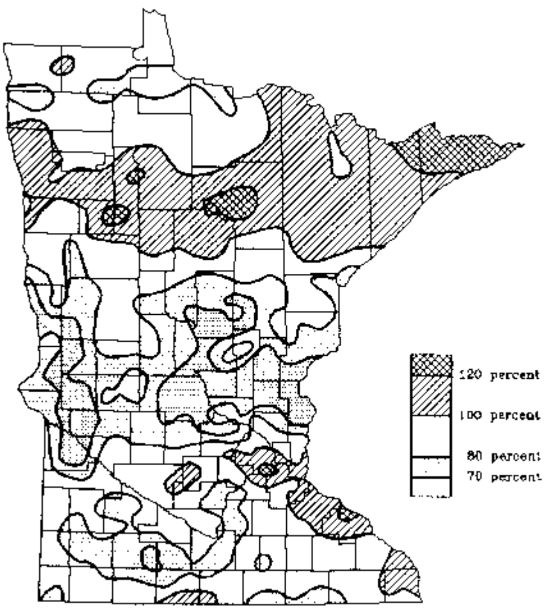


Figure 3.4
Percent of Normal Precipitation
(April 1 - September 30, 1987)

While the drought was not part of the public consciousness in the Twin Cities following the July storms, most of Minnesota continued in prevailing dryness. Near normal to somewhat below normal precipitation persisted through the late summer and fall, failing to provide adequate late season soil moisture recharge. A large portion of Minnesota was four to eight inches of precipitation below the long-term average (Figure 3.4). The drought intensity for late fall of 1987 was calculated to be moderate to severe in northwest, west central and central Minnesota.

The winter of 1987-1988 gave mixed results. Various parts of the state experienced episodes of warmth, extreme cold, dryness, and heavy snows - in other words, a typical Minnesota winter. On the average only 15 percent of winter precipitation enters the soil moisture profile. Most evaporates or runs off the frozen soil to replenish surface waters. Even average winter precipitation would have done little to alleviate soil moisture deficits heading into 1988.

1988

The 1988 growing season began with a soil moisture deficit in all but north central and northeastern Minnesota. April is typically a period of recharge when soil moisture reserves are replenished and little water is drawn from the soil by vegetation. April precipitation provides moisture for germinating seeds and rejuvenating perennial plants. Unfortunately, much like April of 1987, April of 1988 was extraordinarily dry.

Most of the state received below normal precipitation. The northern two-thirds of Minnesota reported less than 50 percent of the norm. Some locations in the northwest reported only a trace of precipitation for the month, making it their driest April on record. Blowing dust in the Red River Valley created scenes reminiscent of the Dust Bowl years. Grassland fires were again a problem, surface water levels continued to retreat, and perennial crops such as alfalfa suffered.

May 1988

Rainfall was again inadequate during May, varying from one-half to two inches below normal. The April-May combined totals were generally less than 75 percent of normal and in northwest and west central Minnesota less than 50 percent of normal (Figure 3.5). In addition, excessive evaporation rates became a concern. Abnormally high temperatures (5 to 8 degrees above normal), low relative humidity, and high winds teamed to create a high evaporative demand, an important component in drought. Pan evaporation rates ranged from 9 to 11 inches for the month compared to a normal rate of 7 inches.

The reality of the drought started gaining the attention of the news media and the general public in early May. The headline on the cover of this document is from the May 4 edition of the Minneapolis Star Tribune. Farmers were of course concerned with the extremely dry soil conditions, but public awareness of the potential seriousness of the drought was not yet widespread.

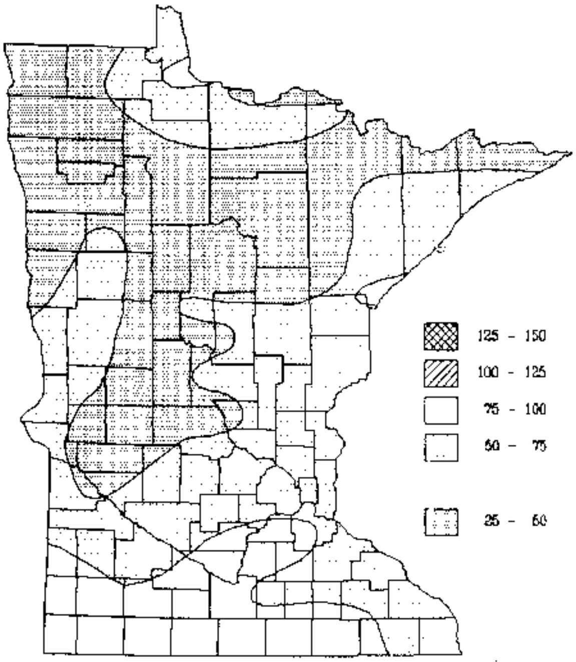


Figure 3.5
Percent of Normal Precipitation
(April 1 - May 31, 1988)

By month's end the National Weather Service (NWS) Climate Analysis Center categorized northwest, west central, central, and east central Minnesota in an "extreme drought", the worst scenario possible in their classification scheme. The rest of Minnesota was placed in the "mild drought" category, three levels better than "extreme". The dryness and heat caused spotty seedling emergence over broad regions. The first cutting of hay was far below expected yield goals. Grass and forest fires continued to be a major problem in central and northern Minnesota. Surface and groundwater levels continued to decline.

June 1988

The drought intensified in June and its effects became more apparent in the southern third of Minnesota. In Minneapolis-St. Paul, a paltry 0.22 inches of rain fell for the month of June, making it the driest June ever recorded in the metro area. The June average temperature for Minneapolis/St. Paul was 74.4 degrees F which equaled the second warmest June ever. Statewide temperatures ranged from six to nine degrees above normal, and precipitation in the southern two-thirds of the state was 2.5 to 4 inches below the norm. The forested regions of northern Minnesota received some relief in the form of general rains but conditions remained dry.

The combined effects of a dry fall, a poor spring recharge, and a dry and hot summer began to elicit comparisons with the 1930's and other drought years such as 1910 and 1976. However, the 1988 drought cannot match the overall geographic extent of the drought of 1934 which covered approximately two-thirds of the country. In late June of 1988, Minnesota and North Dakota appeared to be at the drought epicenter. However, it became apparent that the drought was also intensifying across much of the central and southeastern United States.

By the end of June most of the state was classified as either in "severe" or "extreme" drought. Forage shortages became critical and it was becoming evident that yield reductions in small grains and row crops were inevitable. Many farmers around the state hedged their annual gamble on the weather a step further by applying for "drought insurance". River and lake levels continued to drop and wetlands were drying up. In many urban areas water use could not be met by the distribution systems.

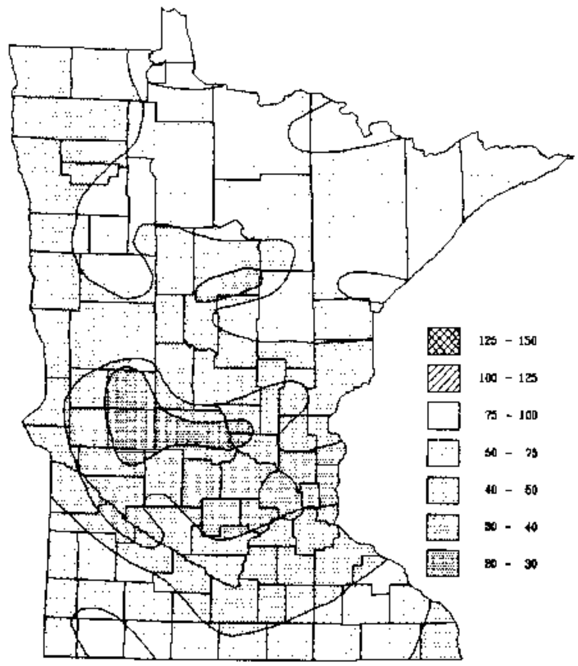


Figure 3.6
Percent of Normal Precipitation
(April 1 - June 27, 1988)

June was a month of heightened public awareness as well as greatly accelerated activity by various agencies. The Star Tribune published over 70 drought-related articles during June. The DOW's Director and the State Climatologist made the first of several appearances on public television's "Almanac" program on June 17. On June 21, the Drought Task Force held their first meeting. The Drought Task Force consisted of members from various public and private organizations with the purpose of examining the impacts of the drought and planning a coordinated response (Appendix A). The first suspension of surface water appropriation permits occurred on the Elk River on June 22.

It should be remembered that at this time the prospect of an additional two or more months of hot, dry weather was a very real possibility. The response to the drought may have been different had these severe conditions been reached in mid-August with cooler temperatures just around the corner.

On June 30, the DNR, NSP and the cities of Minneapolis and St. Paul agreed to a water conservation plan if the Mississippi River flow dropped below 1000 cubic feet per second (cfs) at Anoka. At that time, the flow was 1180 cfs. The previous day Minneapolis instituted an odd-even sprinkling ban while St. Paul requested a voluntary ban from its residents. Many suburban communities had also issued sprinkling restrictions in June.

July 1988

The drought continued to deepen through July. A large area of Minnesota received less than 50 percent of normal rainfall for the April through July period (Figure 3.7). May through July 1988 was the warmest and driest such period on record in many counties. The hardest hit areas continued to be west central and central Minnesota. Statewide temperatures for July were three to six degrees above normal and rainfall was 1.5 to 3 inches below the norm. Soil moisture levels reached

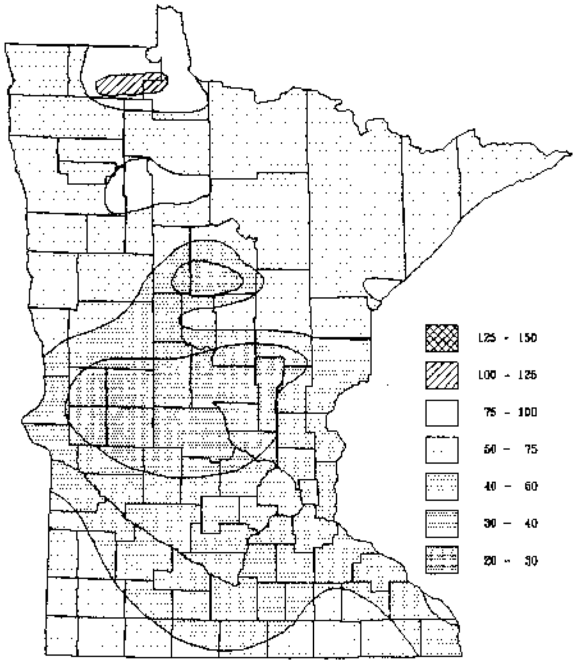


Figure 3.7
Percent of Normal Precipitation
(April 1 - July 25, 1988)

record lows at most University of Minnesota Experiment Stations. Evaporation rates lingered at all-time recorded highs.

By the end of July all but northeastern Minnesota was in the "extreme drought" category. The Palmer Drought Severity Index reached an all-time extreme value in northwestern Minnesota (Figure 3.8). In the Minneapolis/St. Paul area, maximum temperatures of 90 degrees or greater were recorded on 17 days, a record high for July. Most locations reported maximum temperatures exceeding 100 degrees at least once during the month, producing great human discomfort and stress on livestock. Yield reduction in most row crops appeared certain.

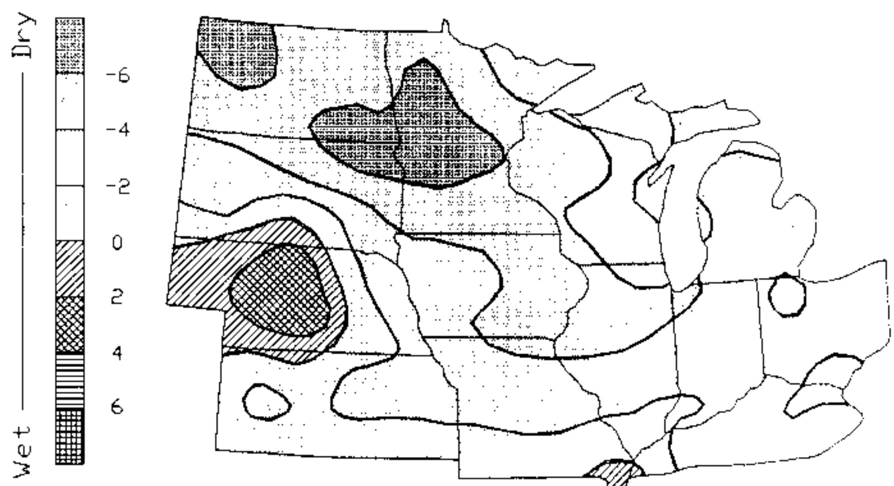


Figure 3.8
Palmer Drought Severity Index - July 1988

Throughout July there was no doubt that Minnesota was in the midst of a severe drought. There was daily media coverage of parched fields and dry rivers. Radio, television and newspapers reported virtually all actions and meetings by public agencies regarding their response to the drought.

Topics discussed at the July 20 Drought Task Force meeting give a good indication of conditions throughout the state:

- NSP reported purchasing power from outside the state;
- report of fish kill on Lake Pepin;
- the National Guard was called to provide water to the Wayside Addition in Haven Township near St.Cloud;
- well drillers reported a three to four month backlog of work; and
- the "silver lining" award went to the NWS who reported a change in the weather pattern with the possibility of precipitation. (Their forecast proved very accurate!)

A predominant issue facing the Drought Task Force was the potential request for release of water from the Mississippi River Headwater Reservoirs. This issue was first raised in a June 28 newspaper article. Northern interests, represented by the MN Resort Association, objected to the lowering of the reservoirs to allow Twin Citians to continue watering their lawns. They were also concerned that lower lake levels would keep tourists away.

The primary concern of public officials in the Twin Cities was to ensure sufficient flow in the Mississippi River for: 1) waste assimilation downstream of the Pig's Eye wastewater treatment plant; 2) power production and 3) municipal water supply. To help alleviate the northern concerns, Minneapolis and St. Paul agreed to institute procedures to reduce water use to winter levels if the Mississippi River at Anoka dropped below 1000 cfs for 72 consecutive hours. This level was reached on July 25 - 27 resulting in the first total ban of nonessential water use in Minneapolis and St. Paul on August 1. The ban primarily included the sprinkling of established lawns and the washing of vehicles. Most suburbs had also instituted water use restrictions by this time.

The above criterion also triggered the Governor on July 28 to formally request the Corps of Engineers to release an additional 300 cfs from the Lake Winnibigoshish Reservoir. This reservoir was recommended because of its relatively high levels and anticipated lower impacts to wild rice production and commercial resort operations. On August 3, 1988, the COE denied the Governor's request citing recent rains in northern Minnesota.

August 1988

The August climate brought welcome changes. A shift in the atmospheric circulation patterns brought wet weather the first week of August and rains returned periodically throughout the month. While the drought did not end, its intensification was curtailed. The majority of the state received normal to above normal precipitation for the first time since the growing season began. Statewide precipitation averaged about 5 inches (Figure 3.9). Temperatures remained hot early in the month but cooled as August ended. Replenishment of soil moisture profiles and the rejuvenation of forage and row crops that had survived was a pleasing sight indeed.

The August rains were a relief to most Minnesotans, but unfortunately were too late to rescue much of the agricultural production. Many agricultural and other water-dependent operations were beyond the help of the late summer rains. The Mississippi River reached its lowest 1988 mean daily flow of 842 cfs on July 30. The Twin Cities sprinkling ban was lifted on August 17 since the Mississippi River had been above 1000 cfs for several days. Prior to August 17, the Drought Task Force had not set any specific criteria as to when the ban would be rescinded.

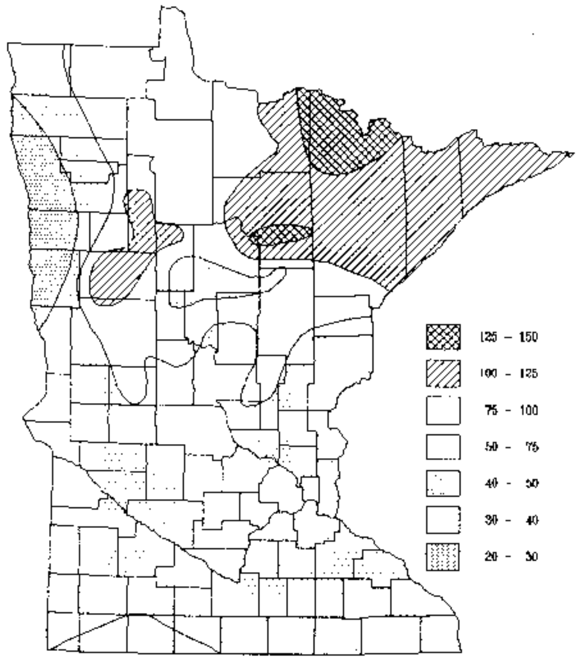


Figure 3.9
Percent of Normal Precipitation
(April 1 - August 29, 1988)

Fall 1988

The return to "normal" precipitation generally continued throughout the fall months. Except for the northwest corner, most of the state received 1 to 2 inches above normal precipitation for September. These rains helped recharge soil moisture levels. October provided very little additional recharge as rainfall was approximately one inch below normal levels throughout the state. During the first two weeks of November, much of the southern half of Minnesota received up to twice the normal monthly precipitation totals (Figure 3.10). This precipitation provided unexpected and very welcome recharge of the unfrozen soils.

Much of the northeastern and north central parts of the state are at or above normal soil moisture levels. They received up to 50 percent above normal rainfall during the summer and fall. Much of southeastern Minnesota is near normal for this time of year thanks to the 4 to 6 inches of rain in September and the 1 to 2 inch amounts of early November. However, soil moisture levels throughout a large part of south central, southwest, central and west central Minnesota are still below normal but have shown significant recharge in the first two feet of soil. Figure 3.11 shows the improvement in the Palmer Drought Index in the northeastern and north central portions of the state, but much of central and northwest Minnesota remain in the extreme drought category.

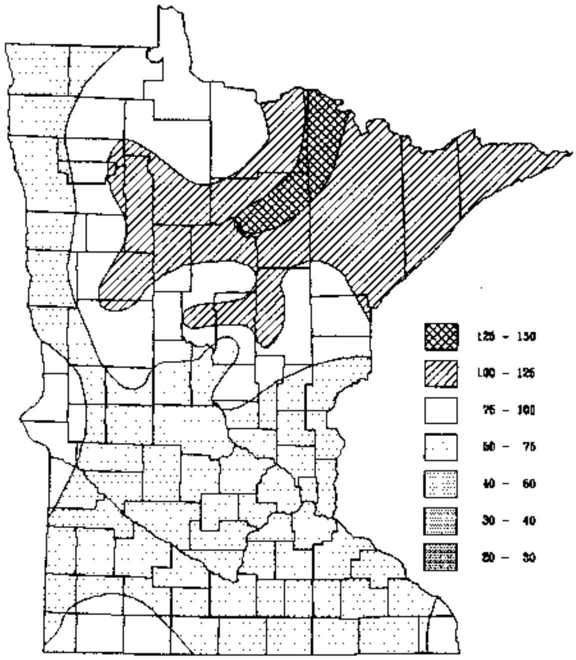


Figure 3.10
Percent of Normal Precipitation
(April 1 - November 21, 1988)

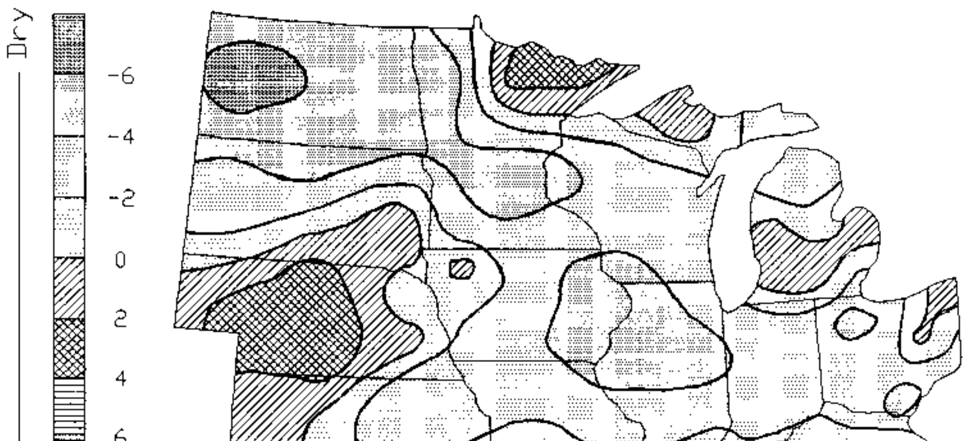


Figure 3.11
Palmer Drought Severity Index - October 1988

Hydrologic Effects

The definition given for drought used the term "serious hydrologic imbalance". Water levels throughout Minnesota were affected by the drought, but by how much? How do the levels experienced in 1988 compare to the 1930's and 1976? Were groundwater levels affected as significantly as streamflow?

This chapter will look at streamflow, lake levels and groundwater levels throughout Minnesota. The discussion for each component will generally follow the trend from very high levels during the mid-1980's to the extremely low levels during 1988.

STREAMFLOW

The dry conditions throughout the state since fall of 1986 set the stage for abnormally low streamflow in the spring and summer of 1988. A statewide perspective of streamflow during 1988 is most easily depicted using data from USGS Monthly Water Resource Summaries. Streamflow data from throughout the state are used by the U. S.Geological Survey (USGS) to provide a general representation of whether streamflow was excessive, normal or deficient in various regions. The cover sheets for these reports are shown in Figure 4.1 on pages 18-19.

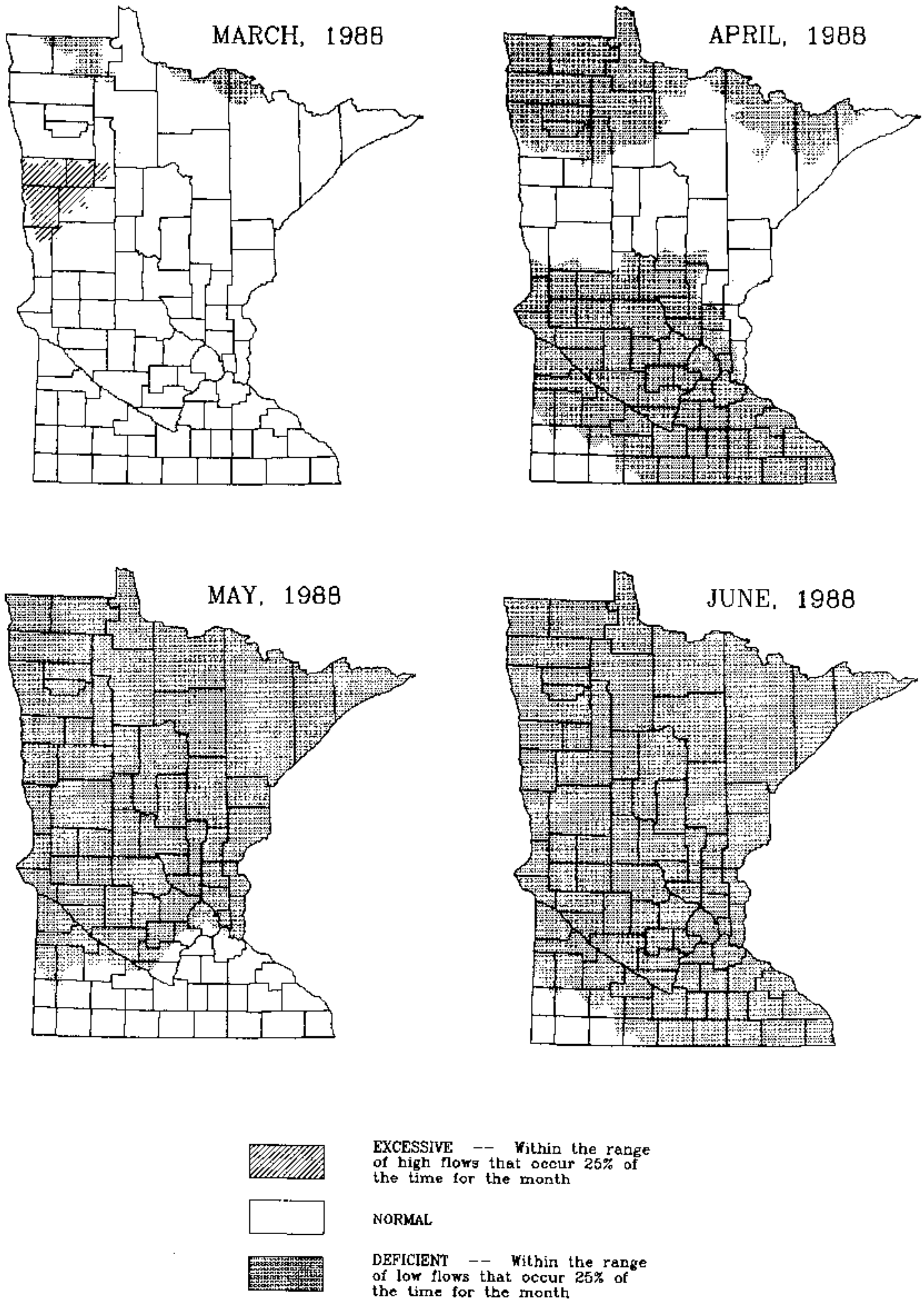
March 1988 ended a string of 11 consecutive months in which streamflow had been in the "normal" range throughout much of the state. Even though the drought is considered to have started in October of 1986, generally adequate lake and groundwater levels helped maintain streamflow in the normal range through March of 1988. Conditions changed quickly, as shown on the April map. By July streamflow throughout Minnesota was deficient. Rainfall during August and September helped restore portions of the state to normal and even excessive ranges. Streamflow in western and portions of central Minnesota is still considered in the deficient range.

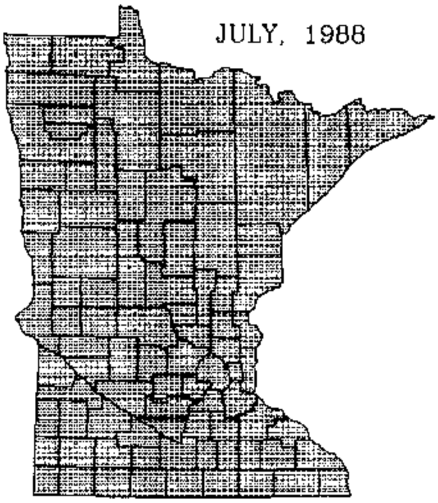
Streamflow Monitoring

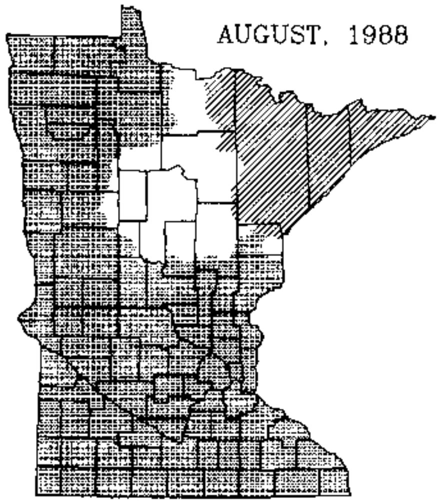
Streamflow monitoring was a crucial activity throughout the drought. Of primary concern were flow levels in the Mississippi River at the Twin Cities. Additionally, the DOW monitored streams throughout the state to respond to its statutory responsibilities relating to resource protection limits.

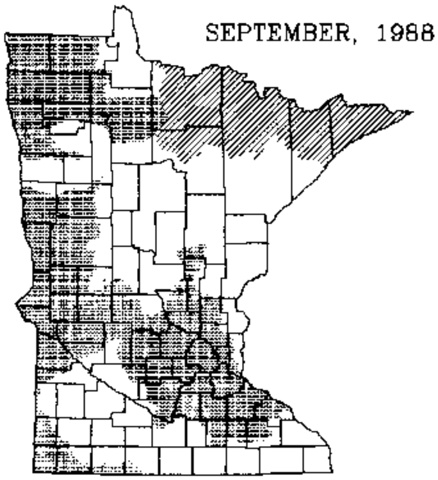
The USGS stream gaging network provided the base for the data collection efforts. Additional data were available from the COE reservoir network and the National Weather Service (NWS).

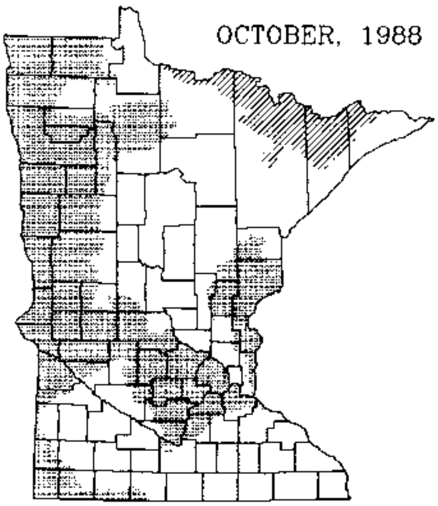
Figure 4.1 **USGS WATER RESOURCE SUMMARIES**
March - November 1988

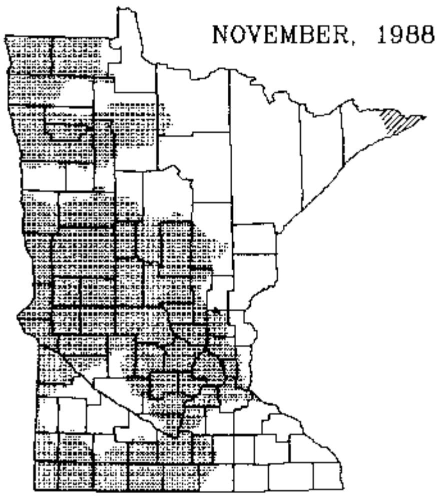



JULY, 1988


AUGUST, 1988


SEPTEMBER, 1988


OCTOBER, 1988


NOVEMBER, 1988

Satellite transmission technology provided up-to-the-minute data collection through USGS and U. S. Army Corps of Engineers (COE) Data Collection Platforms (DCP) at selected gage sites. "Telemark" gage sites provided access to additional gage height data by electronic coded messages obtained by telephoning the gage. Unfortunately these "real-time" data transmission technologies were available only at a limited number of gages. Since decisions regarding the suspension of appropriation permits required up-to-date flow data, additional data were collected by volunteers living near gage sites and by Department personnel.

Mississippi River

The Mississippi River flow through the Twin Cities was closely monitored due to the recognized need of the river for waste assimilation, instream flow, power production and water supply. While data from many other sites within and near the Twin Cities were monitored, the most widely used and publicized data came from the USGS Anoka gaging station (#05288500) located downstream of the Coon Rapids dam.

August 1986 through September 1988 streamflow for this site is shown in Figure 4.2. Also depicted is a corresponding plot of the long-term average flow for this site. Of special note are the much above average flows of late 1986 and the much below average flows of 1988.

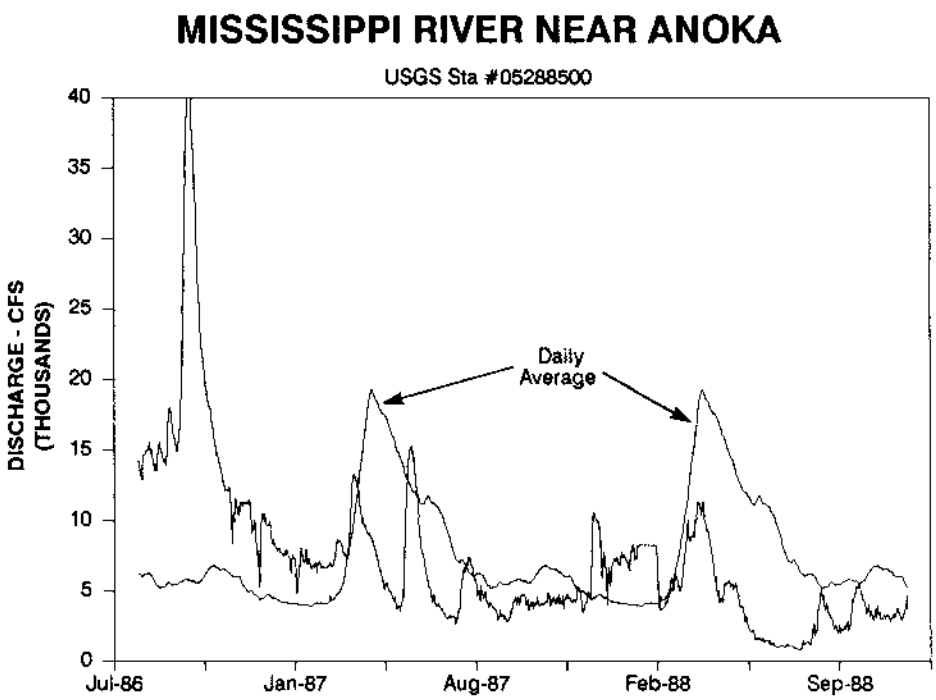


Figure 4.2
Mississippi River Streamflow near Anoka (1986 through 1988)

Flow data for 1988 are compared with data for 1934 and 1976 in Figures 4.3 and 4.4, respectively. Mississippi River flow rates in 1934 were similar to those of early summer 1988. However in 1934 the Mississippi River did not benefit from heavy August rains and therefore continued low throughout late summer and early fall. Flows of 1976 were generally higher than early summer 1988 flows and below late summer 1988 flows.

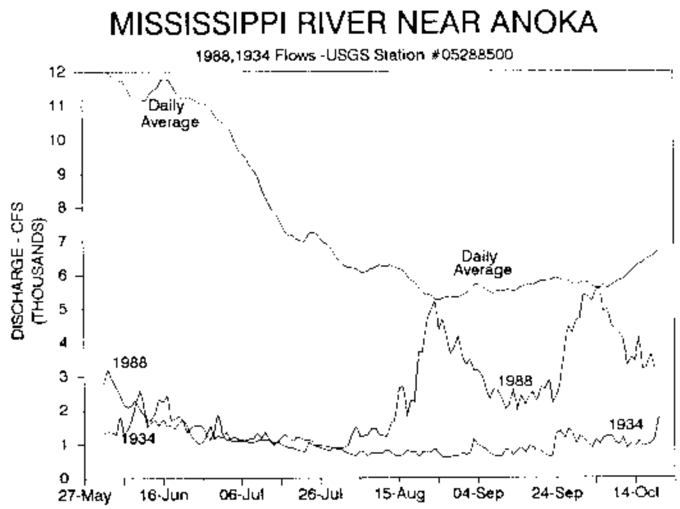


Figure 4.3
Mississippi River Streamflow Comparison: 1934 and 1988

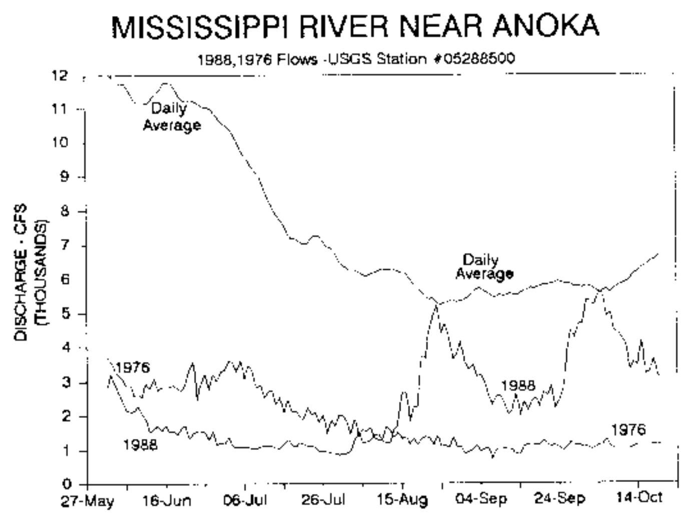


Figure 4.4
Mississippi River Streamflow Comparison: 1976 and 1988

Record low flows for this site occurred in 1934 and 1976. In 1934, the record low daily flow of 602 cfs occurred on September 10 and the record low average monthly flow of 715 cfs occurred in August. In 1976, a record low instantaneous flow of 529 cfs was measured on August 29, although this was a result of automatic gate operation at the Coon Rapids dam.

To avoid a repeat of this problem, automatic gate operation was suspended during the particularly low flow periods of 1988. In 1988, the Mississippi River reached a daily low of 842 cfs on July 30.

Extended Low Flow Forecasts

One question on everyone's mind was how low might the Mississippi River get? The River Forecast Center (RFC) of the National Weather Service was requested to provide extended low flow forecasts for the Mississippi River. Although principally developed for flood forecasting, the RFC fine-tuned and calibrated their forecasting model in an effort to provide the low flow forecasts. A worst case scenario forecast was provided by assuming no rainfall would occur during the forecast period. The fine-tuning of the low flow model required additional real time flow data from sites not used for flood forecasting. Public volunteers, DOW and COE staff were used to read staff gages for this purpose.

The low flow forecasts were provided on a weekly basis beginning July 6 for each of the four weeks following the date of the forecast. Appendix B summarizes the low flow forecasts provided by the River Forecast Center. As can be seen on this table, the actual flow rates were generally higher than the forecasted flow. This should be expected since the forecasts assumed there would be no rainfall over the entire Mississippi River basin. These data do suggest that had the rains not returned in August, the Mississippi River would have fallen to severely low levels, equaling or even dropping below 1934 and 1976 levels.

Headwater Reservoirs

The near record low flow of the Mississippi River during the summer of 1988, concern for potential effects on the users of the river water and instream flow needs prompted consideration of alternatives to supplement flow in the river. One alternative was to release additional flow from the Mississippi River Headwater Reservoir system (Figure 4.5). Built by the Federal Government in the late 1800's and early 1900's and operated and managed by the Corps of Engineers, the principal purpose for this system of six reservoirs was flow augmentation to facilitate downstream navigation. The nagivational benefits provided by the reservoirs were greatly diminished following the construction of the 9 foot channel project in the 1930's.

New regulations for operating the headwater reservoirs were issued by the War Department from 1931 to 1945 and are still in effect today. These regulations set forth relatively vague navigational requirements and established operating limits for the six reservoirs. There are no references in these rules to other considerations, such as water quality, power production, irrigation, public water supply, recreation and fish and wildlife.

In 1961, the Minnesota Legislature directed the Commissioner of Conservation to enter into agreement with the Corps of Engineers for the control and regulation of the headwater reservoirs "with full consideration of all interests". Following a series of public hearings, the Commissioner of Conservation issued an order on April 19, 1963 which outlined a comprehensive operational plan for the headwater reservoirs.

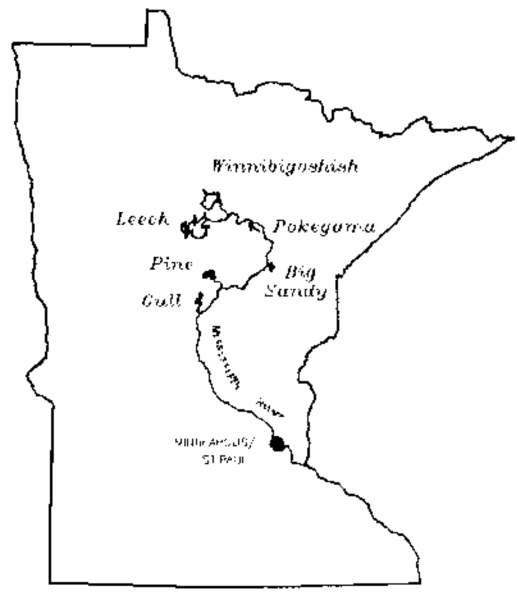


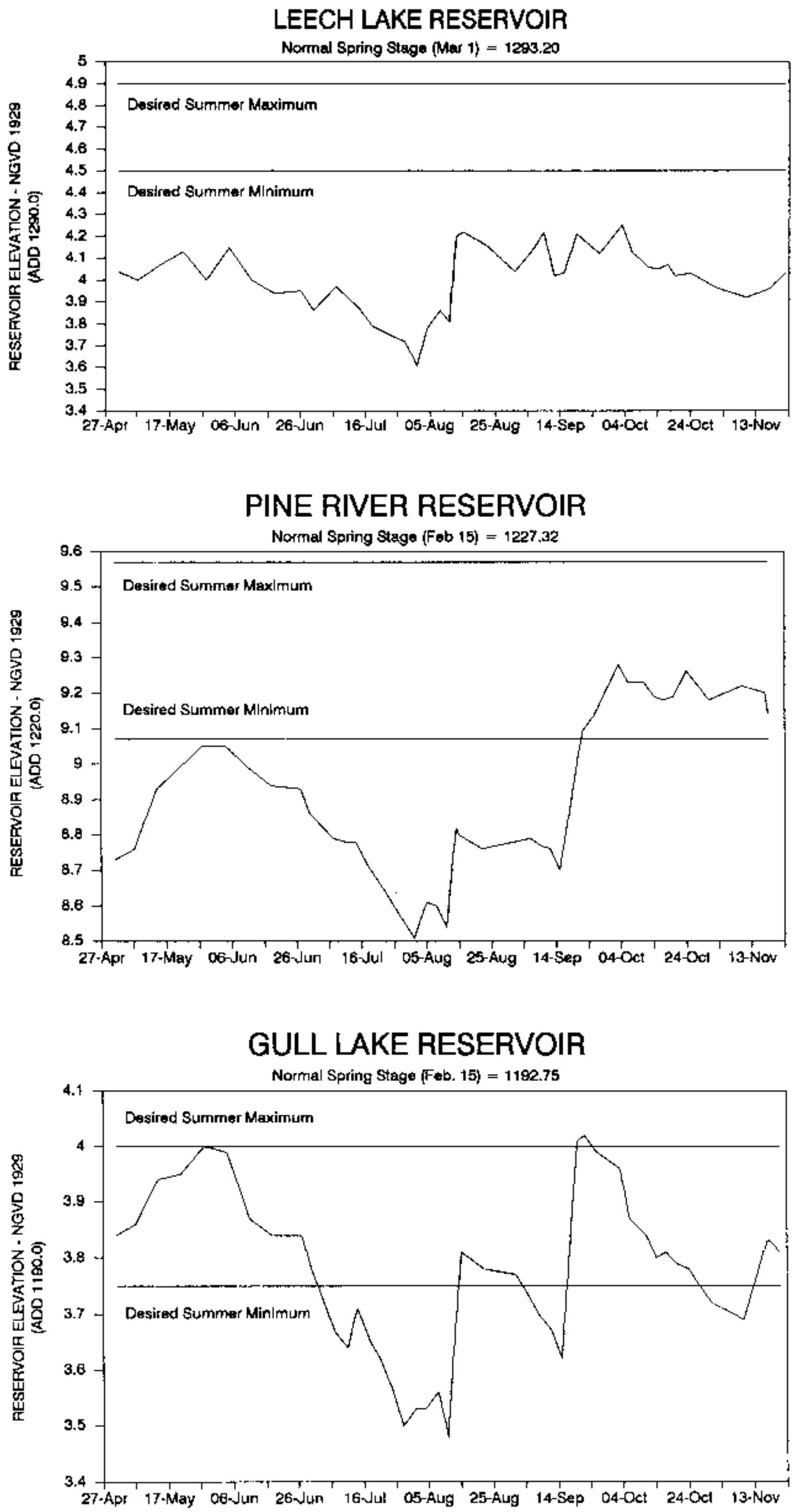
Figure 4.5
Mississippi River Headwater Reservoirs

The COE never entered into formal agreement with the State of Minnesota regarding joint control and regulation of the reservoirs. "However, in actual practice, the St. Paul District attempts to coordinate lake operation in conformance with the 1963 Commissioner's order whenever possible, especially for low flows." (COE, 1982 Feasibility Study.)

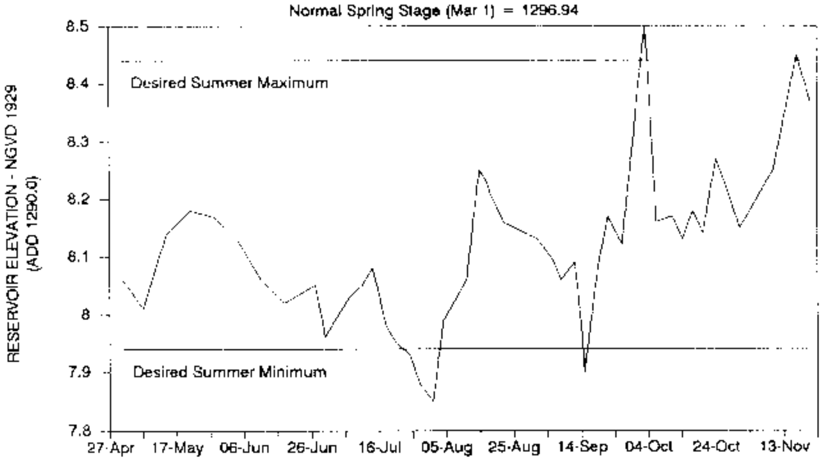
The most recent study regarding the headwater reservoirs is the COE's "Mississippi River Headwaters Lakes in Minnesota Feasibility Study", completed in 1982. While the most comprehensive look at the headwater reservoirs to date, the COE has not adopted this study as official policy. As part of this study, the COE looked at the effects of maintaining a minimum flow of 1600 cfs at Anoka. This flow rate was the estimated critical water demand for the year 2015. From their study the COE concluded:

> It is imperative that the city of Minneapolis develop a water conservation plan and an alternate supply source to preclude serious problems during a drought situation or in the event of an accident such as a hazardous waste spill. Releases from the Mississippi River Headwaters Lakes could possibly be used in drought situations to provide a minimum flow of 1600 cfs at Anoka without causing major environmental damage or severe economic loss. However, the Twin Cities should not rely on this option as a long-term solution or as a definite possibility. The decision to make emergency releases to supply Twin Cities water needs would rest with the Governor of Minnesota after consultation with affected area interests, including representatives of the Leech Lake Tribe and the Mississippi Headwaters Association.

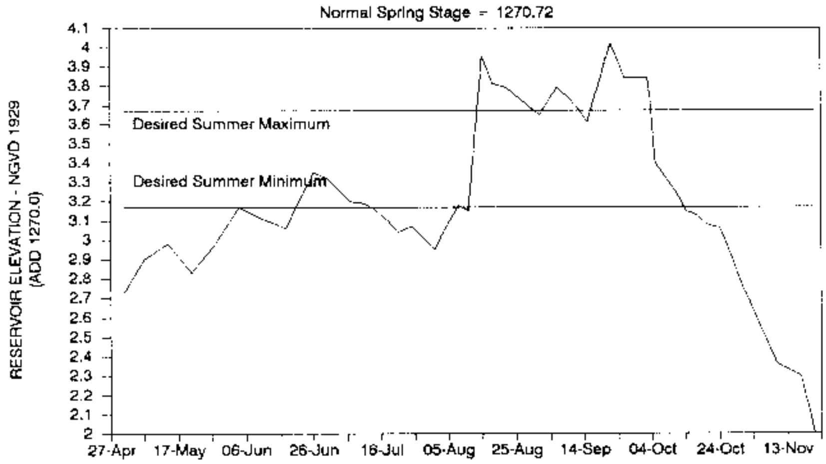
Figure 4.6 MISSISSIPPI RIVER HEADWATER RESERVOIRS
1988 Water Levels (Data from the COE)



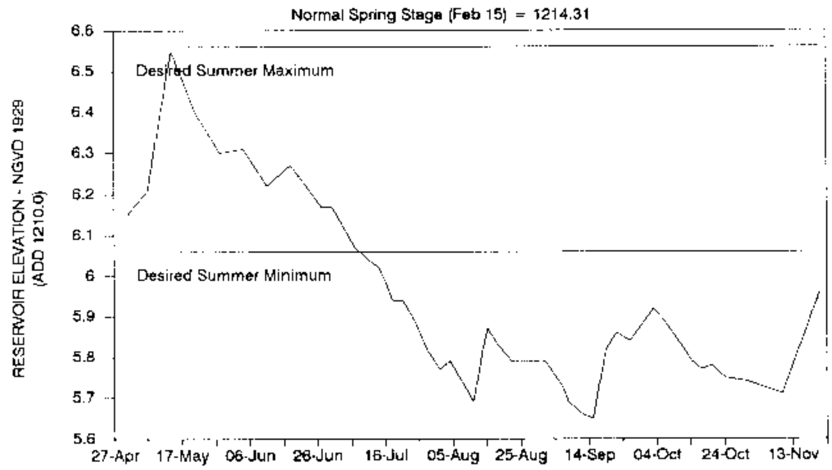
WINNIBIGOSHISH LAKE RESERVOIR



POKEGAMA LAKE RESERVOIR



SANDY LAKE RESERVOIR



On July 28, 1988, Governor Perpich requested the COE to release an additional 300 cfs from Lake Winnibigoshish. The combination of the low flow at the time plus the 300 cfs would have been well less than the 1600 cfs analyzed by the COE in 1982. On August 3, the COE declined, citing recent rains in the northern part of the state. At the time of the request, all reservoirs were below their normal summer operating range although Winnibigoshish had been above the minimum operating range for most of the summer (Figure 4.6, pages 24-25 and Appendix C). Heavy rains in early August in northern Minnesota caused the levels of Winnibigoshish and Pokegama to rise into their normal summer range. As dictated by their operations plan the COE increased outflow rates from these two reservoirs .

Protected Flow Monitoring

Due to the DOW's statutory responsibility regarding instream flow protection, special monitoring activities were instituted on streams with established protected flows. Forty-five watercourses in Minnesota have established protected flows. Only 19 of these watercourses have recording gages. Nine of these streams have USGS telemark stations, another five are monitored by the COE satellite data collection network, and the remaining five require an observer to read the recording gage.

An additional thirteen watercourses have nonrecording staff gages which require observers to monitor flow. Ten of these gages were established during the summer of 1988. The rating curves developed for these new gages are only preliminary and in most cases based only on one flow and one water stage. Gages need to be established and rating curves developed on the remaining thirteen ungaged watercourses with established protected flows.

In several cases data were needed from USGS stations that had been discontinued in previous years due to lack of funding. Public volunteers, DOW and other agency personnel were used to obtain gage height readings that were then transformed to flow data using available rating curves. Since the available USGS rating curves had not been recently updated at discontinued sites, the accuracy of the ratings was in question.

The Elk River was the first river to have water appropriation permits suspended on it. This river no longer has a recording gage and was not being monitored on a routine basis. Division of Waters regional staff first noticed the extremely low flow conditions. On June 16, DOW staff measured flow rates at seven locations on the river and found that the Elk River was 24 cfs below its protected flow. Six days later, surface water appropriation permits were suspended in the Elk River watershed.

Tighter monitoring schedules were subsequently instituted. Those watercourses with telemark stations and DCP stations were monitored from the DOW Central Office. DNR, Fisheries and Waters Region 5 and Region 3 staff began monitoring flow rates in their respective regions. As flows receded in other areas of the state, regional personnel and the USGS were requested to monitor watercourses in their regions. Flow data collected by the DNR is included in Appendix D. Appendix E includes streamflow hydrographs for the 13 watercourses where surface water appropriation permits were suspended in 1988.

LAKE LEVELS

During 1986, many lakes were near or above their recorded highest known levels in response to a decade of above normal precipitation. The 1987 and 1988 hydrologic years combined much lower than normal precipitation with higher temperatures. The impacts of these conditions on lake levels are graphically presented in Figures 4.7 and 4.8.

All of the graphs in Figure 4.8 have the same vertical and horizontal scales. Of special note are the strong similarities in the rate of decline of the six lakes in the southern half of the state. There has been no recovery of lake levels in these lakes even with slightly above normal fall precipitation.

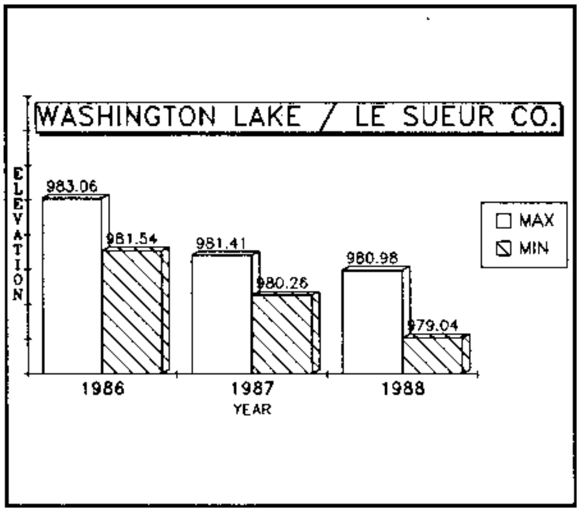
The driest part of Minnesota in 1988 was the area from St. Cloud to Brainerd, or approximately the central third of the state. That dryness is very evident on the graph of Rice/Koronis Lakes (Stearns and Meeker Counties) which experienced over six vertical feet of drop in water level for the period 1986 to 1988. Mille Lacs Lake also experienced an equally significant reduction in water levels.

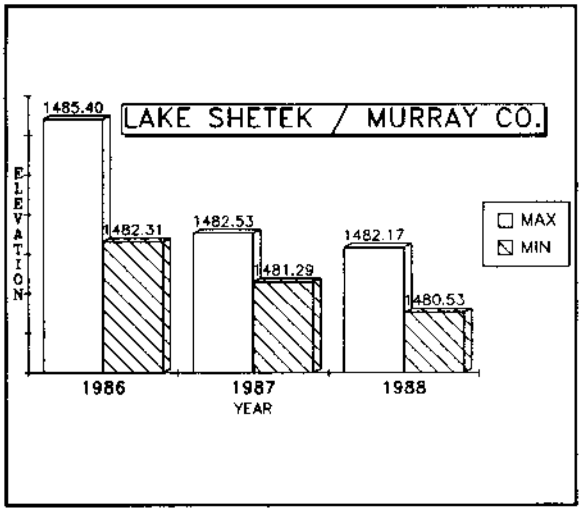
An interesting comparison can be made between the levels of Minnetonka and White Bear Lakes in the Twin Cities metropolitan area. The major difference between the two lakes is that Minnetonka has an actively operated dam at its outlet (which involves an autumn drawdown) while White Bear has a nonoperable outlet. The 1986-1988 graphs for these two lakes show very similar water level regimes, including their responses to the "super storm" of July 23, 1987. During the subject time frame, Minnetonka levels receded by 4.4 feet, while White Bear levels receded by 4.3 feet.

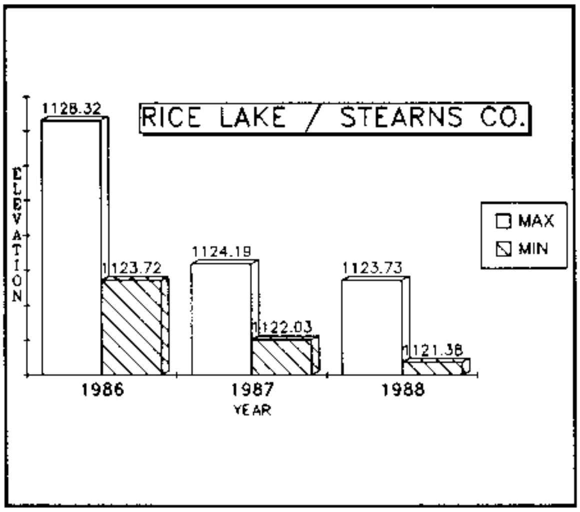
In contrast, Lake Vermilion (St. Louis County) did not recede as dramatically as many lakes throughout Minnesota. Precipitation amounts over much of the Arrowhead Region were closer to normal, resulting in more stable levels on Vermilion. As the graph indicates, the 1988 peak stage was nearly as high as in 1986.

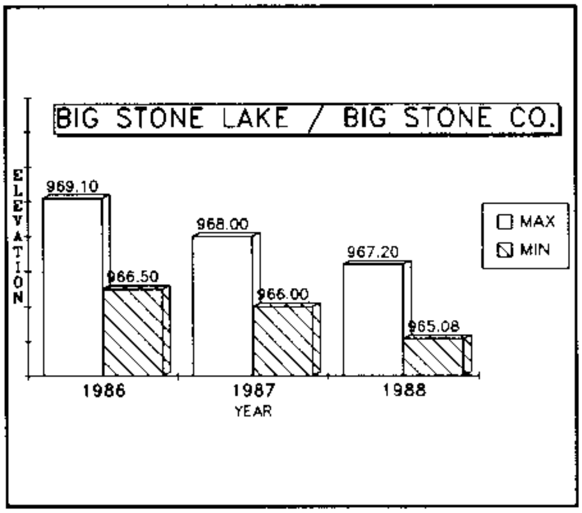
Appendix F contains additional lake level departure data for 1986 to 1988.

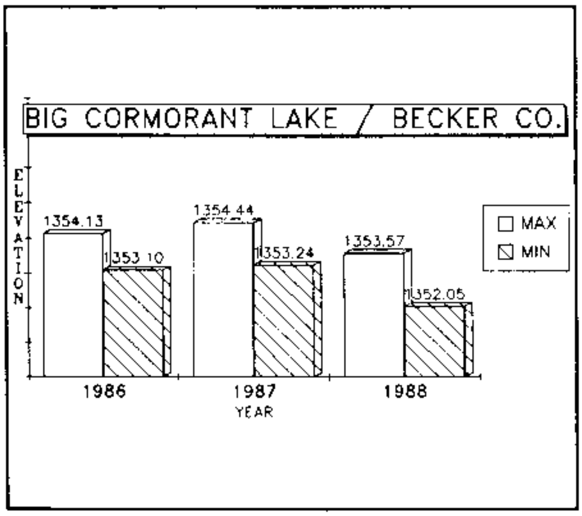
Figure 4.7 **HIGH/LOW LAKE LEVELS FOR 1986, 1987, 1988**

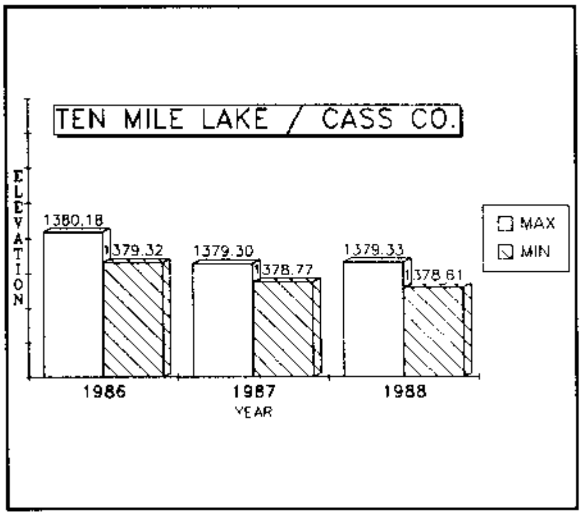


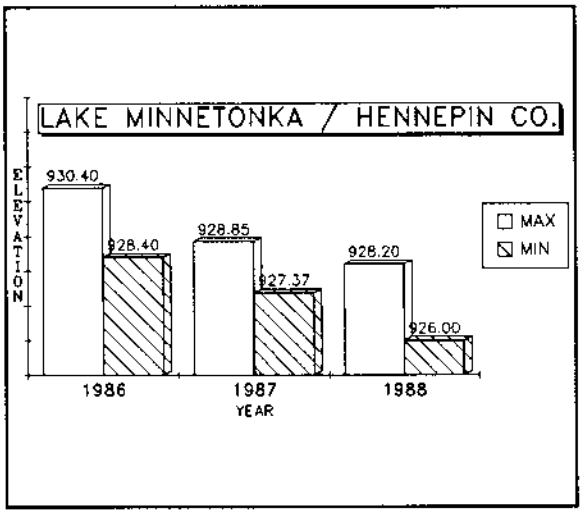


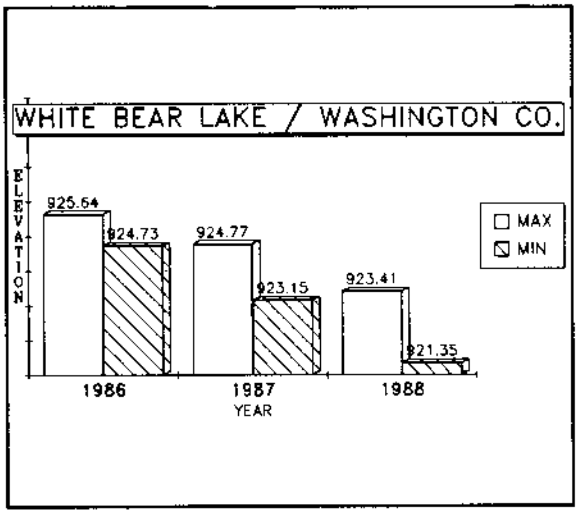


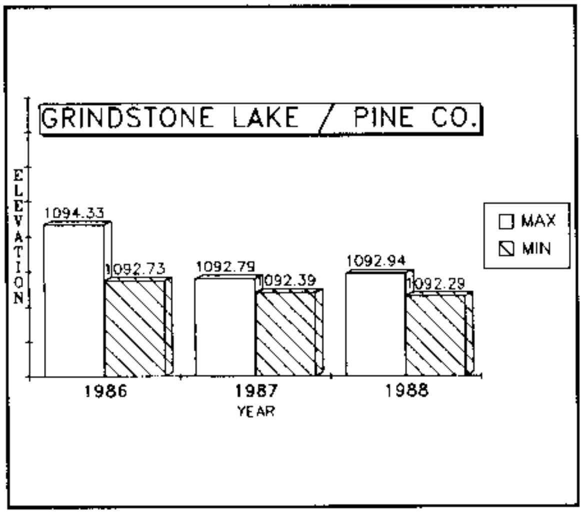


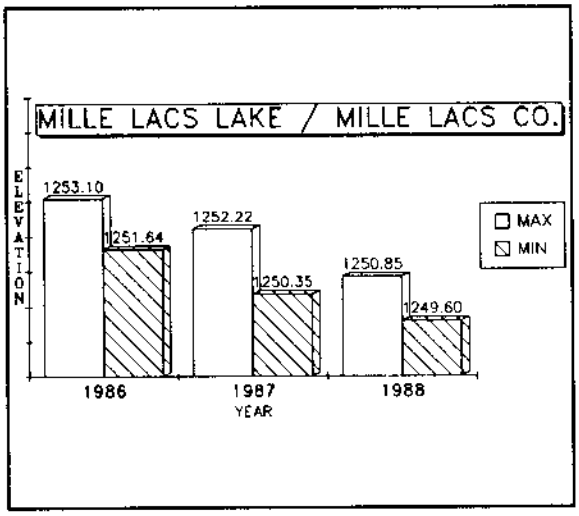


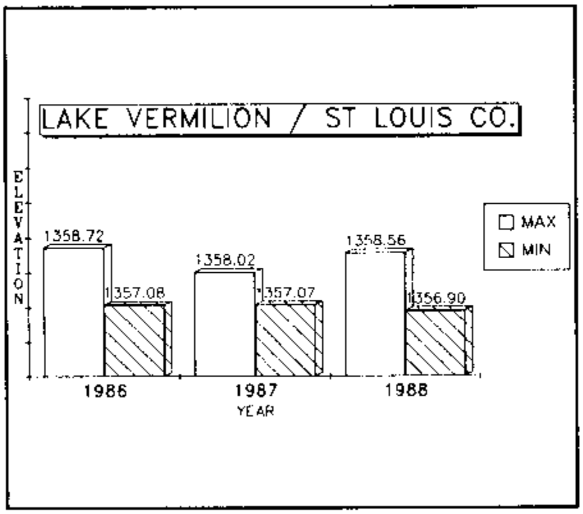



LAKE MINNETONKA / HENNEPIN CO.
ELEVATION
930.40
928.40
928.85
927.37
928.20
926.00
MAX
MIN
1986
1987
1988
YEAR


WHITE BEAR LAKE / WASHINGTON CO.
ELEVATION
925.64
924.73
924.77
923.15
923.41
921.35
MAX
MIN
1986
1987
1988
YEAR


GRINDSTONE LAKE / PINE CO.
ELEVATION
1094.33
1092.73
1092.79
1092.39
1092.94
1092.29
MAX
MIN
1986
1987
1988
YEAR


MILLE LACS LAKE / MILLE LACS CO.
ELEVATION
1253.10
1251.64
1252.22
1250.35
1250.85
1249.60
MAX
MIN
1986
1987
1988
YEAR


LAKE VERMILION / ST LOUIS CO.
ELEVATION
1358.72
1357.08
1358.02
1357.07
1358.56
1356.90
MAX
MIN
1986
1987
1988
YEAR

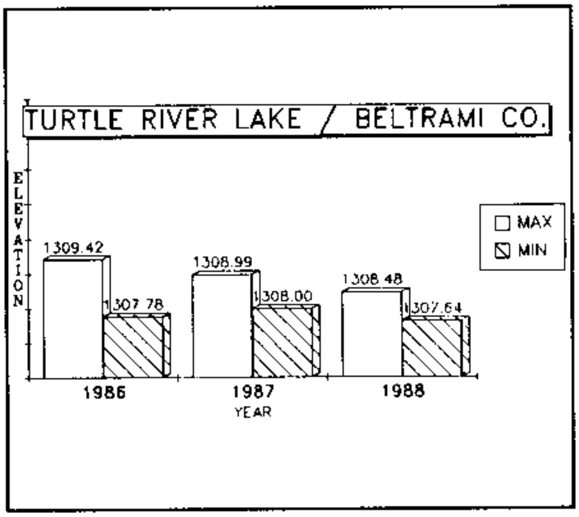
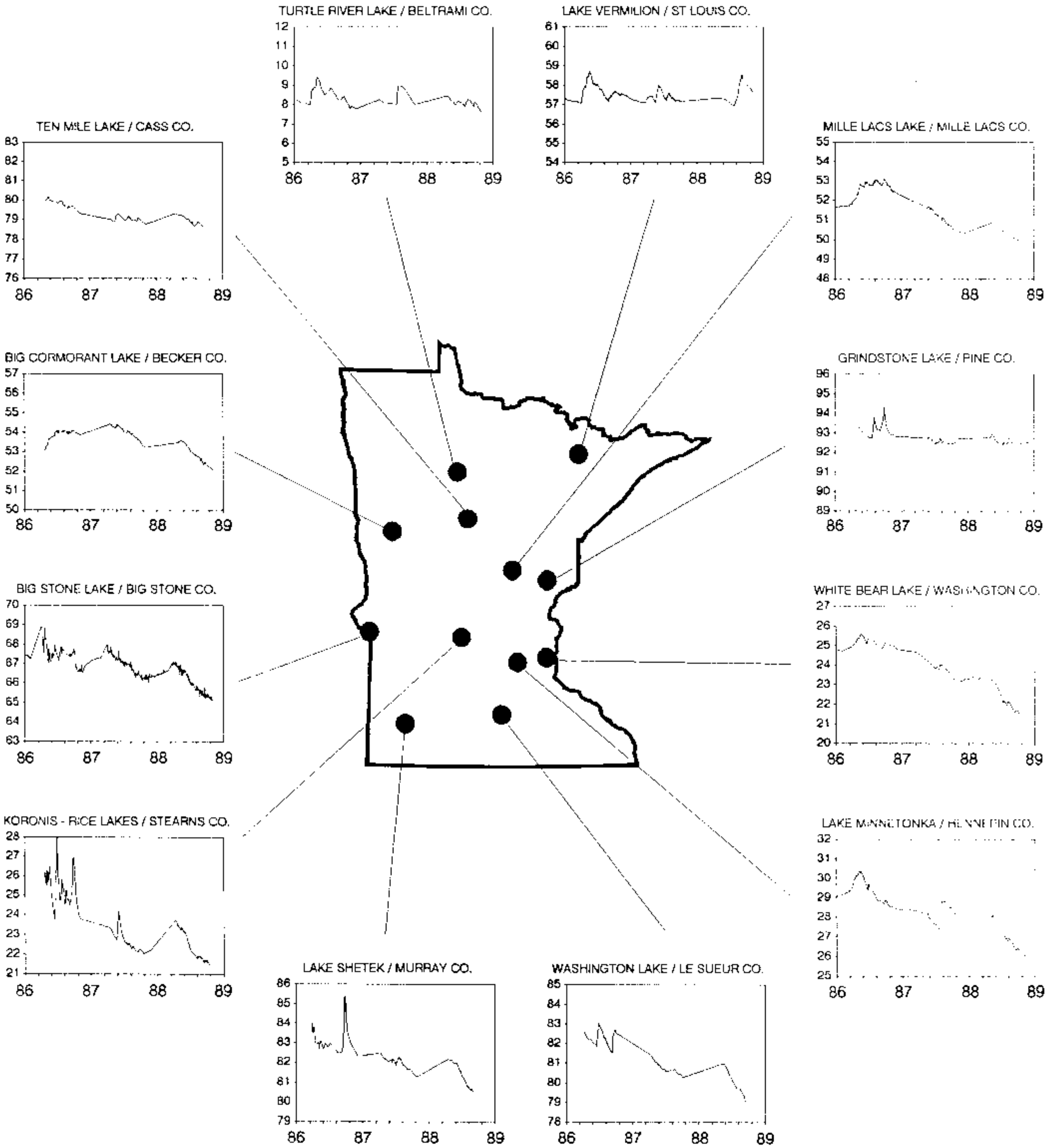

TURTLE RIVER LAKE / BELTRAMI CO.
ELEVATION
1309.42
1307.78
1308.99
1308.00
1308.48
1307.64
MAX
MIN
1986
1987
1988
YEAR

Figure 4.8 **LAKE LEVELS: 1986 - 1988**



GROUND-WATER LEVELS

Monitoring of groundwater levels has been a cooperative effort by the USGS and DNR since 1947. Unfortunately, groundwater data during the drought years of 1930 are not available. The earliest groundwater levels date back to 1942. Prior to 1988, the lowest recorded groundwater levels occurred in the spring of 1977 following the severe drought of 1976.

Largely through the efforts of Soil and Water Conservation Districts, weekly water level readings were recorded in 30 observation wells from June to October of 1988. These readings were in addition to the monthly levels obtained in approximately 600 wells throughout the state. These data were analyzed and used to prepare periodic summaries and assist in evaluating well interference complaints.

This section will compare groundwater levels in confined and unconfined aquifers during 1988 with previous years. Groundwater levels in unconfined aquifers generally respond more quickly to seasonal climatic changes than confined aquifers. However, the magnitude of the water level change will generally be much more pronounced in a confined aquifer.

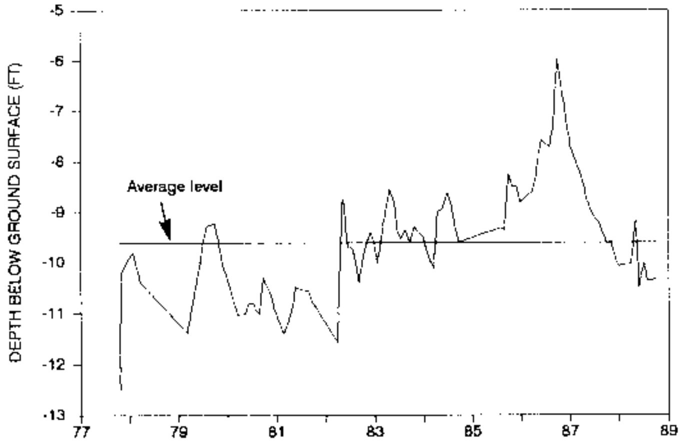
Unconfined Surficial Aquifers

In 1985, water table levels were near or above their highest known levels in response to ten years of above normal precipitation. In the fall of 1986, the heavy rains stopped and water table levels began to decline. The continuation of this drought into 1987 and 1988 caused groundwater levels to decline below previously recorded levels in most of the state. Only the northeastern and north central regions of the state have water table levels that remained near seasonal averages. Levels in the remaining parts of the state were typically 3 - 5 feet below summer averages and about one foot below the recorded lows in 1976-77. These levels are typically 8 feet below the recorded high levels in 1985. Selected water table hydrographs are shown in Figure 4.9.

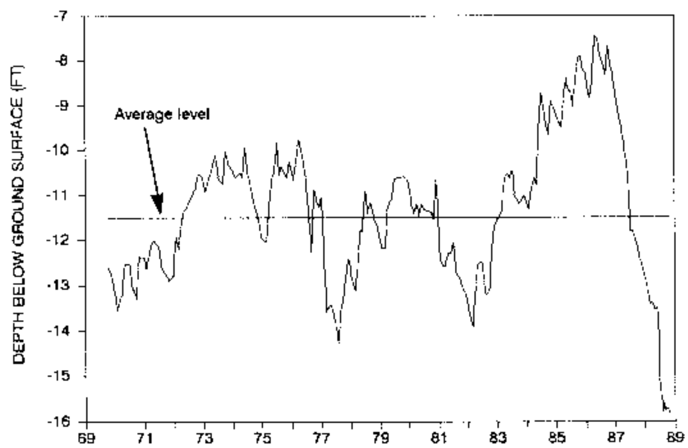
Late summer rains and decreased pumping after the growing season brought small improvement in the status of groundwater levels. However by October, groundwater levels were again declining, setting new record lows in much of the southern two-thirds of the state.

During the winter months aquifer levels generally decline as groundwater is discharged as base flow to rivers and lakes. The next significant recharge opportunity will most likely be in early spring after the ground has thawed. At this time little evaporation from the soil and little or no transpiration from plants occur making more rainfall and surface water available for groundwater replenishment. It should be noted that nearly all groundwater recharge takes place during this season. However, it is expected that water table levels will remain low in 1989 unless rainfall this spring is significantly above normal. If spring

CARLTON COUNTY WELL #09030



SHERBURNE COUNTY WELL# 71001



SWIFT COUNTY WELL #76011

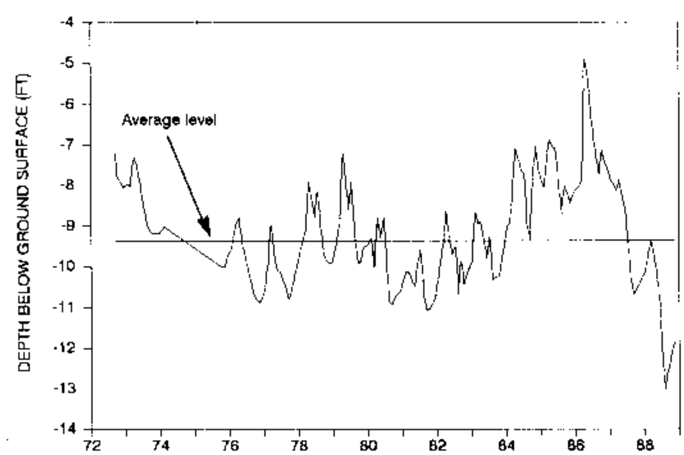


Figure 4.9
Unconfined surficial aquifers

recharge is light for the third consecutive year, groundwater levels will continue to decline. Shallow, poorly constructed and/or maintained wells will be more likely to experience water supply problems under these conditions.

Despite the low levels an adequate volume of water remains in most aquifers. While some shallow wells have experienced problems this past summer, an adequate water supply is available in most cases if wells are deepened or pump intakes lowered.

Heavy Use Confined Aquifers

In the seven county metropolitan area, the primary pumping center of the state, groundwater levels in bedrock aquifers are strongly influenced by seasonal pumping for irrigation and air conditioning purposes. Short-term climatic conditions are not obvious on groundwater hydrographs that are influenced by extensive pumping withdrawals. Levels in these wells will decline sharply at the start of the pumping season (May), continue to decline until the end of the pumping season (late August) and then generally recover to seasonal levels by mid-fall. Lowest levels will typically occur in late summer at the end of the air conditioning season. This pattern is in contrast to water table aquifers where lowest levels typically occur in late winter prior to the spring recharge period. Figures 4.10 and 4.11 show potentiometric surfaces for selected observation wells in the Prairie du Chien-Jordan and the Mount Simon-Hinckley-Fond du Lac bedrock aquifers in the Twin City area.

Groundwater levels in the Prairie du Chien aquifer reached record lows in June and July. Water levels rebounded strongly in September and October due to the cessation of pumping for cooling. Levels now vary from 3 feet below average in St. Paul to 1 foot above average in Minneapolis.

The Mount Simon-Hinckley aquifer, the Twin Cities' other principal

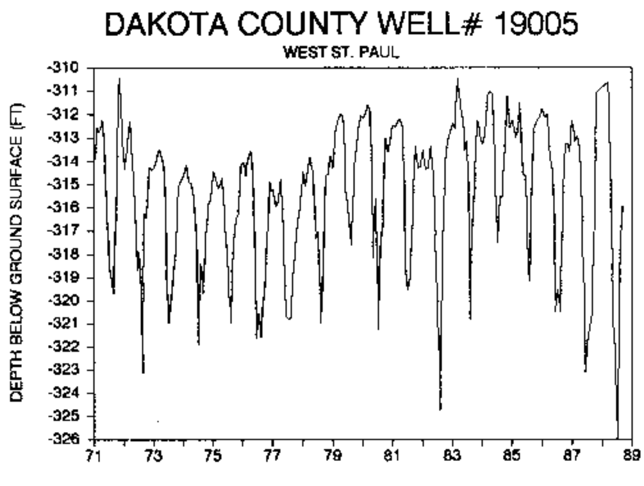


Figure 4.10
Potentiometric Surface: Prairie du Chien - Jordan Aquifer

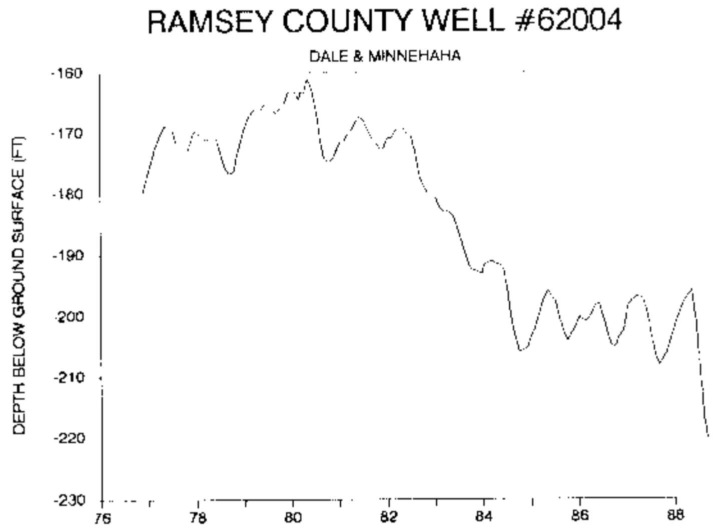


Figure 4.11
Potentiometric Surface: Mount Simon-Hinckley-Fond du Lac Aquifer

aquifer, also reached record low levels throughout the summer. Water levels in the Mount Simon-Hinckley aquifer have not recovered from last summer and now lie about 35 feet below average in the Minneapolis-St. Paul area. Observation well levels in this aquifer remain at all-time recorded seasonal lows for the month of November.

Outstate buried drift aquifers are also showing a short-term effect from last summer's drought and the increase in agricultural irrigation. Figure 4.12 shows an observation well located at the edge of an irrigated region in Swift County. Record low levels were measured in this well. These low levels are being found in several observation wells in the central region of the state. The graph indicates that recovery from recent pumping is not complete and levels have declined 4 feet in two years.

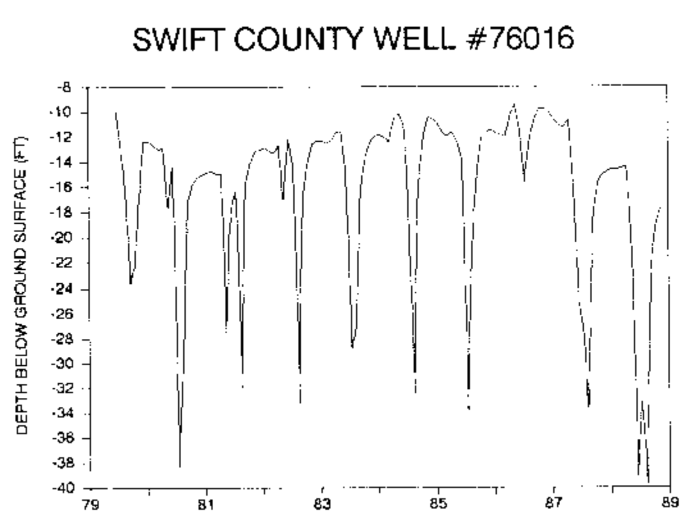


Figure 4.12
Potentiometric surface - buried drift aquifer

REGULATORY ACTIVITIES

WATER APPROPRIATION PROGRAM

Minnesota's water appropriation law was enacted in 1937 (Minnesota Statutes Chapter 105) near the end of the drought of the 1930's. The original act established a water policy for the state and a permit system to regulate water appropriators. The most important changes to the original law include requirements for submitting annual water use reports, the repeal of the exemption for "grandfather appropriators", the establishment of a priority system for water appropriation and the requirement to establish rules governing the allocation of waters. These rules were adopted in August 1980.

Minnesota Rules, Part 6115.0620 requires that a permit be obtained for appropriation of water in excess of 10,000 gallons per day or one million gallons per year. In order to obtain a permit to appropriate water the applicant must own or control (lease or rent) land abutting the surface water source or overlying the groundwater source. Applications are evaluated to determine the effects of the proposal on the environment and other higher priority water users.

In 1973, the legislature established five priority classes for appropriation and use of water (in descending priority):

1. domestic water supply, excluding industrial and commercial uses of municipal water supplies;
2. any use of water involving consumption of less than 10,000 gallons per day;
3. agricultural irrigation and processing of agricultural products;
4. power production; and
5. all other uses, involving consumption in excess of 10,000 gallons per day.

These priorities become important in resolving water use conflicts when competing demands exceed the reasonably available supply of water. If the conflict cannot be resolved by other alternatives, the above priorities are used. Highest priority water users are satisfied first and any remaining available water supply is allocated to the next succeeding priority water users.

While environmental protection is not given in the priority system, it is provided for in Minnesota statutes and rules by the establishment of resource limitations below which no appropriation can occur. These limitations include establishment of protected flows for watercourses, protection elevations for water basins and safe yields for groundwater sources.

Of the 4,200 permitted irrigators in the state, 1,200 pump from surface water sources. Irrigation permits issued for surface water are intended as a supplemental supply in years of normal precipitation. The times when crops need water often coincide with times of low surface water levels. Therefore the DOW has encouraged irrigators since 1975 to use groundwater when an adequate supply exists.

1988 Drought

By late June it was clear that some streams were carrying less water than was necessary to support some uses. When instream flow concerns were raised early in the summer of 1988, the Division of Waters immediately began field surveys and data reviews necessary to establish emergency protected flows for the Sauk and Long Prairie watersheds.

While the drought affected all rivers in Minnesota, the smaller rivers were the first to show the greatest impact. Suspension of appropriations within some of these smaller watersheds was instituted to protect the instream flow requirements and the rights of higher priority water users.

During the summer of 1988, permits were suspended in 13 watersheds where river levels were at critically low levels or were below established protected flows (Figure 5.1). A total of 195 surface water permits were suspended including 167 for agricultural irrigation, 17 for golf courses and 11 for other types of appropriations (Appendix G).

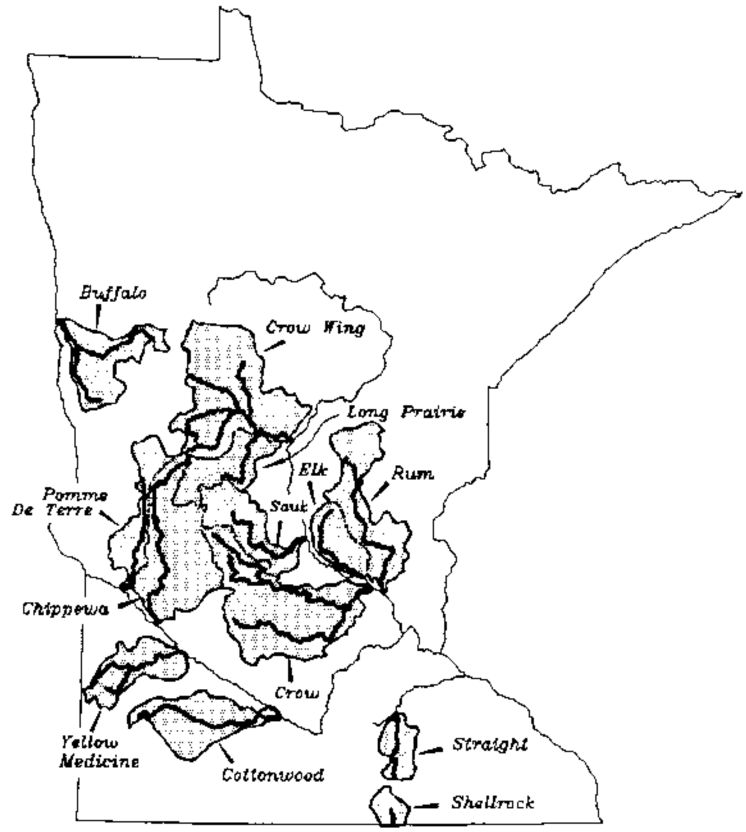
Six of the suspended watersheds are tributary to the Upper Mississippi River above the Twin Cities Metropolitan Area. These suspensions were perceived by the appropriators and by other people outside the metro area as actions taken to preserve water for lawn watering and other nonessential uses in the Twin Cities.

Several days before surface water appropriators were notified in writing to turn off their pumps, an attempt was made to break the news to them by phone. Many irrigators took the news surprisingly well. Some expected the action since they recognized that the river flows were, in some cases, the lowest ever recorded. In the extreme case, there simply wasn't any water to appropriate (see photograph on page 37). In other instances, the suspensions occurred in late July and early August after crops were well established.

Protection Elevations

Minnesota Statutes and Water Appropriation Rules provide for the establishment of protection elevations for waterbasins in addition to protected flow provisions. The protection elevation is the water elevation below which no appropriation can occur. It is defined as "...the water level of the basin necessary to maintain fish and wildlife habitat, existing uses of the surface of the basin by the public and riparian landowners,

Figure 5.1
Watersheds with Suspended Appropriation Permits (Summer 1988)



Pomme de Terre River near Appleton in Swift County (August 10, 1988)

Photograph courtesy of Dan Zappetillo

and other values which must be preserved in the public interest" [Minnesota Rules, Part 6115.0630].

Lake levels declined as the drought continued through the summer. Waterbasins with permitted water appropriations were monitored by regional staff. In watersheds where water appropriation permits were suspended on watercourses, they were also suspended on the waterbasins. Permits were suspended on 17 waterbasins in six watersheds.

Well Interference

Groundwater was a less visible issue during the drought than surface water issues involving the Twin Cities water supply or suspension of appropriation permits. The drought did place higher demands on groundwater which resulted in some municipal wells breaking suction. Lowering of pump intakes or water use restrictions were the most common actions taken to resolve these problems.

There were many inquiries from domestic well owners alleging well interference due to irrigation. However, there have been only 21 formal complaints received so far. Domestic wells must be inspected by a licensed well driller to determine if the problem is caused by poor well construction or other causes before investigation by the Department. If the complaint is valid, the appropriator is responsible for providing the higher priority domestic well owner with an adequate water supply. There have been several valid well interference complaints this year. Without adequate recharge there may be many more well interference situations this year.

PROTECTED WATERS PERMITS

While the major focus of the DOW this past year has been on appropriations, there has also been a dramatic increase in the number of permit applications for work in a protected water. Navigational access became a number one priority for many lakeshore owners. Also, the generally lower water levels in streams and lakes provided the opportunity to complete projects previously not required or feasible during the years of generally high water levels.

The increase in permit applications first became apparent in fiscal year 1988 (July 1, 1987 to June 30, 1988) and has continued through the first half of FY 89 as the table below indicates:

Fiscal Year	Permit Applications
1986	1006
1987	1021
1988	1622
1989*	1024

*July 1, 1988 through November 1988

OUTLOOK FOR 1989

The green lawns brought about by the August rains and cooler fall temperatures may have given the false impression that the drought is over! The drought may have left the public consciousness for now, but the drought is not over. At the end of November 1988, the NWS Climate Analysis Center still classified seven of nine Minnesota regions as having Palmer Drought indices of "mild to severe" drought. Only the north central and northwest regions have "moist" indices. Much of the state still requires more than 4 inches of precipitation over normal amounts to reduce the Palmer Drought Severity Index to zero. Soil moisture profiles need replenishment, shallow aquifers need to be recharged, and surface waters such as wetlands, rivers, and lakes need to be refilled. Without adequate spring moisture the outlook for the 1989 growing season will be as sketchy as it was entering 1988.

The hydrologic systems affected by nearly two years of drought will be slow to respond. During the period of unfrozen ground, incoming precipitation will directly impact soil moisture reserves. The slightly above normal September through November rains, accompanied by normally cool fall temperatures and a lack of actively growing plants, have led to a partial recovery of soil moisture in much of Minnesota. Being more dependent on runoff for replenishment, lakes and rivers will be slower to recover. Groundwater can be expected to gain only after soil moisture reserves and surface water systems have returned to a more normal state.

On a longer scale, the traditional best guess as to what comes next has been that the weather tends to return to normal conditions. Such a climatological forecast indicates that extreme drought tends to last less than 12 months in all climate regions in Minnesota. However, during the early 1930's extreme drought lasted as long as 40 months in our west central region. If the past can be used as a model of the future, extreme drought should tend to end before the middle of this summer. Of course there is still a chance that the drought may continue for another year or two.

Even with normal amounts of precipitation throughout 1989, drought conditions will not necessarily vanish. The timing of rainfall and temperatures can be as important as the amount of rainfall. A hot, dry spring could easily deplete soil moisture in the upper portions of the soil profile. Moderate temperatures and timely rains for seed germination and plant growth throughout the growing season will be required for reasonable farm yields.

Normal precipitation during 1989 will help streamflow and lake levels. However, normal amounts of precipitation will likely not be sufficient to cause measurable runoff which most directly affects streamflow and lake levels. Since groundwater levels will be the last to respond to a return to normal precipitation, there will likely be additional well interference complaints during the summer of 1989. This pattern would be similar to that of 1976-77 where the most interference complaints were received the summer following the severe drought of 1976.

FUTURE CONSIDERATIONS

The fact that Minnesota is blessed with abundant water does not preclude periodic shortages. The 1988 drought dramatically illustrates how quickly several years of excess precipitation can change to widespread drought. As the state's population, industry and power production needs increase, so too will the demand for high quality water. Future conflicts over the allocation of water will also increase unless alternative supplies are developed and increased conservation measures are employed. Drought is a natural phenomenon which has occurred in the past and will occur again. The challenge to public and private agencies is to wisely manage the precious water resources of this state.

This past summer also demonstrated the continuing need for wise land use management. In many areas, the dry, hot summer and blowing dust elicited comparisons to the "Dust Bowl" years of the 1930's. Have we not learned how to control wind and water erosion in the last 50 years? Or are attitudes regarding land and water stewardship really unchanged during this period?

The Minnesota River dramatically demonstrates the consequences of uncontrolled soil erosion and nonpoint source pollution. Symptoms include a river channel clogged with sediment, baseflow reduced by the continual drainage of wetlands and extremely poor water quality.

The problems are well-known and reasonably well-understood. But difficult decisions remain. Land practices to reduce erosion may no longer be a luxury, but a necessity. To encourage conservation, water utility rate structures may need to penalize those homeowners/businesses who insist on maintaining a "manicured" green lawn even during the driest summer. Water conservation measures may need to become mandatory, not just voluntary. How these issues are addressed in the next several years will largely dictate how well the state fares during the next drought.

POSITIVE ASPECTS

Before discussing specific recommendations, a few words are needed regarding positive aspects of the 1988 drought. The Drought Task Force established by Governor Perpich should be at the top of the list. The task force presented an excellent opportunity for numerous public agencies and private organizations to discuss all aspects of the drought. All sides had the opportunity to present their side of the story. At each meeting the most up-to-date and best available information was presented, limiting the spread of rumors and misinformation. A sense of cooperation was largely achieved through the sharing of ideas and open discussion. A consensus was reached on many difficult issues.

This cooperation extended down to the daily interaction at the staff level of involved agencies. Requests for data were generally honored at a moment's notice. The USGS and NWS were extremely helpful in providing streamflow data. The COE regularly provided headwater reservoir level data. Volunteer gage readers, particularly those organized by the SWCD's, also proved invaluable in providing data that otherwise would have been unobtainable.

Many actions were taken to communicate with the general public in an effective and meaningful way. For example, July and August lake level summaries were prepared for the state Office of Tourism. The Office had been receiving many phone calls regarding lake accessibility with respect to the drought. With the lake level summary, their operators were then generally able to answer the calls that would otherwise have been referred to the DNR. Similarly, the DNR Bureau of Information and Education was very effective in preparing press releases, as well as providing names and phone numbers of key staff to respond to specific inquiries. All actions which reduce the number of phone calls and telephone transfers are beneficial to both the DNR and the general public.

Finally, the media stayed involved throughout the drought, generally providing excellent coverage and presenting all sides of the issues. The negative aspect (but well worth the effort) is the time-consuming nature of keeping the media informed. Since the drought was a statewide and national issue, it was not just the Twin Cities media requesting information and interviews, but radio and television stations and newspaper offices throughout Minnesota and the United States. The number of phone messages from the media was overwhelming at times. The phone calls were too numerous for only task force members to handle; therefore it was important that accurate information was passed to others, including regional staff.

FUTURE ACTIONS

In 1985, the Legislative Commission on Minnesota Resources (LCMR) funded a two year Water Allocation and Management Study. The principal participating agencies included the DNR, USGS, Natural Resources Research Institute and the Water Resources Research Center. In the summary report, *The Economic Value of Water*, four of their seven recommendations have particular relevance to the 1988 drought.

1. Re-evaluate the Current Water Allocation Framework.

No water allocation policy can be expected to resolve all problems arising from a constraint on water supplies. Therefore, current statutes and rules should be re-evaluated and more appropriate guidelines and procedures should be established.

An example that is often cited is how are irrigators going to use electric pumps if power producers are shut down before irrigators. This example shows the importance of power production in today's society and the widespread economic impacts that could occur without alternative power sources.

The solution to this problem is not as easy as changing power production from fourth priority to second priority. The differences in water use also need to be considered. Agricultural irrigation accounts for only 5 percent of the total water use in Minnesota and only 1 percent of the total surface water use. On the other hand, power production uses about 50 percent of the total water use, but less than 1 percent of the total groundwater use in Minnesota. There are only a few instances of actual conflict between irrigators and power producers because they utilize different sources of water. Therefore, proposed changes to the water use priorities need to be based on actual, rather than perceived, conflicts with the existing system.

Minnesota Rules (Parts 6115.0600-6115.0810) regarding appropriation of water relate mostly to agricultural irrigation. Although 4000 of the 6000 active permits authorize appropriation for agricultural purposes, irrigators only account for 5 percent of the total water use. These rules should be expanded to further address larger water users in the last two water use priority classes. The environmental and economic impacts relating to these lower priority water uses also need to be evaluated.

Water appropriation rules also need to be updated to reflect new trends in water use like pumpouts for contamination confinement and removal. Most of these pumpouts discharge water to sanitary or storm sewers. There may be alternative uses of this water which should be considered such as noncontact cooling or treatment and reuse of the water for municipal purposes.

2. Expand Data Collection Activities.

The 1988 drought highlighted the importance of accurate, timely data to informed and effective planning and policy decisions. Several specific areas need improvement:

Instream Flow Requirements - The protection of instream flow values is not an exact science. The DNR is currently developing a statewide instream flow program under LCMR funding. The DOW is coordinating program development with the DNR Division of Fish & Wildlife and the U.S. Fish & Wildlife Service. The 1988 drought was a good opportunity to test theories and the existing water allocation program, especially for surface waters. Data collected and methods evaluated and developed under the LCMR project proved invaluable in the analysis of low flow conditions. However, much work and study is still required to improve our ability to establish reasonable protected flows.

Instream flow conditions that were observed during this past summer indicate that some of the existing protected flows need to be re-evaluated. Additional hydrologic and biologic data need to be collected for this purpose.

Data - The second major area that needs work is the availability of streamflow and groundwater data. Expanded data collection of both surface and groundwater are needed for crisis management and program implementation and evaluation. Surface water appropriation permits were suspended in thirteen watersheds. Some of the streams had gaging stations, others did not. As a result, several of the suspensions occurred well after the streams had receded below their protected flow level. Virtually no data are available for the remaining streams in which appropriations were not suspended.

A key to effective instream flow protection is monitoring. All streams having established protected flows should be periodically monitored, especially during dry periods. The USGS monthly stream flow summaries (see Figure 4.1) could provide an initial warning system as to those areas of the state with deficient streamflow.

Groundwater Investigations - Groundwater is the predominate source of water supply throughout Minnesota. The current drought has created an awareness that groundwater supplies are not uniformly distributed and that some areas may not have enough groundwater to satisfy everyone's needs. In order to further the management of groundwater supplies to assure long-term availability for all users, water managers must have:

- an understanding of the physical system and its dynamics;
- tools for predicting impacts of water withdrawals and forecasting available supplies; and
- follow-up monitoring to verify forecasts and adjust management strategies.

To gain this knowledge and capability, specific actions are required:

- to accelerate the investigation of aquifers (particularly in high-use areas);
- to examine ground/surface water relationships;
- to maintain and expand our groundwater level monitoring;
- to initiate specific studies in high-use areas for the development of aquifer management plans; and
- to assist with county and regional hydrogeological assessments.

3. Expand Water Conservation Measures.

In most cases conservation of municipal water supplies occurs only when treatment facilities reach capacity or when the resource cannot supply the demand. Municipalities usually construct new wells to supply peak demands rather than developing and implementing long-term conservation plans. Peak municipal water demands are primarily caused by lawn sprinkling, car washing, golf course and park irrigation and other nonessential uses. The approval for construction of new wells to supply peak demands should be contingent on the municipality having an adequate conservation plan that includes a pricing structure to reduce water use.

Appropriation permits require water conservation, but the most effective conservation measures are taken by individual water users at the local level. A water conservation program which would provide public education and technical assistance for local conservation planning is needed.

4. Establish Surface Water Allocation Plans.

The water use priorities are important in allocating available water above resource protection limits. However, allocation planning is needed to provide the maximum use of limited water supplies among all users within a priority class. Appropriators using surface water sources need to develop allocation plans to efficiently use the resource.

When water levels reach a protection limit, permitted appropriators are notified to cease water withdrawals. Suspension of appropriations continues until the level of the resource is above the protection limit plus the total draft of all authorized appropriations. However, with an approved allocation plan, appropriation could occur sooner as long as the water level of the resource is above the protection limit. While this may not allow everyone to pump all the water they want, it would provide for the earliest reinstatement of limited water withdrawals.

Allocation plans are developed for surface water sources by local water users within a defined area. Because all water users must agree to the allocation plan to make it work, existing and proposed users are responsible for the actual development of allocation plans. This provides local participation in planning and resolution of water user conflicts to better serve local interests. The DNR will assist with the development process.

The DNR will be notifying suspended appropriators to take advantage of the benefits that allocation planning offers.

Drought Task Force

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MISSISSIPPI RIVER NEAR ANOKA

EXTENDED FLOW FORECASTS 12/19/88

#0528850

National Weather Service -- River forecast center

*Assumes No Additional Rainfall

Forecasted Flow Date	DATE FORECAST ISSUED Jul. 6	Jul. 13	Jul. 20	Jul. 27	Aug. 3	Aug. 10	Aug. 17	Aug. 24	Aug. 31	Sept. 7	Sept. 14	Sept. 21
	(1070)	----	----	----	----	----	----	----	----	----	----	----
07/13	800	(1100)	----	----	----	----	----	----	----	----	----	----
07/20	700	1050	(1210)	----	----	----	----	----	----	----	----	----
07/27	600	750	850	(944)	----	----	----	----	----	----	----	----
08/03	550	600	750	800	(1300)	----	----	----	----	----	----	----
08/10	----	550	650	700	1100	(1280)	----	----	----	----	----	----
08/17	----	----	600	650	900	1070	(1780)	----	----	----	----	----
08/24	----	----	----	600	750	880	4500	(5190)	----	----	----	----
08/31	----	----	----	----	700	760	400	3900	(3550)	----	----	----
09/07	----	----	----	----	----	700	2500	2700	2700	(2300)	----	----
09/14	----	----	----	----	----	----	1500	2200	2100	2300	(2000)	----
09/21	----	----	----	----	----	----	----	1700	1800	1900	1700	(2640)
09/28	----	----	----	----	----	----	----	----	1500	1600	1500	3500
10/05	----	----	----	----	----	----	----	----	----	1400	1400	2800
10/12	----	----	----	----	----	----	----	----	----	----	1300	2100
10/19	----	----	----	----	----	----	----	----	----	----	----	1600

( ) -OBSERVED FLOW ON DAY OF FORECAST

**********RESERVOIR ELEVATION DATA*********
(Data collected from COE)

12/29/88

WINNIBIGOSHISH		LEECH LAKE		POKEGAMA LAKE		SANDY LAKE		PINE RIVER		GULL LAKE	
Date	Elev(ft)	Date	Elev(ft)	Date	Elev(ft)	Date	Elev(ft)	Date	Elev(ft)	Date	Elev(ft)
01-May	1298.06	01-May	1294.04	01-May	1272.73	01-May	1216.15	01-May	1228.73	01-May	1193.84
07-May	1298.01	07-May	1294	07-May	1272.9	07-May	1216.21	07-May	1228.76	07-May	1193.86
14-May	1298.14	14-May	1294.07	14-May	1272.98	14-May	1216.55	14-May	1228.93	14-May	1193.94
21-May	1298.18	21-May	1294.13	21-May	1272.83	21-May	1216.4	21-May	1228.99	21-May	1193.95
28-May	1298.17	28-May	1294	28-May	1272.98	28-May	1216.3	28-May	1229.05	28-May	1194
04-Jun	1298.13	04-Jun	1294.15	04-Jun	1273.17	04-Jun	1216.31	04-Jun	1229.05	04-Jun	1193.99
11-Jun	1298.06	11-Jun	1294	11-Jun	1273.11	11-Jun	1216.22	11-Jun	1228.99	11-Jun	1193.87
18-Jun	1298.02	18-Jun	1293.94	18-Jun	1273.06	18-Jun	1216.27	18-Jun	1228.94	18-Jun	1193.84
27-Jun	1298.05	26-Jun	1293.95	26-Jun	1273.35	27-Jun	1216.17	27-Jun	1228.93	27-Jun	1193.84
30-Jun	1297.96	30-Jun	1293.86	30-Jun	1273.32	30-Jun	1216.17	30-Jun	1228.86	30-Jun	1193.78
07-Jul	1298.03	07-Jul	1293.97	07-Jul	1273.2	07-Jul	1216.07	07-Jul	1228.79	07-Jul	1193.67
11-Jul	1298.05	14-Jul	1293.87	11-Jul	1273.19	11-Jul	1216.04	11-Jul	1228.78	11-Jul	1193.64
14-Jul	1298.08	18-Jul	1293.79	14-Jul	1273.16	14-Jul	1216.02	14-Jul	1228.78	14-Jul	1193.71
18-Jul	1297.98	25-Jul	1293.74	18-Jul	1273.1	18-Jul	1215.94	18-Jul	1228.71	18-Jul	1193.65
21-Jul	1297.95	28-Jul	1293.72	21-Jul	1273.04	21-Jul	1215.94	21-Jul	1228.67	21-Jul	1193.62
25-Jul	1297.93	01-Aug	1293.61	25-Jul	1273.07	25-Jul	1215.88	25-Jul	1228.61	25-Jul	1193.56
28-Jul	1297.88	04-Aug	1293.78	01-Aug	1272.95	28-Jul	1215.82	01-Aug	1228.51	28-Jul	1193.5
01-Aug	1297.85	08-Aug	1293.86	04-Aug	1273.06	01-Aug	1215.77	04-Aug	1228.59	01-Aug	1193.53
04-Aug	1297.99	11-Aug	1293.81	08-Aug	1273.18	04-Aug	1215.79	05-Aug	1228.61	04-Aug	1193.53
11-Aug	1298.06	13-Aug	1294.2	11-Aug	1273.15	11-Aug	1215.69	08-Aug	1228.6	08-Aug	1193.56
15-Aug	1298.25	15-Aug	1294.22	15-Aug	1273.95	15-Aug	1215.87	11-Aug	1228.54	11-Aug	1193.48
17-Aug	1298.23	22-Aug	1294.16	18-Aug	1273.81	18-Aug	1215.83	14-Aug	1228.82	15-Aug	1193.81
18-Aug	1298.21	31-Aug	1294.04	22-Aug	1273.79	22-Aug	1215.79	15-Aug	1228.8	22-Aug	1193.78
22-Aug	1298.16	06-Sep	1294.15	01-Sep	1273.65	01-Sep	1215.79	22-Aug	1228.76	01-Sep	1193.77
01-Sep	1298.13	09-Sep	1294.22	06-Sep	1273.79	06-Sep	1215.73	01-Sep	1228.78	06-Sep	1193.72
06-Sep	1298.09	12-Sep	1294.02	09-Sep	1273.75	08-Sep	1215.69	06-Sep	1228.79	08-Sep	1193.7
08-Sep	1298.06	15-Sep	1294.03	12-Sep	1273.69	12-Sep	1215.66	09-Sep	1228.77	12-Sep	1193.67
12-Sep	1298.09	19-Sep	1294.21	15-Sep	1273.61	15-Sep	1215.65	12-Sep	1228.76	15-Sep	1193.62
15-Sep	1297.9	22-Sep	1294.17	19-Sep	1273.84	19-Sep	1215.82	15-Sep	1228.7	20-Sep	1194.01
19-Sep	1298.08	26-Sep	1294.12	22-Sep	1274.02	22-Sep	1215.86	19-Sep	1228.92	22-Sep	1194.02
22-Sep	1298.17	03-Oct	1294.25	26-Sep	1273.84	26-Sep	1215.84	22-Sep	1229.09	26-Sep	1193.99
26-Sep	1298.12	06-Oct	1294.13	03-Oct	1273.84	03-Oct	1215.92	26-Sep	1229.14	03-Oct	1193.96
03-Oct	1298.5	11-Oct	1294.06	05-Oct	1273.40	06-Oct	1215.89	03-Oct	1229.28	06-Oct	1193.87
06-Oct	1298.16	14-Oct	1294.05	11-Oct	1273.25	11-Oct	1215.83	06-Oct	1229.23	11-Oct	1193.84
11-Oct	1298.17	17-Oct	1294.07	14-Oct	1273.15	14-Oct	1215.79	11-Oct	1229.23	14-Oct	1193.8
14-Oct	1298.13	19-Oct	1294.02	17-Oct	1273.13	17-Oct	1215.77	14-Oct	1229.19	17-Oct	1193.81
17-Oct	1298.18	24-Oct	1294.03	20-Oct	1273.08	20-Oct	1215.78	17-Oct	1229.18	20-Oct	1193.79
20-Oct	1298.14	31-Oct	1293.97	24-Oct	1273.06	24-Oct	1215.75	20-Oct	1229.19	24-Oct	1193.78
24-Oct	1298.27	10-Nov	1293.92	31-Oct	1272.75	31-Oct	1215.74	24-Oct	1229.26	31-Oct	1193.72
31-Oct	1298.15	17-Nov	1293.96	10-Nov	1272.36	10-Nov	1215.71	31-Oct	1229.18	10-Nov	1193.69
10-Nov	1298.25	22-Nov	1294.03	17-Nov	1272.3	17-Nov	1215.87	10-Nov	1229.22	17-Nov	1193.83
17-Nov	1298.45			21-Nov	1272	21-Nov	1215.96	17-Nov	1229.2	18-Nov	1193.83
21-Nov	1298.37							18-Nov	1229.14	21-Nov	1193.81

1988 MISCELLANEOUS DISCHARGE MEASUREMENTS
Mn. Dept. of Natural Resources - Division of Waters Dec-88

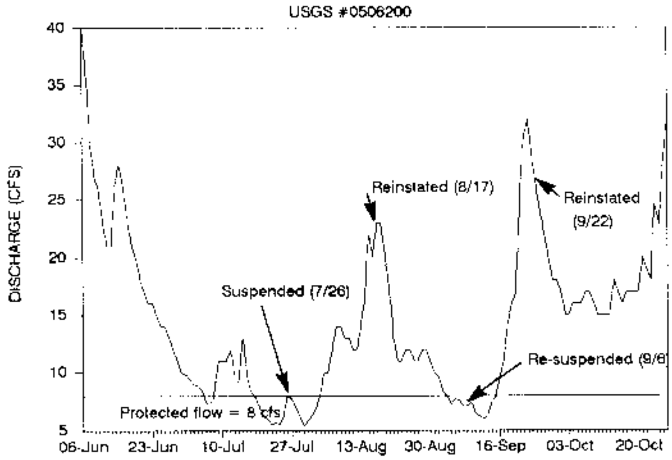
RIVER	SITE DESCRIPTION	DATE	Q (CFS)	GAGE HEIGHT (F
ASHLEY CREEK	@ Todd CSAH 11 bridge	07/20/88	no flow	ungaged
ASHLEY CREEK	@ Todd CSAH 11 bridge	08/16/88	2.68	.69
CEDAR RIV	200 ft upstream Co Hwy 6 bridge	06/30/88	75.8	ungaged
CEDAR RIV	200 ft upstream Co Hwy 6 bridge	07/13/88	183.5	ungaged
CEDAR RIV	200 ft upstream Co Hwy 6 bridge	08/11/88	70.1	ungaged
ELK	@ Sherburne CSAH 4 bridge	06/16/88	7.88	ungaged
ELK	@ Sherburne CSAH 6 bridge	06/16/88	*	ungaged
ELK	@ Sherburne CSAH 5 bridge	06/16/88	16.54	ungaged
ELK	@ Sherburne CSAH 3 bridge	06/16/88	*	ungaged
ELK	@ Sherburne Co. Rd 54 bridge	06/16/88	15.72	ungaged
ELK	@ Benton CSAH 4 near Popple Creek, MN	06/16/88	1.57	ungaged
ELK	@ State Hwy 25 bridge near Becker, MN	07/07/88	4.76	.66
ELK	@ State Hwy 25 bridge near Becker, MN	07/20/88	7.58	.81
ELK	@ State Hwy 25 bridge near Becker, MN	08/16/88	10.38	.84
LNG PRAIRIE	@ Todd Csah 11 bridge near Long Prairie	06/29/88	9.4	ungaged
LNG PRAIRIE	@ Todd Csah 14 near Browerville, MN	06/30/88	12.8	ungaged
LNG PRAIRIE	@ Todd Co Rd 79 near Browerville, MN	06/30/88	17	ungaged
LNG PRAIRIE	@ RR bridge off Todd Co Rd 83 nr Motley, MN	07/01/88	21	ungaged
LNG PRAIRIE	@ U.S. Hwy 10 bridge near Motley, MN	07/11/88	17.6	1.48
LNG PRAIRIE	@ U.S. Hwy 10 bridge near Motley, MN	07/21/88	22.8	1.64
LNG PRAIRIE	@ U.S. Hwy 10 bridge near Motley, MN	08/16/88	76.5	2.02
MID. FK CROW	@ unnamed twp Rd 2 miles W of Manannah, MN	07/22/88	3.30	ungaged
MORAN CREEK	@ Todd CSAH 21 bridge	07/11/88	1	ungaged
MORAN CREEK	@ Bridge on unnamed twp Rd nr Staples, MN	07/21/88	no flow	ungaged
MORAN CREEK	@ Todd Co Rd 74 bridge near Staples, MN	07/21/88	1.30	.72
MORAN CREEK	@ Todd Co Rd 74 bridge near Staples, MN	08/16/88	10	1.08
N BRCH ROOT	200 Ft upstream of quarry	06/21/88	5.61	ungaged
N BRCH ROOT	200 Ft upstream of quarry	07/29/88	2.07	ungaged
N FK ZUMBRO	Nr Wanamingo 30 ft upstrm of Shingle Crk	06/16/88	14.82	ungaged
N FK ZUMBRO	50 ft dwnstrm where Trout Brook enters	06/23/88	31.3	ungaged
N FK ZUMBRO	50 ft dwnstrm where Trout Brook enters	07/19/88	653.1	ungaged
N FK ZUMBRO	50 ft dwnstrm where Trout Brook enters	07/27/88	652.8	ungaged
N FK ZUMBRO	Nr Wanamingo 30 ft upstrm of Shingle Crk	08/09/88	3.70	ungaged
N FORK CROW	@ 182nd St. NE, 3 miles W of Paynesville, MN	07/22/88	no flow	ungaged
N FORK CROW	@ State Hwy 23 bridge in Paynesville, MN	07/22/88	1.47	ungaged
PRAIRIE CRK	Sectn 16 T112N R18W 20' upstm of culverts	06/23/88	12.2	ungaged
PRAIRIE CRK	Sectn 16 T112N R18W 20' upstm of culverts	07/13/88	12.9	ungaged
PRAIRIE CRK	Sectn 16 T112N R18W 20' upstm of culverts	07/19/88	9.5	ungaged
PRAIRIE CRK	Sectn 16 T112N R18W 20' upstm of culverts	07/27/88	9.3	ungaged
PRAIRIE CRK	Sectn 16 T112N R18W 20' upstm of culverts	08/02/88	7.1	ungaged
PRAIRIE CRK	Sectn 16 T112N R18W 20' upstm of culverts	08/03/88	8.5	ungaged
PRAIRIE CRK	Sectn 16 T112N R18W 20' upstm of culverts	08/09/88	9.09	ungaged
PRAIRIE CRK	Sectn 16 T112N R18W 20' upstm of culverts	08/12/88	7.71	ungaged
PRAIRIE CRK	Sectn 16 T112N R18W 20' upstm of culverts	08/15/88	7.9	ungaged
ROOT RIVER	Section 16, T103N, R9W in Whalen	07/29/88	193.85	ungaged
SAUK	@ Stearns CSAH 14, near Spring Hill, MN	06/23/88	12.4	ungaged
SAUK	@ Stearns CSAH 14, near Spring Hill, MN	07/08/88	3.9	.35

SAUK	@ Stearns CSAH 14, near Spring Hill, MN	08/16/88	15.2	.58
SAUK	@ Stearns CSAH 14, near Spring Hill, MN	08/16/88	1.25	.58
SAUK	@ Waite Park, MN	06/24/88	13	ungaged
SAUK	@ Stearns CSAH 17, near Sauk Centre, MN	07/08/88	.83	.36
SAUK	@ Stearns CSAH 17, near Sauk Centre, MN	07/21/88	4.20	ungaged
SAUK	Near jnct. of CSAH 4 & 134 @ St. Cloud, MN	07/20/88	1.09	.46
SHELL ROCK	Under Hwy bridge on Co Rd 13 in Glennville	06/23/88	14.7	ungaged
SHELL ROCK	Under Hwy bridge on Co Rd 13 in Glennville	06/29/88	13.63	3.75
SHELL ROCK	Under Hwy bridge on Co Rd 13 in Glennville	07/06/88	7.31	3.62
SHELL ROCK	Under Hwy bridge on Co Rd 13 in Glennville	07/15/88	10.4	3.68
SHELL ROCK	Under Hwy bridge on Co Rd 13 in Glennville	07/21/88	6.9	3.64
SHELL ROCK	Under Hwy bridge on Co Rd 13 in Glennville	07/26/88	4.39	3.57
SHELL ROCK	Under Hwy bridge on Co Rd 13 in Glennville	08/01/88	3.90	3.56
SHELL ROCK	Under Hwy bridge on Co Rd 13 in Glennville	08/02/88	11.39	3.74
SHELL ROCK	Under Hwy bridge on Co Rd 13 in Glennville	08/09/88	7.73	3.66
SHELL ROCK	Under Hwy bridge on Co Rd 13 in Glennville	08/11/88	10	3.74
SHELL ROCK	Under Hwy bridge on Co Rd 13 in Glennville	08/15/88	3.16	3.51
SHELL ROCK	Under Hwy bridge on Co Rd 13 in Glennville	08/17/88	not meas.	3.60
SHELL ROCK	Under Hwy bridge on Co Rd 13 in Glennville	08/22/88	not meas.	3.70
SHELL ROCK	Under Hwy bridge on Co Rd 13 in Glennville	08/29/88	not meas.	3.56
SHELL ROCK	Under Hwy bridge on Co Rd 13 in Glennville	09/06/88	not meas.	3.48
SHELL ROCK	Under Hwy bridge on Co Rd 13 in Glennville	09/21/88	not meas.	3.70
SHELL ROCK	Br on Co Hwy 1 near Gordansville	06/29/88	16.9	3.76
SHELL ROCK	Br on Co Hwy 1 near Gordansville	07/06/88	8.8	3.63
SHELL ROCK	Br on Co Hwy 1 near Gordansville	07/15/88	12.6	3.69
SHELL ROCK	Br on Co Hwy 1 near Gordansville	07/21/88	9.9	3.66
SHELL ROCK	Br on Co Hwy 1 near Gordansville	07/26/88	5.3	3.58
SHELL ROCK	Br on Co Hwy 1 near Gordansville	08/01/88	3.8	3.57
SHELL ROCK	Br on Co Hwy 1 near Gordansville	08/11/88	14.4	3.76
SHELL ROCK	300 Ft downstream of Co 7 Hwy bridge	07/15/88	12	ungaged
SHELL ROCK	300 Ft downstream of Co 7 Hwy bridge	08/11/88	15.1	ungaged
SILVER CREEK	Under Br. for Silver Creek Rd	06/23/88	.4	ungaged
SKUNK	@ State Hwy 25 bridge nr Genola, MN	07/20/88	2.7	ungaged
SKUNK	@ Bridge on Co Rd 253 near Genola, MN	07/21/88	4.7	.6
SKUNK	@ Bridge on Co Rd 253 near Genola, MN	08/16/88	64.5	1.46
THOMPSON CRK	50 Ft Dwnstrm of Unamed Co Rd bridge	07/05/88	14.3	ungaged
THOMPSON CRK	50 Ft Dwnstrm of Unamed Co Rd bridge	07/12/88	13.8	ungaged
UND TRB ZUMBRO	E side of Rd nr flare culvert, nr Hammond	06/22/88	1.1	ungaged
VERMILLION	@ 170th St E bridge near Hastings, MN	07/25/88	21.9	.76
VERMILLION	@ Dakota CSAH 31 near Farmington, MN	07/25/88	4.44	.44
WEISEL CREEK	20 ft. E of Twp. Rd bridge crossing creek	06/06/88	2.82	ungaged
WEISEL CREEK	20 ft. E of Twp. Rd bridge crossing creek	06/07/88	2.15	7.72
WEISEL CREEK	20 ft. E of Twp. Rd bridge crossing creek	06/21/88	1.79	7.68
WEISEL CREEK	20 ft. E of Twp. Rd bridge crossing creek	07/29/88	.98	7.58

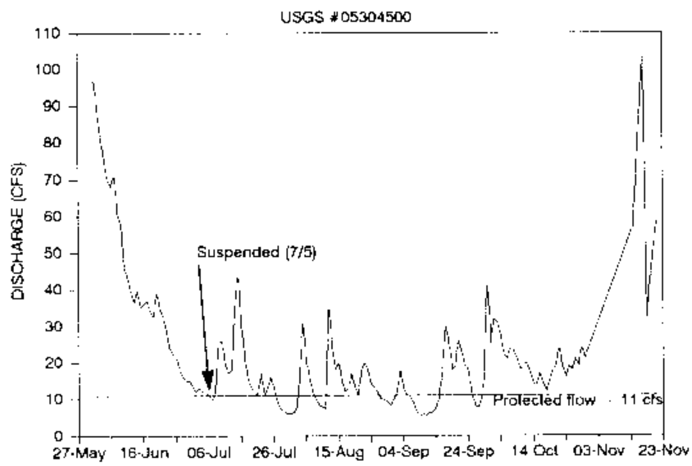
* Discharge less than measurable with available instruments.

APPENDIX E: Hydrographs of Streams with Suspended Appropriations

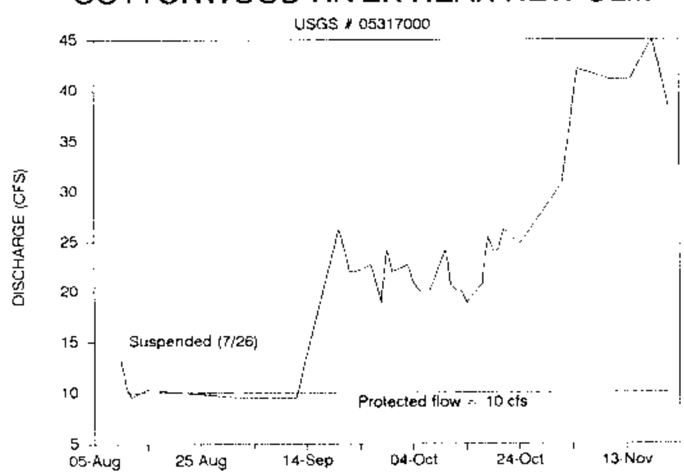
BUFFALO RIVER NEAR DILWORTH



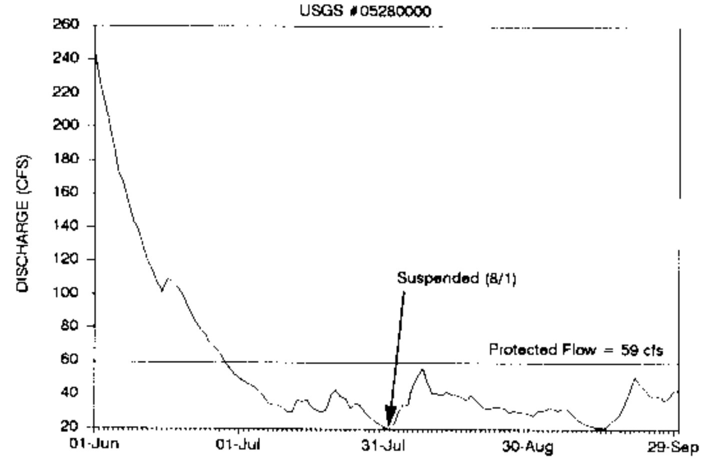
CHIPPEWA RIVER NEAR MILAN, MN



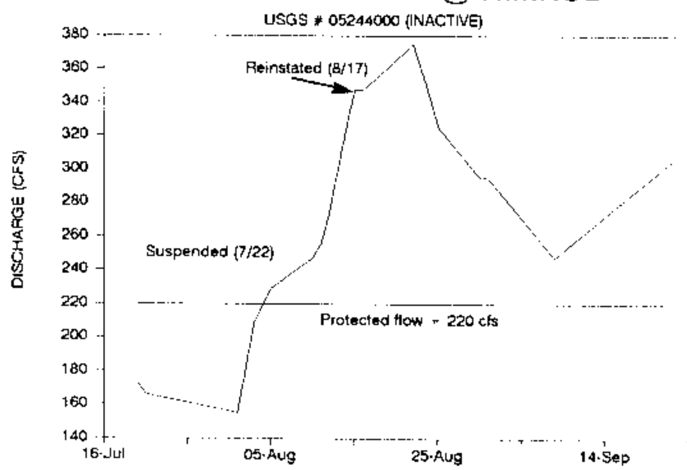
COTTONWOOD RIVER NEAR NEW ULM



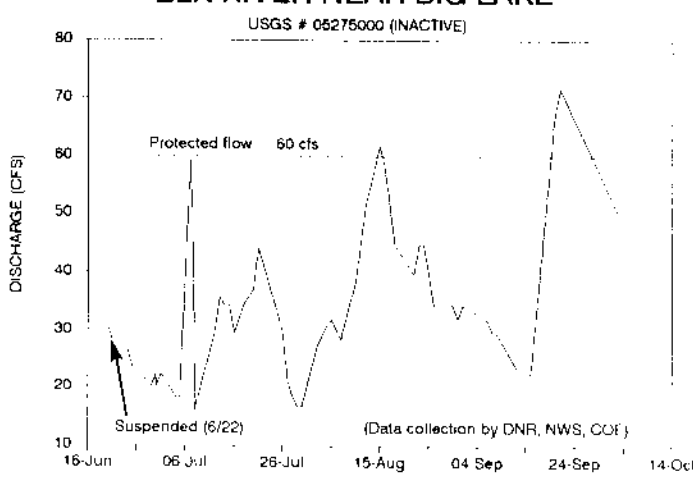
CROW RIVER @ ROCKFORD, MN



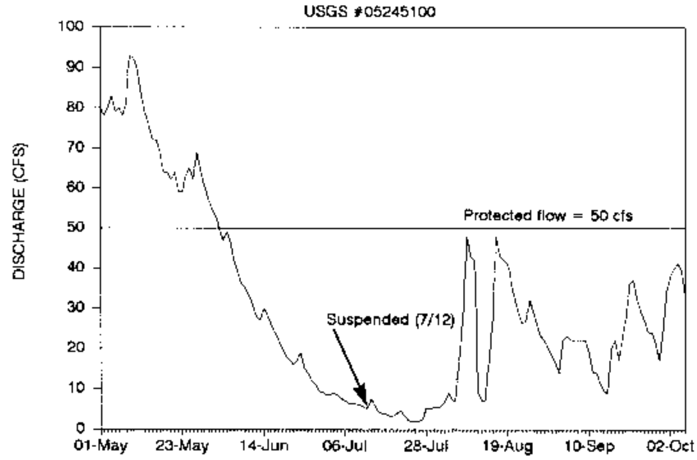
CROW WING RIVER @ NIMROD



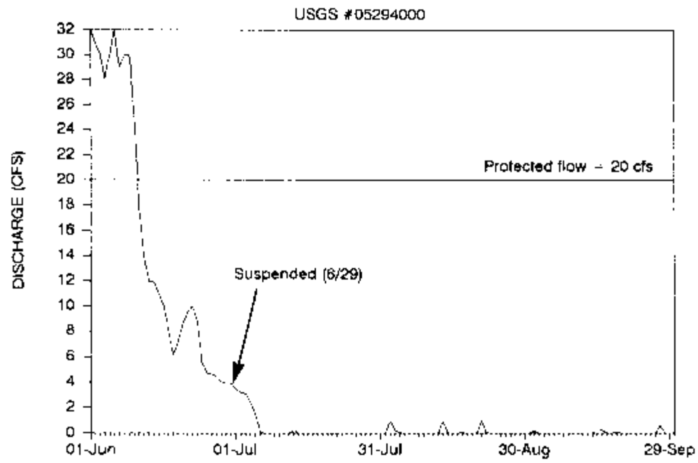
ELK RIVER NEAR BIG LAKE



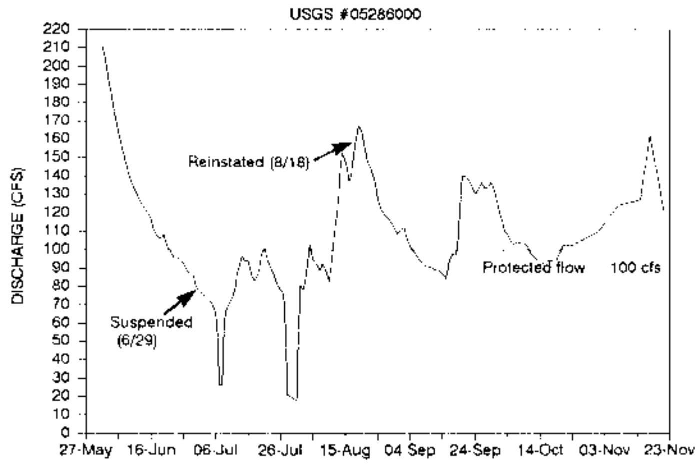
LONG PRAIRIE NEAR LONG PRAIRIE



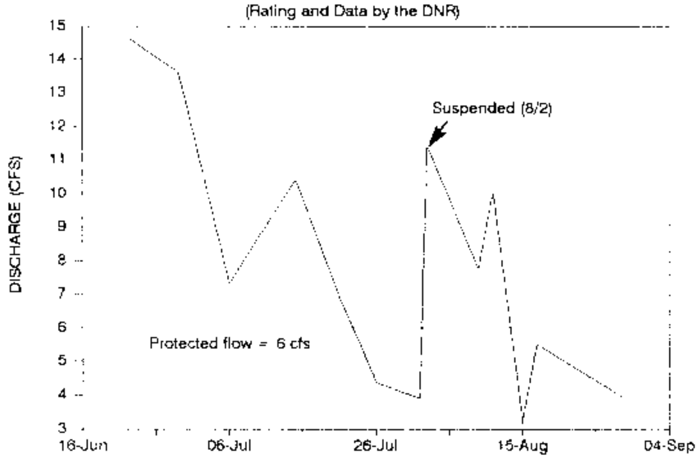
POMME DE TERRE NEAR APPLETON, MN



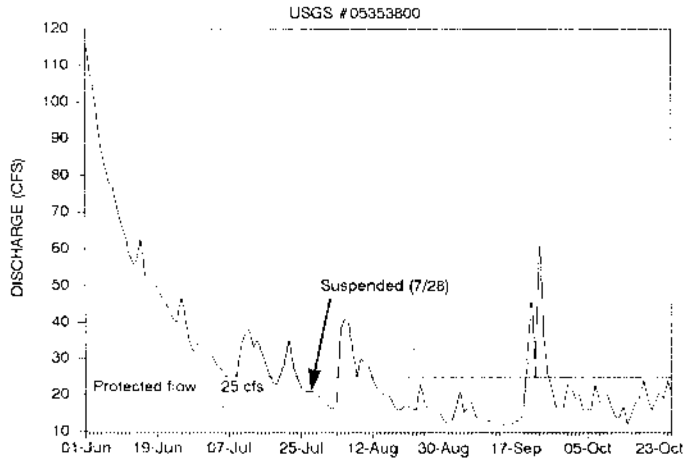
RUM RIVER NEAR ST. FRANCIS, MN



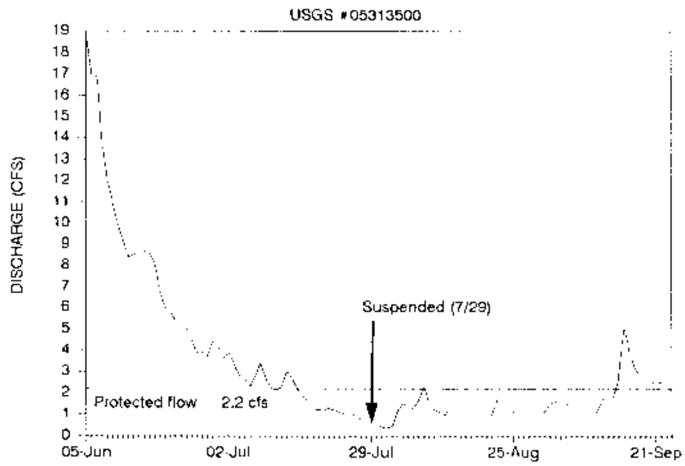
SHELL ROCK @ CO RD 13 IN GLENNVILLE



STRAIGHT RIVER NEAR FARIBAULT, MN



YELLOW MEDICINE NEAR GRANITE FALLS



MnDNR DIVISION of WATERS
LAKES-DB

LAKE LEVEL CHANGE 1986-1988

DNR ID #	LAKE / COUNTY	1986 HIGH	1988 LOW	CHANGE
1-0159-00	FARM ISLAND / AITKIN	1255.91	1254.06	-1.85
1-0176-00	LITTLE PINE / AITKIN	1256.03	1254.15	-1.88
2-0013-00	BALDWIN / ANOKA	883.38	877.73	-5.65
2-0042-00	COON / ANOKA	905.11	900.27	-4.84
2-0026-00	LINWOOD / ANOKA	899.74	897.98	-1.76
3-0576-00	BIG CORMORANT / BECKER	1354.44	1352.05	-2.39
3-0286-00	COTTON / BECKER	1444.00	1441.83	-2.17
3-0195-00	HEIGHT OF LAND / BECKER	1454.32	1452.96	-1.36
3-0588-00	UPPER CORMORANT / BECKER	1354.63	1352.53	-2.10
4-0092-00	GALLAGHER / BELTRAMI	1319.90	1318.70	-1.20
4-0152-00	MOVIL / BELTRAMI	1344.68	1343.75	-0.93
4-0111-00	TURTLE RIVER / BELTRAMI	1309.42	1307.64	-1.78
6-0152-00	BIG STONE / BIG STONE	969.10	965.08	-4.02
7-0098-00	CRYSTAL / BLUE EARTH	971.10	966.70	-4.40
7-0044-00	MADISON / BLUE EARTH	1017.70	1013.69	-4.01
8-0011-00	CLEAR / BROWN	97.18	92.52	-4.66
10-0088-00	HYDES / CARVER	968.47	965.01	-3.46
10-0059-00	WACONIA / CARVER	962.74	958.57	-4.17
11-0413-00	TEN MILE / CASS	1380.18	1378.61	-1.57
13-0053-00	COMFORT / CHISAGO	887.86	885.64	-2.22
13-0041-00	GREEN / CHISAGO	894.33	889.26	-5.07
13-0032-00	NORTH CENTER / CHISAGO	901.68	895.91	-5.77
13-0035-00	NORTH LINDSTROM / CHISAGO	901.68	895.23	-6.45
13-0069-00	RUSH / CHISAGO	915.07	912.47	-2.60
13-0028-00	SOUTH LINDSTROM / CHISAGO	901.68	895.08	-6.60
15-0016-00	ITASCA / CLEARWATER	1467.21	1466.45	-0.76
17-0022-00	COTTONWOOD / COTTONWOOD	1373.11	1367.11	-6.00
18-0305-00	EDWARD / CROW WING	1208.13	1205.46	-2.67
18-0372-00	NORTH LONG / CROW WING	1198.50	1195.81	-2.69
19-0027-00	CRYSTAL / DAKOTA	934.06	932.46	-1.60
19-0026-00	MARION / DAKOTA	982.83	976.45	-6.38
27-0133-00	MINNETONKA / HENNEPIN	930.40	926.00	-4.40
29-0156-00	PLANTAGENET / HUBBARD	1344.00	1341.90	-2.10
31-0813-00	BOWSTRING / ITASCA	1320.86	1317.93	-2.93
31-0882-00	DORA / ITASCA	1320.45	1317.71	-2.74
31-0896-00	ROUND / ITASCA	1321.14	1317.64	-3.50
31-0826-00	SAND / ITASCA	1320.71	1317.77	-2.94
31-0554-00	SISEEBAKWET / ITASCA	1329.81	1328.91	-0.90
31-0877-00	SQUAW / ITASCA	1321.10	1317.34	-3.76
32-0057-05	HERON (NORTH HERON) / JACKSON	1404.23	1398.58	-5.65
32-0057-01	HERON (NORTH MARSH) / JACKSON	1402.56	1398.31	-4.25
32-0057-07	HERON (SOUTH HERON) / JACKSON	1405.30	1398.93	-6.37
33-0028-00	KNIFE / KANABEC	1047.06	1044.83	-2.23
34-0062-00	CALHOUN / KANDIYOHI	1157.72	1154.13	-3.59
34-0204-00	FLORIDA SLOUGH / KANDIYOHI	1122.73	1117.85	-4.88
34-0079-00	GREEN / KANDIYOHI	1158.79	1154.40	-4.39
34-0096-00	LITTLE KANDIYOHI / KANDIYOHI	1105.90	1103.07	-2.83
34-0158-00	MUD / KANDIYOHI	1204.18	1201.96	-2.22
40-0117-00	WASHINGTON / LE SUEUR	983.06	979.04	-4.02
41-0021-00	DEAD COON / LINCOLN	1638.16	1632.86	-5.30
48-0002-00	MILLE LACS / MILLE LACS	1253.10	1249.60	-3.50
48-0009-00	ONAMIA / MILLE LACS	1250.69	1245.20	-5.49

MnDNR DIVISION of WATERS
LAKES-DB

LAKE LEVEL CHANGE 1986-1988

DNR ID #	LAKE / COUNTY	1986 HIGH	1988 LOW	CHANGE
51-0046-00	SHETEK / MURRAY	1485.40	1480.53	-4.87
56-0475-00	PICKEREL / OTTER TAIL	1330.02	1328.57	-1.45
56-0239-00	WEST BATTLE / OTTER TAIL	1333.24	1331.05	-2.19
58-0131-00	FISH / PINE	1115.45	1107.36	-8.09
58-0123-00	GRINDSTONE / PINE	1094.33	1092.29	-2.04
58-0062-00	ISLAND / PINE	1077.01	1074.35	-2.66
58-0081-00	SAND / PINE	1071.78	1067.84	-3.94
58-0067-00	STURGEON / PINE	1070.11	1067.69	-2.42
60-0069-00	SAND HILL / POLK	1273.17	1270.84	-2.33
60-0217-00	UNION / POLK	1212.66	1209.91	-2.75
69-0565-00	ESQUAGAMA / ST. LOUIS	1348.42	1345.20	-3.22
69-0378-00	VERMILION / ST. LOUIS	1358.72	1356.90	-1.82
70-0072-00	UPPER PRIOR / SCOTT	903.50	896.90	-6.60
73-0106-00	BIG FISH / STEARNS	1197.01	1193.78	-3.23
73-0038-00	CARNELIAN / STEARNS	1133.51	1125.83	-7.68
73-0200-00	KORONIS / STEARNS	1125.50	1121.44	-4.06
73-0196-00	RICE / STEARNS	1128.32	1121.38	-6.94
73-0138-00	TWO RIVERS / STEARNS	1134.49	1128.29	-6.20
77-0089-00	LITTLE BIRCH / TODD	1185.36	1181.97	-3.39
82-0140-00	ONEKA / WASHINGTON	932.01	928.83	-3.18
82-0167-00	WHITE BEAR / WASHINGTON	925.64	921.35	-4.29
86-0023-00	BEEBE / WRIGHT	968.80	965.42	-3.38
86-0243-00	GRASS / WRIGHT	992.58	989.65	-2.93
86-0223-00	INDIAN / WRIGHT	1012.37	1006.84	-5.53
86-0134-00	MAPLE / WRIGHT	1001.54	996.81	-4.73
86-0053-00	PULASKI / WRIGHT	969.28	962.65	-6.63
86-0233-00	SUGAR / WRIGHT	988.93	985.83	-3.10
86-0279-00	TWIN / WRIGHT	1049.91	1047.20	-2.71

10/3/88

List of Rivers with Appropriation Suspensions

River	Suspension Date	Agricultural Irrigation Permits: Number of Permits	Total Acres Authorized	1987 Reported Acreage	Golf Course Irrigation Permits: Number of Permits	Total Acres Authorized	1987 Reported Acreage	Other Appropriation: Number of Permits	Total Authorized Pumping Capacity
Upper Mississippi River Watershed									
Elk	6/22/88	20	1480	811	--	--	--	--	10,950 gpm (24.3 cfs)
Rum & Trib. REINSTATED	6/29/88 8/18/88	8	580	176	4	213	93	1	5,950 gpm (13.2 cfs)
Sauk & Trib.	7/8/88	16	963	566	2	105	25	--	8,850 gpm (19.67 cfs)
Long Prairie & Tributaries	7/12/88	27	2425	1085	2	67	42	1	21,835 gpm (48.52 cfs)
Crow Wing & Tributaries REINSTATED	7/22/88 8/17/88	30	2134.5	640	1	26	26	2	17,430 gpm (38.73 cfs)
Crow River & Tributaries	8/1/88	13	839	418	3	98	88	2	9,030 gpm (20.07 cfs)
Lower Mississippi Watershed									
Shell Rock River	8/2/88	9	677	192	--	--	--	--	5,090 gpm (11.31 cfs)
Straight	7/28/88	1	110	42	--	--	--	--	600 gpm (1.3 cfs)

River	Suspension Date	Agricultural Irrigation Permits			Golf Course Irrigation Permits			Other Appropriation	Total Authorized Pumping Capacity
		Number of Permits	Total Acres Authorized	1987 Reported Acreage	Number of Permits	Total Acres Authorized	1987 Reported Acreage	Number of Permits	
Minnesota River Watershed									
Pomme de Terre	6/29/88	4	230	6	1	15	15	1	2,850 gpm (6.3 cfs)
Chippewa	7/5/88	6	645	0	--	--	--	--	4,600 gpm (10.2 cfs)
Cottonwood & Tributaries	7/26/88	17	1751	327	1	70	70	1	14,750 gpm (32.78 cfs)
Yellow Med. & Tributaries	7/29/88	5	351.3	92	1	40	0	0	2,141 gpm (4.76 cfs)
Red River of the North Watershed									
Buffalo REINSTATED RESUSPENDED REINSTATED	7/26/88 8/17/88 9/6/88 9/22/88	12	1788	220	2	170	85	3	7,795 gpm (17.32 cfs)