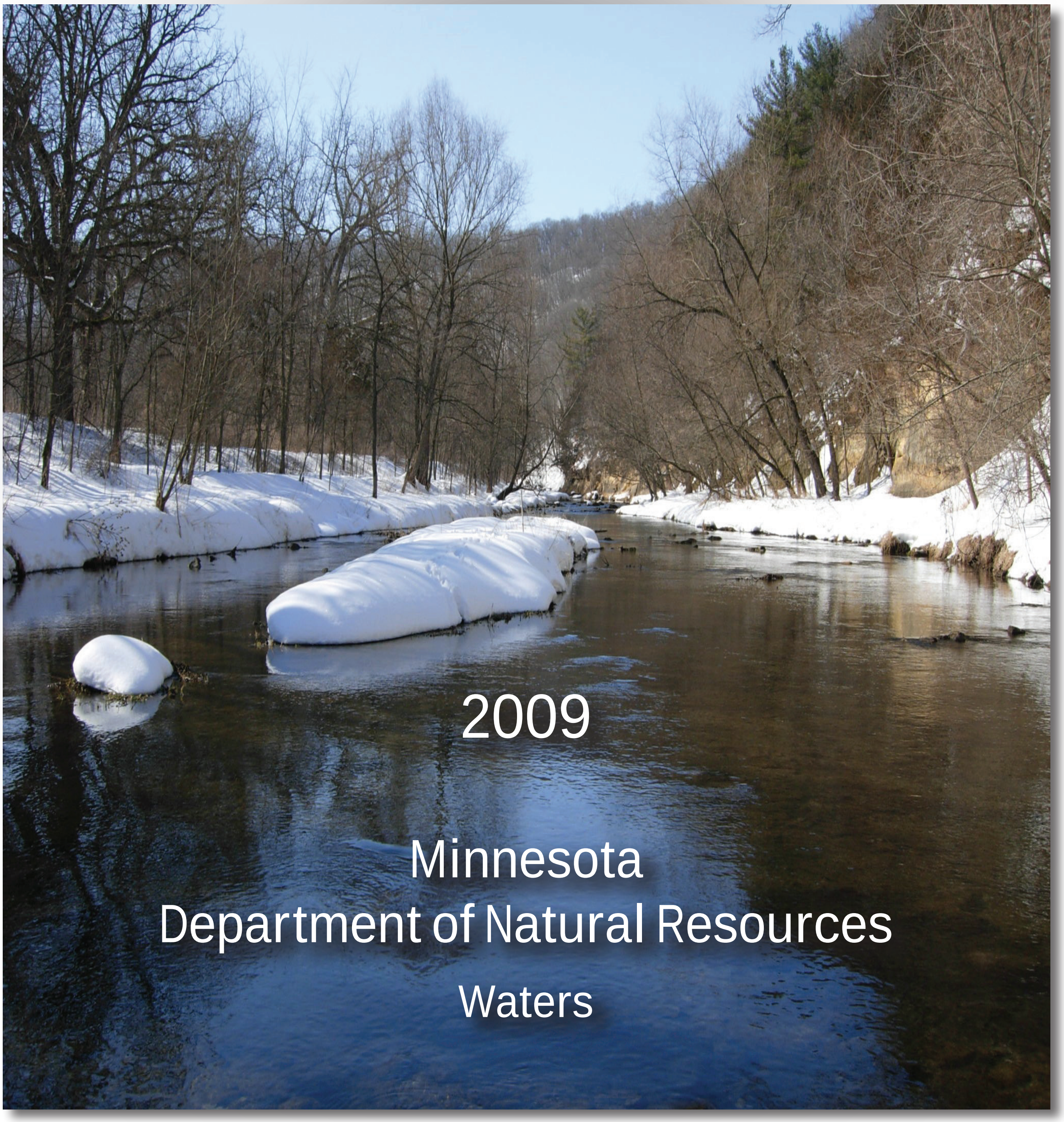
Water Year Data Summary

2007-08



2009

Minnesota
Department of Natural Resources
Waters

Introduction

This publication provides a review and summary of basic hydrologic data gathered through DNR Waters programs. There are four major areas of data collection, including climatology, surface water, ground water and water use. These areas are arranged in order of the hydrologic cycle (see diagram on page iv), and important facts are provided concerning the distribution and availability of Minnesota's water resources.

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

The DNR Waters website at **mndnr.gov/waters** provides a wealth of information on Minnesota's lakes, rivers and streams, wetlands, ground water and climate - much more than can be included in this summary report. Maps, publications, forms, educational resources and answers to common water resources questions can be found on the site. Visitors will find access to lake level data, stream flow information and ground water level data. The site, which is updated regularly, is intended to help the citizens of Minnesota become better stewards of the state's water resources by providing comprehensive information about those resources.

This report is a continuation of Water Year reports published by DNR Waters in 1979, 1980, 1991, 1993, 1995, 1997, 1999, 2001, 2003, 2005 and 2007. Because of the increasing sophistication of data users and the popularity of the report published in 2007, we again are providing this Water Year Data Summary Report in full color via the DNR Waters website. There will be an option of downloading separate chapters of the report. If you would like a printed version or compact disk (CD) of any portion of the report, please let us know and we will accommodate you.

Water Year

The climatology, surface water and ground water data presented are for Water Years 2007 and 2008.

WY 2007: October 1, 2006 - September 30, 2007
WY 2008: October 1, 2007 - September 30, 2008

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

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

Acknowledgements

Most of the photographs have been taken by DNR staff, particularly from the Division of Waters. Although we weren't able to use all photos submitted, we thank all those people who took the time to respond to our request.

We wish to express our gratitude to the listed authors and others who contributed to this publication. Special thanks to Jim Zicopula for assistance with layout and design.

Judy Boudreau, Editor

Kent Lokkesmoe, Director

Cover photo by Michele Hanson

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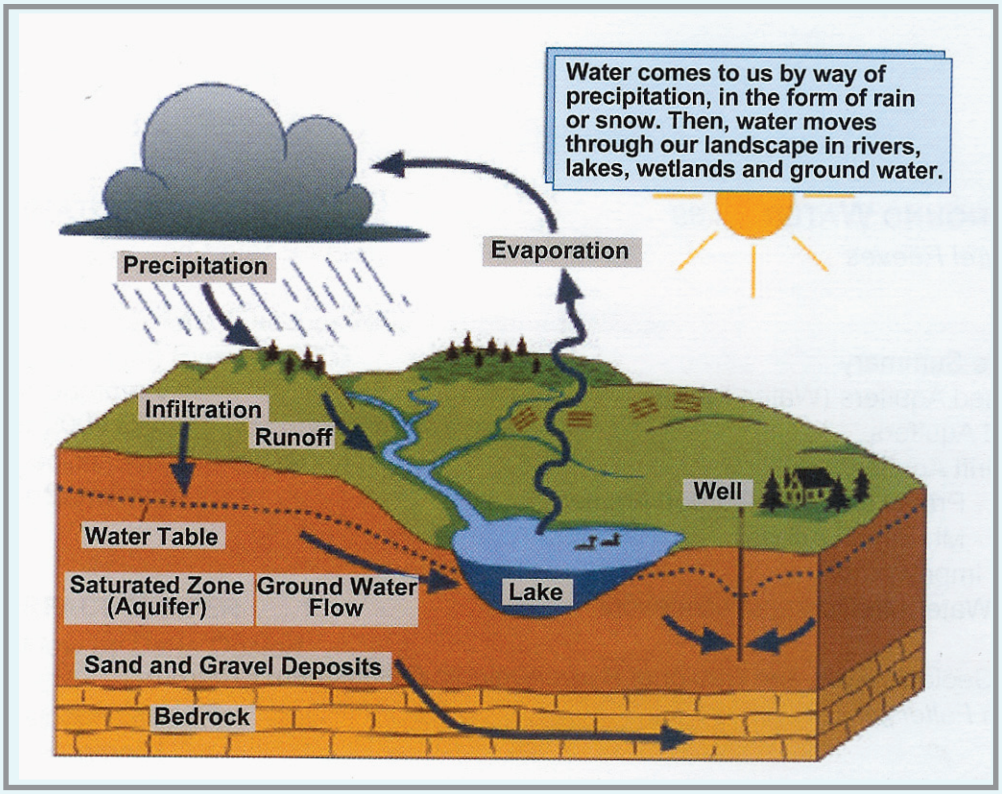
Hydrologic Cycle

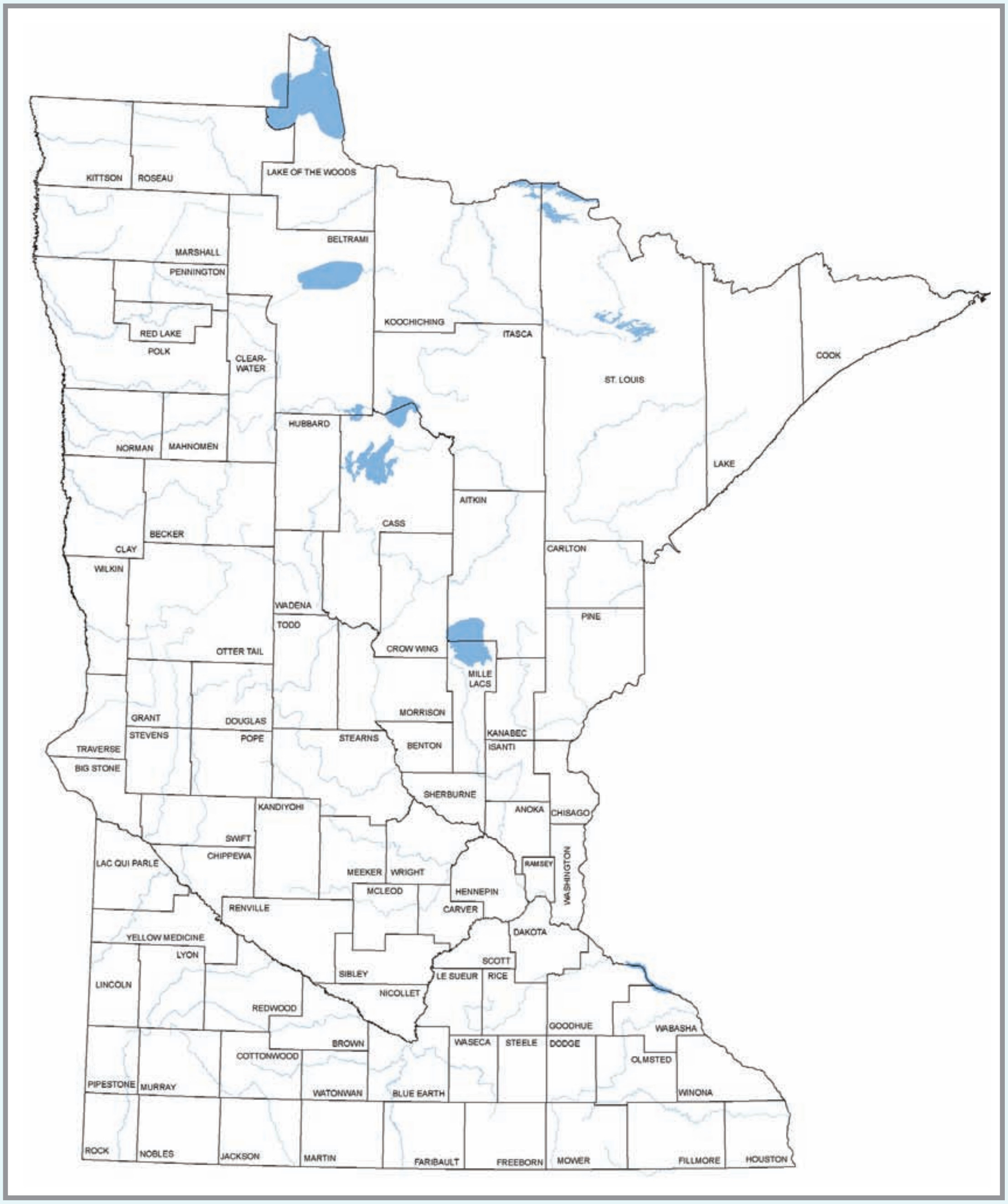


The hydrologic cycle is a concept used to explain the movement of water around the earth. This movement is continuous and has no beginning or end. Change at any point in the cycle will be reflected later in the cycle.

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

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

Minnesota Counties



Chapter 1 Climatology


Peter Boulay

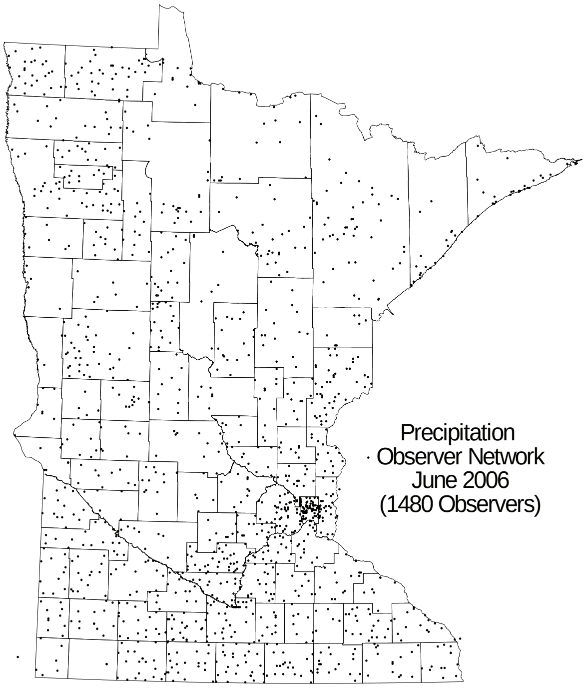
Introduction

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

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

Climate Data Sources:

Soil and Water Conservation Districts
National Weather Service
University of Minnesota
Department of Natural Resources
  - Ecological Resources
  - Division of Forestry
  - Division of Parks
  - Division of Trails and Waterways
  - Division of Waters
State Climatology Office Back Yard Network
Metropolitan Mosquito Control District
Minnesota Association of Watershed Districts
Metropolitan Waste Control Commission
Minnesota Power and Light Company
Emergency Management Offices



"Normal"

The word "normal" in this chapter refers to a 30-year mathematical average of measurements made over the period 1971-2000. Many individuals tend to (erroneously) perceive "normal" weather as what they should expect. Dr. Helmut E. Landsberg, former Director of Climatology for the U.S. Weather Bureau, summarized this misconception as follows: "The layman is often misled by the word. In his every-day language, the word 'normal' means something ordinary or frequent...When (the meteorologist) talks about 'normal' it has nothing to do with a common event. For the meteorologist, the 'normal' is simply a point of departure or index which is convenient for keeping track of weather statistics."

photo by Deb Rose

The 2007 Water Year

October 2006-September 2007

Highlights

- *Snow Drought 2006-07*
- *Snowy February*
- *Damp Spring*
- *Summer Drought*
- *Historic August 18-20, 2007 Flood, Southeast*
- *Wet Autumn 2007*

Autumn 2006

The previous water year (2006) ended with a lingering drought in northern and central Minnesota. Parts of Minnesota did receive significant rain in September 2006, most notably in west central Minnesota.

October

The drought that began in June 2006 continued into October – another in a series of dry months. The unusually dry late autumn weather raised concerns about topsoil moisture in the southern half of the state. The Twin Cities had the tenth driest October on record. Cool and Dry October 2006 in the Twin Cities. October was also much cooler than normal across the state and was the coolest month, relative to normal, since May 2005.

November

November was another dry month with one major exception: a classic late fall storm moved from Oklahoma to Illinois on November 10th, resulting in a narrow band of heavy snow over southeast Minnesota, northern Iowa and Wisconsin. The heaviest snow fell in a swath from 10 to 13 inches from Austin to Rochester. The heaviest amount in Minnesota (reported to the National Weather Service) was 13 inches near Byron in Olmstead County.

One positive aspect of this storm is that it brought copious amounts of water to the landscape over south central and southeast Minnesota. Since the ground was not frozen yet, much of the melting snow percolated into the ground. One-half to three-quarters of an inch of liquid fell from this storm at its heaviest. Heavy Snow over Southeast Minnesota: November 10, 2006

Despite the snowstorm, November was a warmer than normal month, delaying ice formation on lakes in the state. As of November 30, many larger lakes were free of ice, enabling some fairly uncommon "lake effect snow". November 30 Lake Effect Snow

Lake-effect snow is produced in the winter when cold winds move across long expanses of warmer lake water, providing energy and picking up water vapor which freezes and is deposited on the lee shores.

Winter 2006-07

December

Thoughts of a normal winter melted away with a statewide December temperature average that was a whopping ten degrees above normal. In the Twin Cities it was the sixth warmest December in the modern record.

December 2006 precipitation totals were above average in most Minnesota locations, but that doesn't mean it was a snowy month -- the bulk of the precipitation fell as rain. Much of Minnesota experienced a "brown" Christmas (it was the first time in Duluth's climate record that no snow was reported on the ground on the morning of December 25).

“Panhandle Hooker”

This is a storm that develops in the lee of the Rockies, near the Texas and Oklahoma panhandles, then moves to the northeast. This type of storm can draw in ample Gulf moisture and may bring heavy snow to Minnesota depending on which path the storm takes.

January

January 2007 followed December as another warm month with mean temperatures ranging from five to eight degrees above normal. The first part of January was exceptionally warm with the mercury 15 to 30 degrees above normal. High-temperature records and warm low-temperature records were tied or set on January 3, 4, and 5. Temperatures returned to typical January readings by mid-month and remained near, to below, normal for the remainder of the month.

January 2007 precipitation totals were below average across most of Minnesota. Precipitation was short of the historical normal by more than one-half inch in many places (a few locations in the southern one quarter of the state reported near normal, to above normal, precipitation for the month). A “snow drought” continued for much of Minnesota. The lack of snowfall was most acute in central and northern Minnesota with landscape so bare that grass and cattail fires occurred in the middle of the month. Snow Drought in Minnesota 2006-07

February

An arctic blast during the first week of February was the pinnacle of the frigid month. There were 63 hours of continuous below zero temperature readings in the Twin Cities. The statewide average temperature was only 8.5 degrees, making this the coldest month in Minnesota since January 2005. Extended Period of Below Zero in the Twin Cities

“Old Man” winter also staged a comeback with a double whammy of snowstorms for the final days of February into March. The first occurred from February 23 to February 26, dumping a foot of snow or more across parts of central and southern Minnesota. La Crosse, Wisconsin reported its largest snowstorm total ever with 21 inches of snow. Winona had one of the highest totals with 29.5 inches. Snowfall of February 23-26, 2007

The second storm at the end of the month was also formidable. This one began as a classic “Texas Panhandle Hooker” type of storm on February 28. This storm dumped a foot or more of snow across central and southern Minnesota and along the north shore of Lake Superior before it wrapped up on March 2. The University of Minnesota in the Twin Cities closed during the afternoon on March 1st marking the first time since January 18, 1994 that the University closed due to a weather event. Another memorable aspect of this storm was the blizzard conditions in the Duluth area, which caused 10 to 15 foot high snowdrifts on Minnesota Point along the shore of Lake Superior. There were also blizzard warnings in the Red River Valley and in southern Minnesota. Snowstorm and Blizzard: February 28 to March 2, 2007

Despite the snowy February finish, seasonal snow totals for 2006-07 were generally below average, with the exceptions of Rochester and La Crosse (which happened to be at the epicenter of the largest snowstorms of the year). Duluth finished near average while International Falls, St. Cloud and the Twin Cities were all below average.

Spring 2007

March

March 2007 was the second consecutive month of above-average snowfall. Precipitation totals ranged from two to four inches statewide, topping the historical average by one or more inches in many communities. Most of the precipitation came from the blizzard at the start of the month, and a soggy system at the end of the month (which brought heavy rains over much of the state).

Mean temperatures for March 2007 ranged from three to six degrees above the historical average. Cool conditions in early March were more than offset by very warm readings during the last ten days of the month. Numerous records were set on March 25 and March 26 when the temperature soared into the 70's and low 80's in central and southern Minnesota. Record Warmth: March 26, 2007

The warm temperatures in mid-March produced rapid snow melt in many southern and western Minnesota watersheds. In addition to the hasty melt, unusually thick ice created jams in constricted locations along stream courses. The combined result led to isolated moderate-to-major flooding, the worst of which affected Browns Valley.

April

April 2007 was the third consecutive month of above-average precipitation except in south central and southeastern Minnesota. Monthly precipitation totals ranged from one to four inches statewide. West central Minnesota received the greatest amount with many locations reporting over four inches of liquid (melted snow plus rainfall), - double the historical average.

One of the more notable weather events of April 2007 was an early spring snowstorm that dropped six or more inches of snow across central and northeastern Minnesota on April 2 and 3. Brainerd reported 11 inches of snow and Duluth set a local record (12.1 inches) for the greatest single-day snowfall total during the month of April. Another event on April 10 and 11 dropped three or more inches upon most of the southern one half of Minnesota. Fairmont reported a record 8 inches of snowfall.


Coon Rapids Ice Jam

Dale Homuth

Monthly mean temperatures for April 2007 were near average across much of the state. However, temperatures were two to four degrees below the historical average in west central Minnesota. Across the state, very cold temperatures in early April were balanced by warmer-than-average temperatures during the later half of the month. It was the coldest start to an April in over 30 years. During the first eleven days of the month daytime highs struggled to top the freezing mark in many locations. Cold First Week of April 2007

May

Early May brought weather conditions that were highly conducive to an explosive wildfire situation. The rapid spread of the "Ham Lake" fire in Cook County was the result of the very dry conditions. As the month began, the area was deemed to be in a "Severe" to "Extreme" drought. Light and heavy fuels were very dry and spring green-up was just underway. Daytime temperatures on May 8 and 9 reached well into the 80's while the relative humidity was below 30 percent. In addition, strong winds of variable direction impacted the firefighting effort. Smoke from the Ham Lake fire was seen as far south as the Twin Cities. Smoky Skies: May 11, 2007

The "Ham Lake Fire" started on May 5, 2007 and was the largest and most destructive fire in Minnesota in recent history. It burned slightly more acreage in Canada (39,000 acres) than in the US (36,000 acres). One hundred and forty structures were lost in the fire.

May rainfall was spotty across the state. For west central Minnesota, it was the fourth month in a row of above normal precipitation. Welcome showers fell in west central, northwest, and north central parts of the state, bringing monthly totals above average in these locations. The rest of northern Minnesota fell short of normal, but the rains were ample enough to ease wildlife concerns and improve drought conditions somewhat. Rainfall was below average in central and parts of southwestern Minnesota.

Monthly mean temperatures for May 2007 were mild across all of the state. Temperatures were generally two to four degrees above the historical average. On the other hand, frost was reported on the morning of May 17 in northern Minnesota and in southeastern Minnesoya, but little crop damage was reported.

Summer 2007

June

The same area that saw heavy rains in May also saw some of the heaviest rain in June. In some communities in west central Minnesota, rainfall totals topped six inches for the month. Elsewhere in Minnesota, June rainfall totals were very light. Some central, east central, south central, and southwestern Minnesota locations reported monthly rainfall totals of less than two inches. This is two or more inches less than the historical average for the month. In many of these areas, the dry weather marked the second consecutive month of below-average rainfall. The dryness raised concerns about deteriorating soil moisture supplies and lower than average surface water levels.

West-central Minnesotans were wondering what all the fuss was regarding dry weather. Falling upon an already saturated landscape, torrential rains in early June in west central and northwestern Minnesota, led to rural flooding. Some roadways were inundated and crop re-planting was necessary in some spots. The heavy rain also led to flooding along the Red River and some of its tributaries throughout the month of June.

The heaviest rain event of the month occurred June 13 and 14 in eastern Polk and northern Clearwater counties. A sequence of thunderstorms dropped a narrow band of over six inches of rain in a 36-hour period in this area. Tornadoes and Heavy Rains in Northwest Minnesota: June 13-14, 2007

Monthly mean temperatures for June 2007 were warm across Minnesota. Temperatures for the month were generally two to four degrees above the historical average.

July

July 2007 was one of the driest Julys on record in some cities. Many locations reported less than two inches of rain for the month, with totals only half of what falls on average in July. Monthly Summary for July 2007 Most locations in west central, central, and southwestern Minnesota received less than one inch of rain in July. Hutchinson reported their 2nd driest July in history with 0.50 inch of rainfall for the month. A 0.30-inch July rainfall total in Pipestone was also the second driest on record. The monthly rainfall total for Redwood Falls was 0.16 inch, the driest July in their historical record. Dry and Warm July 2007

Monthly mean temperatures for July 2007 were near, to somewhat above, historical averages across Minnesota. A warm finish to the month counterbalanced a spell of seasonally cool weather during the middle of the month.

August

August 2007 was dry in the north, and exceedingly wet in the south. While rainfall amounts fell short of average by one to three inches in northern Minnesota, many southern locations set all-time August rainfall records. Rainfall totals in the southern three to four tiers of Minnesota counties topped eight inches for the month, doubling the historical monthly average. Numerous south central and southeastern Minnesota communities reported rainfall totals in excess of ten inches in August. Many locations set all-time August monthly rainfall records. Some examples include the Twin Cities (9.32 inches) and Rochester (14.07 inches). The National Weather Service site one mile south of Hokah received 23.86 inches of precipitation in August 2007, breaking the old August record of 16.52 inches in Alexandria in August 1900. The 23.86 inches was also the most precipitation ever recorded in a month in Minnesota. The old record was July 1987 at the Twin Cities International Airport with 17.90 inches.

Monthly mean temperatures for August 2007 were within two degrees either side of the historical average.

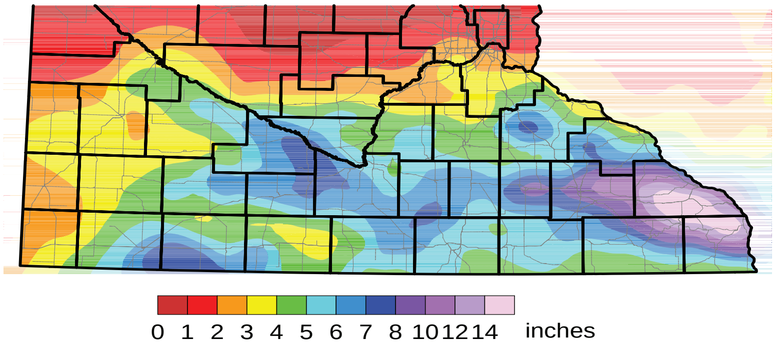
The Historic August 18-20, 2007 Flood

The most memorable singular event of the 2006-07 Water Year is the southeast Minnesota flood of August 18-20, 2007. A series of thunderstorms moving along a stalled frontal boundary dropped extremely heavy rain on much of southern Minnesota beginning August 18. The most intense precipitation rates occurred during the afternoon and evening hours of Saturday, August 18, and the early morning hours of Sunday, August 19. Over the course of the event, all or portions of 28 counties received at least four inches of rain. Six-inch totals were common across the region, and portions of southeastern Minnesota reported astounding rainfall amounts ranging from 8 to 18 inches. The heaviest rainfall reports came from Winona, Fillmore, and Houston counties, where 36-hour totals exceeded 14 inches. The largest multi-day rainfall total reported was 18.17 inches observed west of La Crescent in northern Houston County. An official National Weather Service climate observer near Hokah in Houston County reported a storm total of 16.27 inches. Of the 16.27 inches, 15.10 inches fell within the observer's 24-hour observation cycle ending at 8:00 AM on Sunday, August 19. This is the largest 24-hour rainfall total ever recorded by an official National Weather Service reporting location in Minnesota. The previous Minnesota record was 10.84 inches, measured at the city of Fort Ripley in Crow Wing County on July 22, 1972.

The deluge produced flooding tied to seven fatalities. Major flood damage occurred in many southeastern Minnesota communities. Hundreds of homes and businesses were impacted. Reports of stream flooding, urban flooding, mud slides, and road closures were numerous throughout southern Minnesota. The combination of huge rainfall totals and a very large geographic extent, make this episode one of the most significant rainfall events in Minnesota's climate history. A six-inch rainfall total for a given location in this region over a 24-hour period is said to be a "100-year" (1% probability) storm. The area receiving six or more inches during a 24-hour period in the midst of this torrent encompassed thousands of square miles. Other heavy rainfall events during this decade of comparable magnitude and spatial coverage include extraordinary rainfalls in northwestern Minnesota on June 9-10, 2002, and in southern Minnesota on September 14-15, 2004.

Rainfall Totals for
Southern Minnesota
August 18 through August 20
(8:00 AM CDT), 2007

State Climatology Office
DNR Waters



Autumn 2007

September

September 2007 rainfall totals were well above historical averages in many Minnesota counties. Drought-stricken regions of central and northern parts of the state received beneficial rains, improving the situation considerably. Monthly rainfall totals in excess of four inches were common in these areas, as well as in sections of southeastern Minnesota. In some counties, rainfall totals topped six inches for the month. For a few locations in Minnesota's Arrowhead region, monthly rainfall totals set new September records by exceeding ten inches. This is more than triple the historical average for the month. By contrast, September rainfall in some northwestern and southwestern counties fell short of the historical average by nearly two inches.

On September 6, a strong weather system moving through the Midwest dropped over six inches of rain on portions of St. Louis, Lake, and Cook counties. Rainfall totals surpassed eight inches in central St. Louis County. The deluge led to overtopped and washed out sections of roads and highways. The situation was greatly tempered by the long-term drought conditions that existed prior to the rain event. A storm of this magnitude and intensity would have certainly had a greater impact had the landscape not been so dry. Another heavy rain event also affected portions of the Iron Range on September 18 when intense precipitation flooded Highway 169 near Grand Rapids. Heavy Rains Drench Iron Range: September 6, 2007

Intense rains doused west central and central Minnesota on September 20 and 21. Three to five inches fell along an arc that bisected Minnesota from near Ortonville to Hinckley. The rain drenched portions of Stevens, Pope, Douglas, Todd, Stearns, and Morrison counties; an area that was suffering most intensely from the 2007 drought. Heavy Rains: September 20-21, 2007

Monthly mean temperatures for September 2007 were two to four degrees above the historical average in most locations. Extreme values for September ranged from a high of 97 degrees at Breckenridge (Wilkin County) on the 3rd, to a low of 18 degrees at Embarrass (St. Louis County) on September 15. Three mid-month frosts effectively ended the growing season in most parts of the state. The most notable cold-snap occurred on September 15 when many Minnesota locations reported temperatures in the 20s. Some all-time low temperature records were set that morning. Chilly September 15, 2007


Dale Homuth


Southeast MN Flood

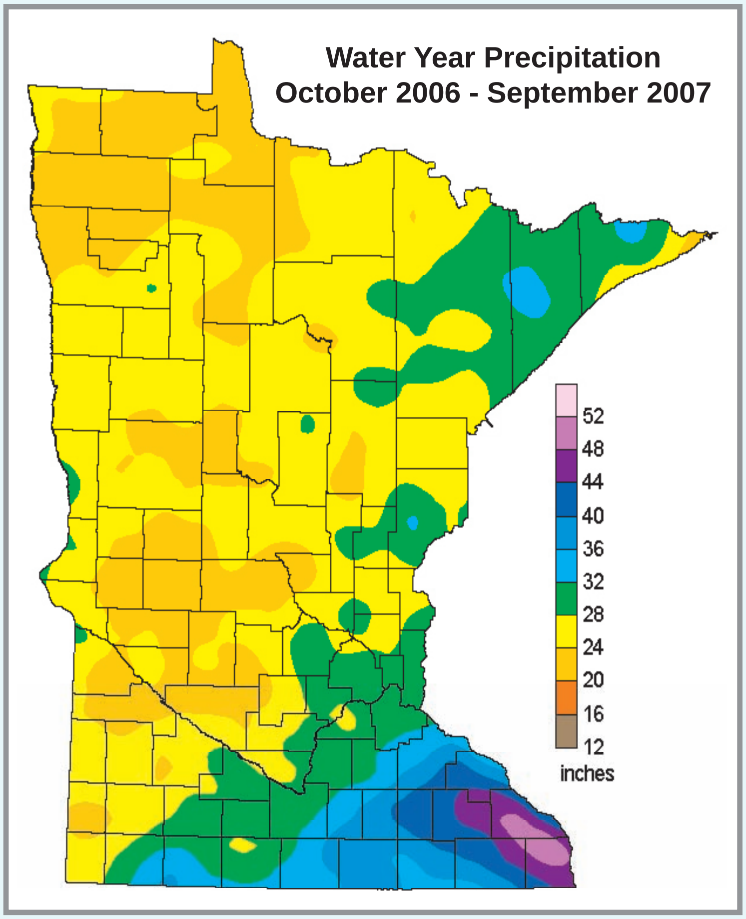
Peter Leete

Drought of Summer 2007

For the second summer in a row, there was a widespread drought in Minnesota. The main focus of the drought during the summer of 2007 was across northern and central Minnesota. September rains significantly improved the situation in many areas. However, rainfall for the sixteen-week period from June 5 through September 24 totaled less than eight inches for some locations in west central and central Minnesota. In these areas, rainfall totals for the period were five or more inches short of the historical average. When compared with historical rainfall totals for the same sixteen-week time frame, 2007 values ranked at or below the 5th percentile (one year in twenty occurrence) in some counties. The period from May through September is historically the wettest time of the year in Minnesota. Long-term average rainfall rates during the heart of the summer are around one inch per week. Very dry weather, occurring during a time of year when ample rain is typical, leads to the rapid intensification of drought. The lack of precipitation, along with very high evaporation rates, produced deteriorating crop conditions, lower stream flows and lake levels, and increased wildfire danger. Drought Situation Report: September 27, 2007

Water Year 2007 Summary

The heavy rain event of August 18-20, 2007 dominated the 2007 Water Year totals for southeast Minnesota. Southeastern Minnesota finished from four to an amazing sixteen inches above normal. For the rest of the state, the drought of summer 2007 impacted totals significantly over much of central and northern Minnesota. Deficits were eased somewhat with substantial September rains. Many areas across a wide swath of Minnesota wound up plus or minus two inches of normal. Some notable drier pockets were in Carlton County and in central Minnesota where deficits were four inches below average. The Red River Valley had a surplus of moisture for the water year with areas four to six inches above normal. This was the first year in Minnesota in which both a flood and a drought federal disaster was declared.



The 2008 Water Year

October 2007-September 2008

Highlights

- *Wet and Warm October 2007*
- *Snowy December 2007*
- *2007-08 Coldest Winter since 2000-01*
- *Cold and Snowy April 2008*
- *Late Ice Out*
- *Another Drought Begins in June*
- *Some Relief to Drought August & Sept*

Autumn 2007

October

October 2007 rainfall totals were well above historical averages in nearly all Minnesota counties. As was the case in September, drought-stricken regions of central and northern Minnesota received wecome rains, further improving the situation. October monthly rainfall totals in excess of four inches were common, approximately doubling the October normal.

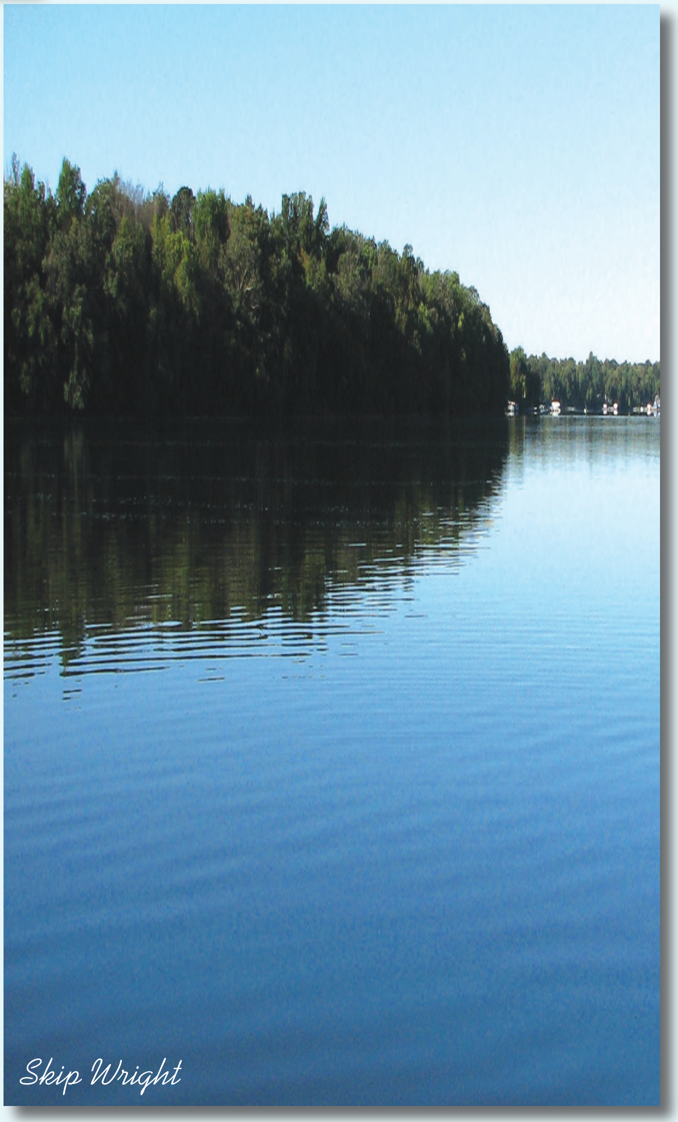
On a statewide basis, it was the third wettest October in the modern record. For many northeastern Minnesota communities, it was the wettest October ever, with precipitation totals topping eight inches in a few places. Many of these same locations had set all-time high precipitation records in September as well. The Twin Cities had its wettest October on record. Top Ten Wettest August-October Periods in the Twin Cities

October 2007 was a very warm month. Average temperatures were four to six degrees above the historical average throughout Minnesota. Numerous high maximum and high minimum temperature records were set on the 6th and 7th.

November

The end of the autumn season was a dry one across the state. Precipitation totals for November 2007 ranged from near zero in west central Minnesota, to just over a half an inch in the northeast. Precipitation in general for the month fell short of normal by one to two inches for most places. Interestingly, after having the wettest October on record, the Twin Cities had the 4th driest November on record. Dry November 2007

November was a somewhat warm month, finishing one to four degrees above historical averages.



Skip Wright

Winter 2007-08

December

Winter returned with a vengeance bringing the snowiest December since 2000. Monthly precipitation totals topped normal by roughly one half inch in most communities. Monthly snowfall totals exceeded one foot in nearly all locations. Some spots in northeastern Minnesota received two to three feet of snow in December.

Mother Nature conjured up a number of winter storms. On December 1, nearly every county in Minnesota received at least three inches of snow. Some locations in northeastern parts of the state reported over 12 inches of snow during this event. Another snowstorm followed shortly behind, dropping three to nine inches of snow across much of central and northern Minnesota on December 4. A strong winter storm moved through the Midwest on December 22 and 23, assuring a white Christmas, but creating significant hardships for holiday travelers. An early and enduring snow cover has been rare in Minnesota in recent years.

Heavy Snow: December 1, 2007
More Snow: December 4, 2007
Still More Snow: December 22-23, 2007

Colder than normal Decembers have been unusual in recent years, but December 2007 bucked that trend. Monthly mean temperatures were generally one to three degrees below the historical average. Cold weather early in the month was counterbalanced by seasonal to above-normal temperatures in the second half of the month.

January

The snowy conditions from December did not continue into January 2008 and, as a result, precipitation finished below average for the month. There were few storms of note, one of which was a blizzard that struck southern Minnesota on January 29. Blizzard: January 29, 2008


Cliff Bentley

The statewide temperature for January finished near average for the month, but that doesn't mean that the actual daily air temperatures were average. There was a classic January thaw from January 5-7. "January Thaw" of January 5-7, 2008. On the other extreme, there was an extraordinary temperature plunge on the 29th. Rapid Temperature Change: January 29, 2008

February

February 2008 had fairly meager snowfall totals across the state. The only exception was in far southeast Minnesota where, in some places, better than a foot of snow fell for the month. What little snow fell over the rest of the state didn't go anywhere fast with average temperatures ranging five to seven degrees below normal. The cool February was the icing on the cake bringing the first colder-than-average winter statewide since the winter of 2000-2001.

Spring 2008

March

Chalk up March 2008 as another dry month. Monthly precipitation totals ranged from one half inch to one inch below average. The snow pack across much of the state began to erode with an occasional flirt of some mild temperatures. The landscape was nearly snow-free across southern Minnesota by the end of the month. As the month came to a close however, it was clear that winter was not done yet with Minnesota. A classic late winter storm took aim on central and southern parts of the state on March 31. Snowstorm of March 31-April 1, 2008 Despite some mild weather, March finished cooler than normal.

April

Any worries of a dry spring (or not seeing any more snow for the season) were quickly put to rest in April. With the exception of far northwestern Minnesota, most communities reported significant rain or snowfall totals in April. Precipitation totals in most northeast, east central, and southeastern Minnesota counties topped five inches for the month. Total April precipitation in some southeastern Minnesota locales exceeded seven inches. In a few cases, the monthly precipitation totals were record setting. Many communities in west central, north central, and northeastern areas received over 30 inches of snow for the month, shattering April monthly total snowfall records in many places. There were four major snow events during the month (including the event that began on March 31 mentioned above).

Very Heavy Snow: April 5-7, 2008
Blizzard: April 10-11, 2008
Snowstorm and Blizzard: April 25-26, 2008

April temperatures kept to the winter-like theme and continued the trend of below normal temperatures. Average temperatures ranged from two to four degrees below normal across Minnesota.

May

May started out on the wet side, but became dry by the second half of the month. The statewide average precipitation wound up nearly normal for the month.

And it was yet another cold month -- the fourth month in a row that the average monthly statewide temperature was below normal. With the cold winter and early spring, there was worry that the ice would not be off some of the larger lakes in time for fishing opener. Indeed, for the first time since 1996, there was still some ice on far northern lakes on the opener. Lake Ice Out 2008

Summer 2008

June

June precipitation was hit or miss across the state, with numerous rounds of severe weather and heavy rainfall. Two notable flash flood events occurred in southeast Minnesota, one on June 7-9, and another on June 11-12.

Southeast Minnesota Flooding: June 7-9, 2008
More Southeast Minnesota Flooding: June 11-12, 2008

After these two events, much of the state settled into a dry spell for the rest of June. The driest parts of the state were south central and east central parts of the state, finishing about a half to three-quarters of an inch behind normal for the month.

Once again, the monthly mean temperatures for the state were below normal with average June temperatures ranging from one to three degrees below.

July

For the third year in a row, Minnesota saw itself in the midst of a summer drought. The rainfall deficits for July 2008 fell short of normal by two or more inches. There were a few isolated spots of heavy rainfall, but in general a pattern of dryness prevailed. There was one flood event of note despite the overall dry month. On July 16-17 a small, but intense area of thunderstorms produced torrential downpours over extreme southeastern Minnesota in Winona and Houston County. Heavy Rain: July 16-17, 2008

The drought of summer, 2008 was not as intense of the drought of 2007 because there was a lack of hot temperatures. Monthly mean temperatures for July 2008 were very near historical averages keeping evaporation near seasonal norms and mitigating the situation somewhat. St. Paul Campus Climatological Observatory Monthly Pan Evaporation

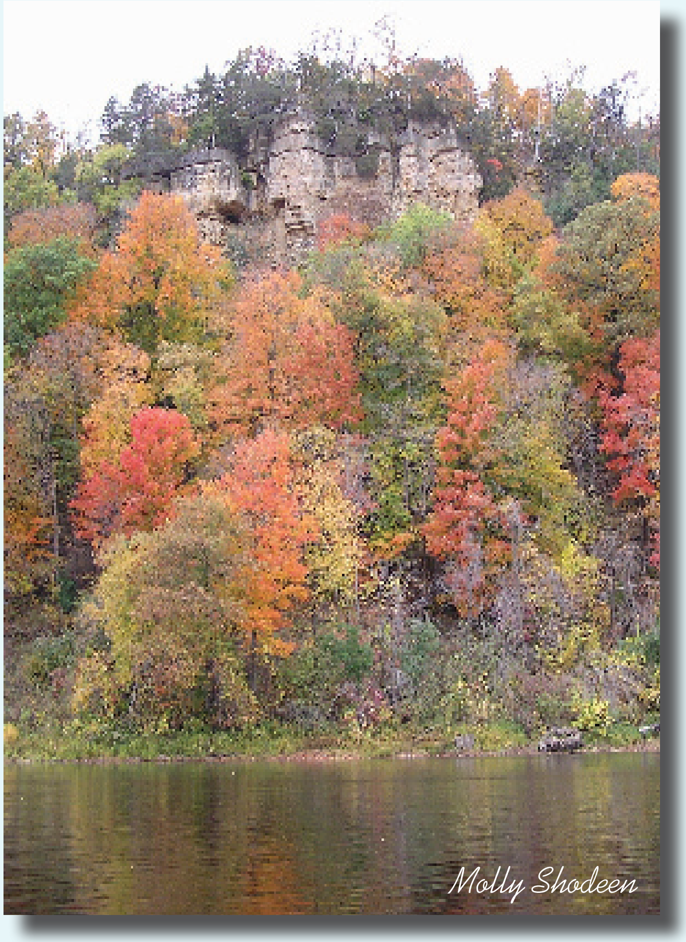
August

The drought that began in June persisted in August as precipitation totals fell short of average by two or more inches in most counties. There were some exceptions. A line of heavy thunderstorms hit a few areas of west central Minnesota on August 11-12, causing some localized street flooding. Heavy Rain in West Central Minnesota: August 11-12, 2008. And beneficial rains fell over eastern Minnesota on August 27-28, helping to alleviate the drought conditions. Beneficial Rains: August 27-28, 2008. But while the showers were welcome, more rain was needed to eliminate the drought.

As with June and July, there weren't too many hot days. The highest temperature found in the state for August (and the summer) was 99 degrees at Redwood Falls. The Twin Cities did not reach 90 in August. The statewide average temperature for August wound up near normal.


Molly Shodeen

Autumn 2008


Molly Shodeen

September

September 2008 precipitation totals fell short of average by one to three inches in the southern one-third of Minnesota. By contrast, heavy rainfalls in some sections of the northern one-half of the state caused monthly rainfall totals to exceed the long-term average by two or more inches. Unfortunately, the bulk of the rainfall missed many of the drought-stricken areas. One exception was the four or more inches of September rainfall reported in northwestern Crow Wing, eastern Cass, and southwestern Itasca counties where drought conditions were among the worst found in Minnesota. Dry 2008 Growing Season

Monthly mean temperatures for September 2008 were one to three degrees above historical averages. As was the case throughout the summer, maximum temperatures above 90 degrees were not common. Frosts occurred in several northern counties during September, but the remainder of the state escaped the month without frost, a factor that helped crops reach maturity.

Drought of Summer 2008

For the third summer in a row, there was a prolonged summertime dry spell in Minnesota. For the ten-week period during the last two weeks of June and into late August, many Minnesota communities received less than four inches of rainfall. This came at a time of year when rainfall rates average roughly one inch per week. Thus, rainfall deficits over the ten-week dry spell topped four inches in many areas. Described another way, ten-week rainfall totals were less than 50 percent of normal for the period. When compared with the same ten-week time span in previous years, 2008 growing season rainfall ranked below the 5th percentile (one year in twenty) in many locales.

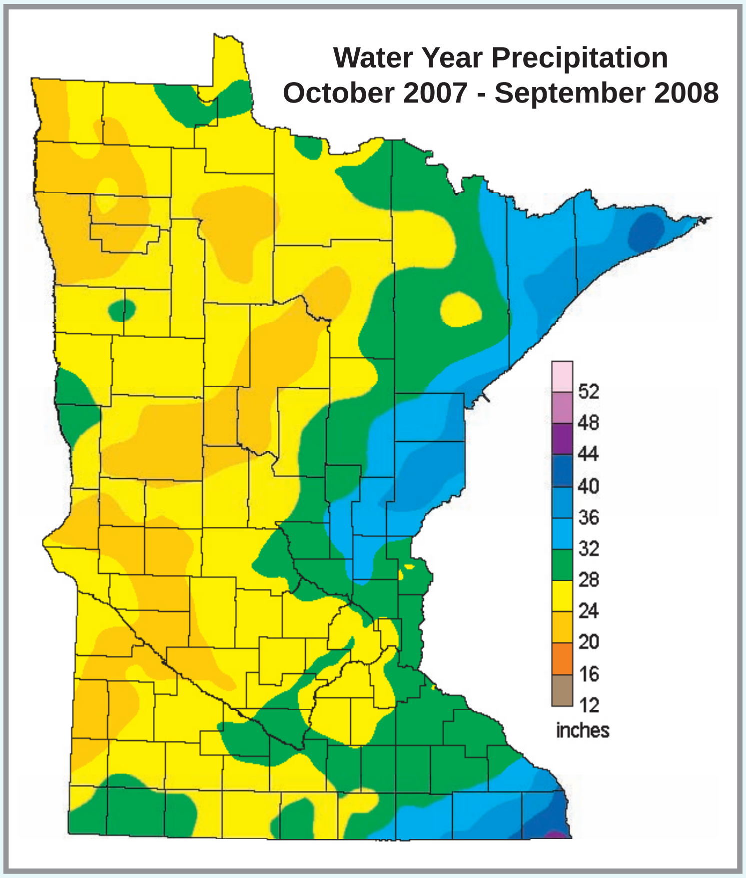
There were some beneficial rains in late August that took the edge off the drought over eastern Minnesota. Nonetheless, through the end of the 2008 Water Year, a large swath of southern Minnesota was in a moderate drought, as well as the Mississippi headwaters and parts of northeast Minnesota.

The drought would have been worse if it was a warm summer with many 90-degree temperatures. This was not the case. Maximum temperatures above 90 were not common. This held evaporation rates close to normal. The drought persisted into the next water year season.

Water Year 2008 Summary

For the 2008 Water Year, precipitation totals tended to be above normal along the edges of the state with the dry areas in the middle. Some of the areas that had above-normal precipitation include: the Red River Valley, east central Minnesota north of the Twin Cities, the extreme southeast tip of the state, the North Shore of Lake Superior and along the Canadian Border. Some of the wettest areas of the state were spots around Grand Marais in Cook County, and in Houston County near the Iowa Border. Some of these locations were six to ten inches above normal.

The summer drought of 2008 dominated the 2008 Water Year in a large swath though the center of the state. The water year finished drier from the Mississippi Headwaters, southwestward though Pope County, through the Twin Cities and then south along Interstate 35 to Albert Lea. There were locations in this arc of dryness that were four to six inches below normal.




Molly Shodeen

Chapter 2 Surface Water

Eric DeKleyn

Stream Flow

Introduction

Rivers and streams are a defining characteristic of Minnesota's landscape, from the fast flowing streams along the north shore of Lake Superior and the Mississippi River bluffs to the slow flowing streams meandering through the Red River valley and the southwest prairie lands. These rivers and streams all provide a sense of place, each contributing to Minnesota's heritage.

Minnesota is unique in that it exports large volumes of water and receives very little water from out of state. Two of the three Continental Divides in North America cross through the state and meet at a point near Hibbing. These divides route surface water into three separate continental drainage areas: the Hudson Bay/Arctic Ocean, the Great Lakes/Atlantic Ocean and the Mississippi River/Gulf of Mexico (Figure 1). Only two rivers receive out-of-state water: the headwaters of the Minnesota River from South Dakota, and the Blue Earth River from Iowa. This is why it is important for Minnesota to be a good steward of the land to ensure its waters leave the state in optimal condition.

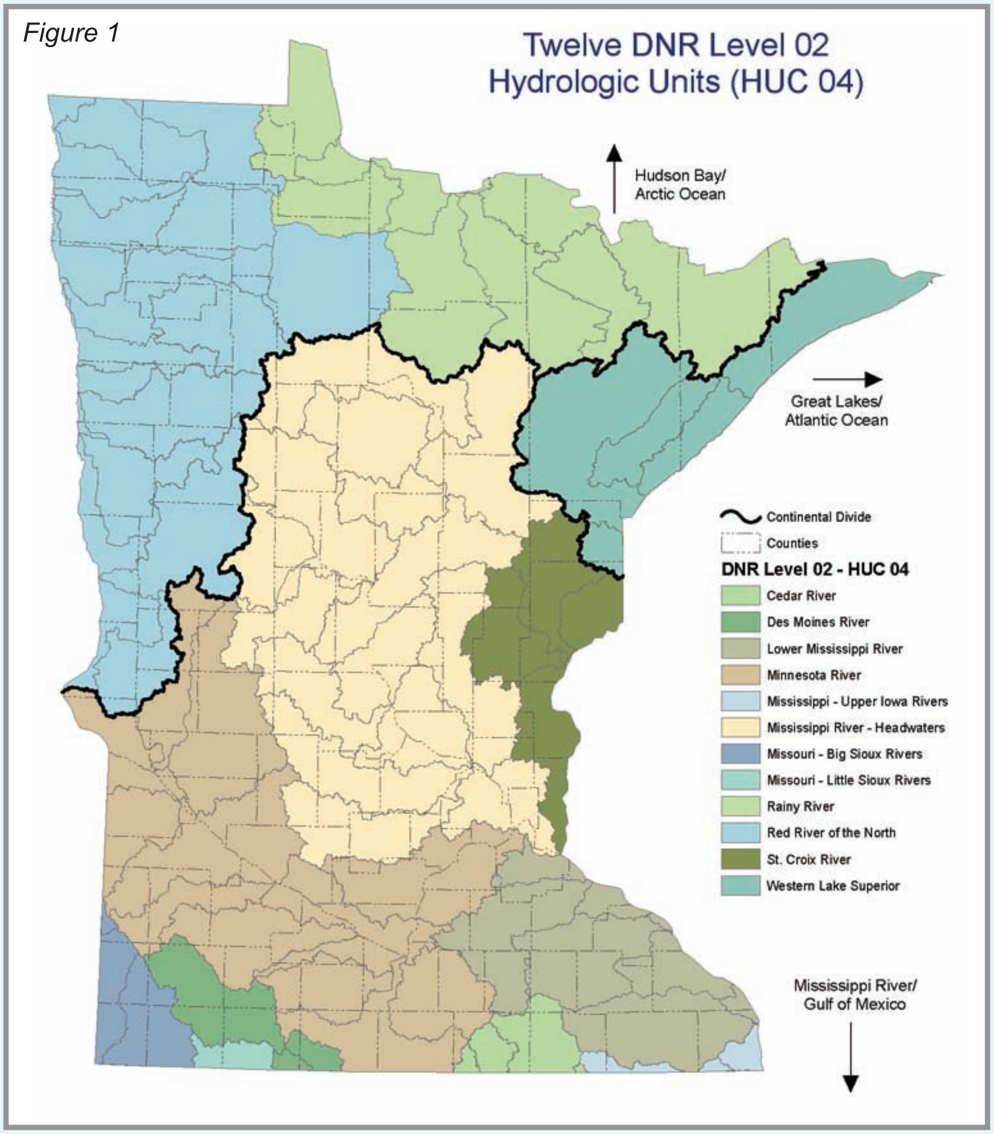
In the 1970s to help understand and manage Minnesota's water, the United States Geological Survey (USGS) and Water Resources Council created a mapping and classification system that partitioned the U.S. into four hierarchically nested watershed levels called Hydrologic Units (HU). In 1979, The DNR developed a standardized set of 81 Major Watersheds that were coincident with the smallest (Level 4) HU division in Minnesota (Figure 2). The DNR proceeded to further divide those Major Watersheds into approximately 5,600 Minor Watersheds. Since these initial mapping efforts, delineations at a higher resolution were required for hydrologic studies. This need was recognized at both the state and national level.

Over the last decade, the DNR Watershed Delineation Project staff worked to develop a high-resolution watershed boundary dataset. New technology and higher quality source data were used to assess the original 1979 delineations and to further subdivide those Minor Watersheds at certain hydrologic points of interest such as lake outlets, dams, and stream gaging locations.

At the national level during this time the USGS, in cooperation with the Natural Resources Conservation Service (NRCS), ramped up efforts to subdivide the HU system into six levels of Hydrologic Units. This expanded delineation system is known as the National Watershed Boundary Dataset. DNR has worked in cooperation with other state and federal agencies to ensure that their products are consistent with the national standardized mapping effort. DNR watershed delineations have been incorporated onto the National Watershed Boundary Dataset (see Watershed Delineation Project website for more detail).


Michele Walker

Figure 1



Stream Gaging in Minnesota

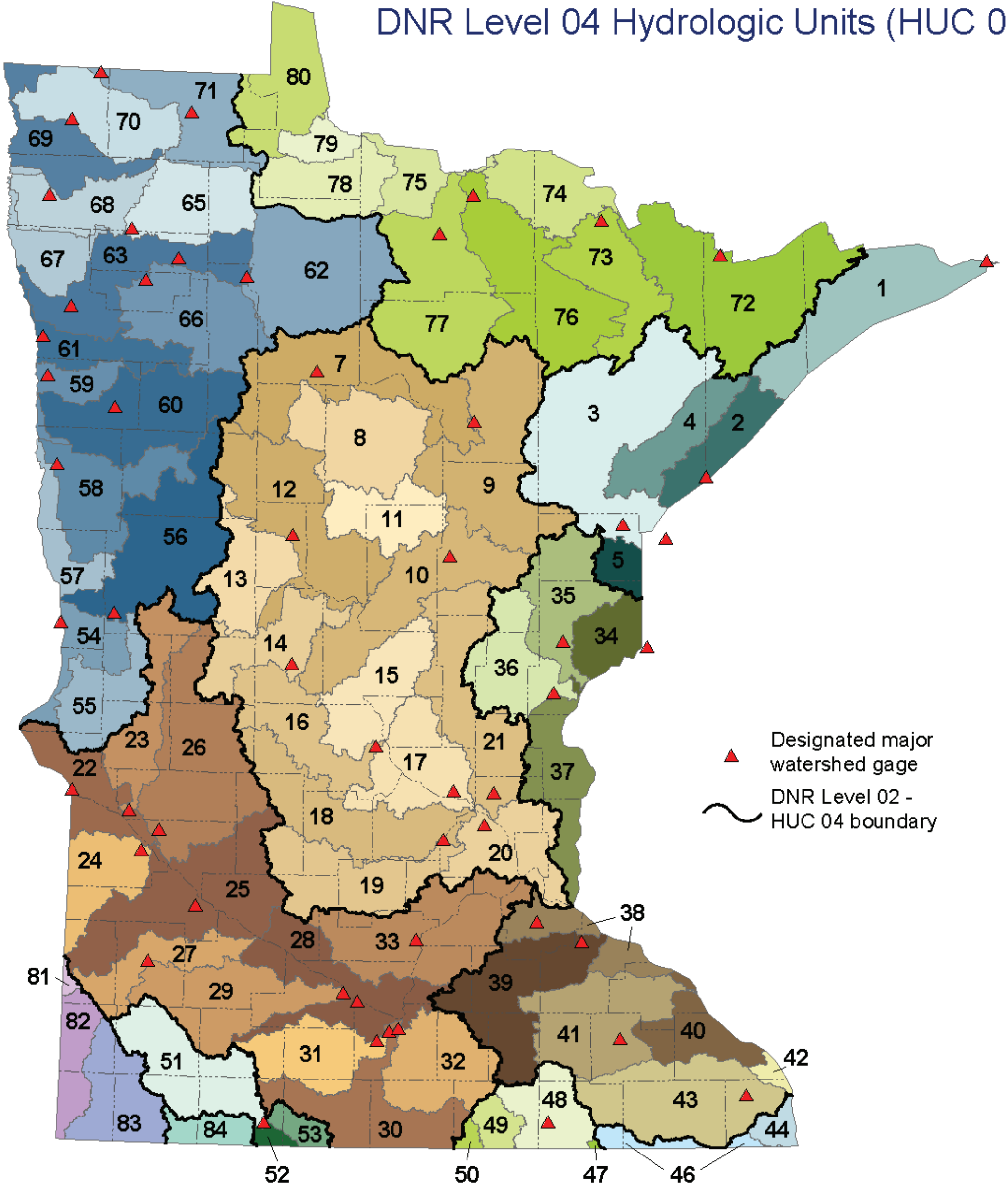
The USGS is the primary agency doing nationwide stream gaging. At the present time, the USGS maintains a network of approximately 135 continuously recording stream gages and approximately 400 high-flow and miscellaneous flow gages in Minnesota. The Minnesota Department of Natural Resources, Division of Waters (DNR Waters) acts as a cooperative funding partner for 34 of the USGS gages. However, as needs for additional stream information become necessary, additional agencies and organizations are gaging as well.

Other federal agencies that monitor stream flow in Minnesota include the United States Army Corps of Engineers, with approximately 40 gages, and the National Weather Service.

DNR Waters is one of the primary state agencies that provide stream flow information through a network of approximately 65 continuously recording gages and 75 seasonal gages. Other agencies that support or monitor stream flows in Minnesota include the Minnesota Department of Agriculture and the Minnesota Pollution Control Agency. The Metropolitan Council also has several stream gages to monitor flows for public water supply and the discharge of treated waste waters. In addition, several watershed districts, water management organizations and lake associations provide funding support or operate gages.

Gaging is an essential tool in analyzing stream flows. A stream gage is used to record the water surface elevation of a stream at a specific location. Measure-

Figure 2



81 Major Watersheds
DNR Level 04 Hydrologic Units (HUC 08)

Major Watershed (HUC 08 id)

1. Lake Superior - North (04010101)
2. Lake Superior - South (04010102)
3. St. Louis River (04010201)
4. Cloquet River (04010202)
5. Nemadji River (04010301)
6. (none)
7. Mississippi River - Headwaters (07010101)
8. Leech Lake River (07010102)
9. Mississippi River - Grand Rapids (07010103)
10. Mississippi River - Brainerd (07010104)
11. Pine River (07010105)
12. Crow Wing River (07010106)
13. Redeye River (07010107)
14. Long Prairie River (07010108)
15. Mississippi River - Sartell (07010201)
16. Sauk River (07010202)
17. Mississippi River - St. Cloud (07010203)
18. North Fork Crow River (07010204)
19. South Fork Crow River (07010205)
20. Mississippi River - Twin Cities (07010206)
21. Rum River (07010207)
22. Minnesota River - Headwaters (07020001)
23. Pomme de Terre River (07020002)
24. Lac Qui Parle River (07020003)
25. Minnesota - Yellow Medicine Rivers (07020004)
26. Chippewa River (07020005)
27. Redwood River (07020006)
28. Minnesota River - Mankato (07020007)
29. Cottonwood River (07020008)
30. Blue Earth River (07020009)
31. Watonwan River (07020010)
32. Le Sueur River (07020011)
33. Lower Minnesota River (07020012)
34. Upper St. Croix River (07030001)
35. Kettle River (07030003)
36. Snake River (07030004)
37. Lower St. Croix River (07030005)
38. Mississippi River - Lake Pepin (07040001)
39. Cannon River (07040002)
40. Mississippi River - Winona (07040003)
41. Zumbro River (07040004)
42. Mississippi River - La Crescent (07040006)
43. Root River (07040008)
44. Mississippi River - Reno (07060001)
45. (none)
46. Upper Iowa River (07060002)
47. Upper Wapsipinicon River (07080102)
48. Cedar River (07080201)
49. Shell Rock River (07080202)
50. Winnebago River (07080203)
51. Des Moines River - Headwaters (07100001)
52. Lower Des Moines River (07100002)
53. East Fork Des Moines River (07100003)
54. Bois de Sioux River (09020101)
55. Mustinka River (09020102)
56. Otter Tail River (09020103)
57. Upper Red River of the North (09020104)
58. Buffalo River (09020106)
59. Red River of the North - Marsh River (09020107)
60. Wild Rice River (09020108)
61. Red River of the North - Sandhill River (09020301)
62. Upper/Lower Red Lake (09020302)
63. Red Lake River (09020303)
64. (none)
65. Thief River (09020304)
66. Clearwater River (09020305)
67. Red River of the North - Grand Marais Creek (09020306)
68. Snake River (09020309)
69. Red River of the North - Tamarac River (09020311)
70. Two Rivers (09020312)
71. Roseau River (09020314)
72. Rainy River - Headwaters (09030001)
73. Vermilion River (09030002)
74. Rainy River - Rainy Lake (09030003)
75. Rainy River - Black River (09030004)
76. Little Fork River (09030005)
77. Big Fork River (09030006)
78. Rapid River (09030007)
79. Rainy River - Baudette (09030008)
80. Lake of the Woods (09030009)
81. Upper Big Sioux River (10170201)
82. Lower Big Sioux River (10170203)
83. Rock River (10170204)
84. Little Sioux River (10230003)

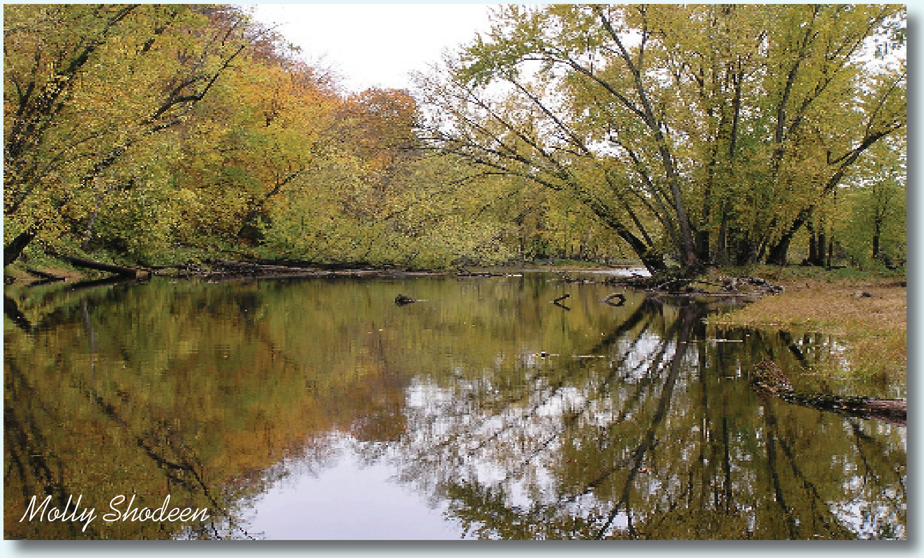
ments of stream discharge must be made periodically at the gage location to develop the relationship between stream elevation and the volume of flow at that location. A well-developed relationship allows recorded stream elevations to be converted to discharge in cubic feet per second (cfs). Once this relationship between stage and discharge is established, regular stream discharge measurements continue to be made in order to verify the relationship and to monitor any changes to the condition or characteristics of the channel. Telemetered gages record stream elevations continuously and transmit the data to a central location for conversion to discharge. These data are used in hydrologic analysis and provide critical real time data for flood warning and forecasting.

There are many uses of information obtained from stream gages. Water surface elevation, the most basic information, assists in the determination of flood elevations, flood plains, and sizing of bridges and is useful for municipal zoning and planning. Planners use stream flow data for land use development and to determine water availability for industrial, domestic and agricultural consumption. Biologists use stream flow data to assist in evaluating aquatic habitat potential in streams. Knowing how much water is flowing or available in a stream is very important for flood and drought planning, as well as for the development of municipal and industrial water supplies.

A recent trend in stream gages is to include water quality sampling at the gage. Water quality sampling, when combined with discharge data, provides information to calculate how much of that chemical or constituent has flowed past the monitoring site. These data are becoming more available with funding and support of the Clean Water Legacy project. (see discussion on page 20).

Skip Wright

Skip Wright



Molly Shodeen

Focus: Clean Water Legacy Network

In 2006 multiple state agencies established a plan to expand stream monitoring throughout the state. This was inspired and funded by the passage of the Clean Water Legacy Act (CWL). Two main players in this project are the DNR and Pollution Control Agency (PCA). These two agencies worked together to identify the condition and coverage of the existing gaging network. One goal of this project was to have a telemetered gaging station located at the outlet of all 81 major watersheds in the state. The DNR is responsible for installing new or upgrading existing gaging stations to have real-time telemetry equipment collecting and transmitting stage, precipitation, and water temperature. The PCA is responsible for sampling and testing water chemistry at these locations. The data collected at these sites will be used to track trends and changes in the water quality, frequency and severity of flooding and low flow conditions, and if these changes may be related to land use and climate changes.

Some major watersheds had an existing gage established as part of the DNR Flood Warning Gage network. These stage only real time telemetry gages were used where possible. Other watersheds that did not have adequate gaging were identified and monitoring locations were selected.

During the winter of 2007-08, DNR Waters increased monitoring on the selected Flood Warning Gages by making stream flow measurements throughout the winter and converting these stage only gages to continuous flow.


Winter Stream Gaging

Eric DeKleyn


Greg Kruse


Greg Kruse

Beginning in late May of 2008, DNR Waters began an intense schedule of installing new gage equipment. Between May 29 and October 23, crews installed real-time equipment at 16 CWL gages to provide a more complete gaging network.

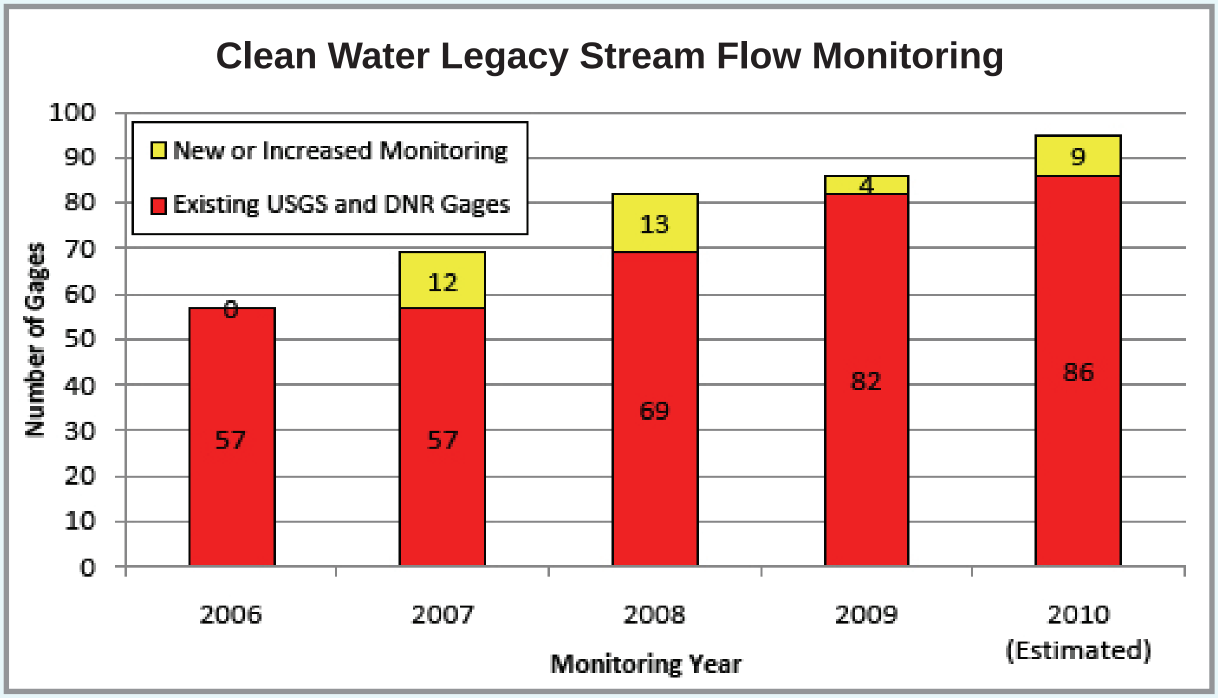
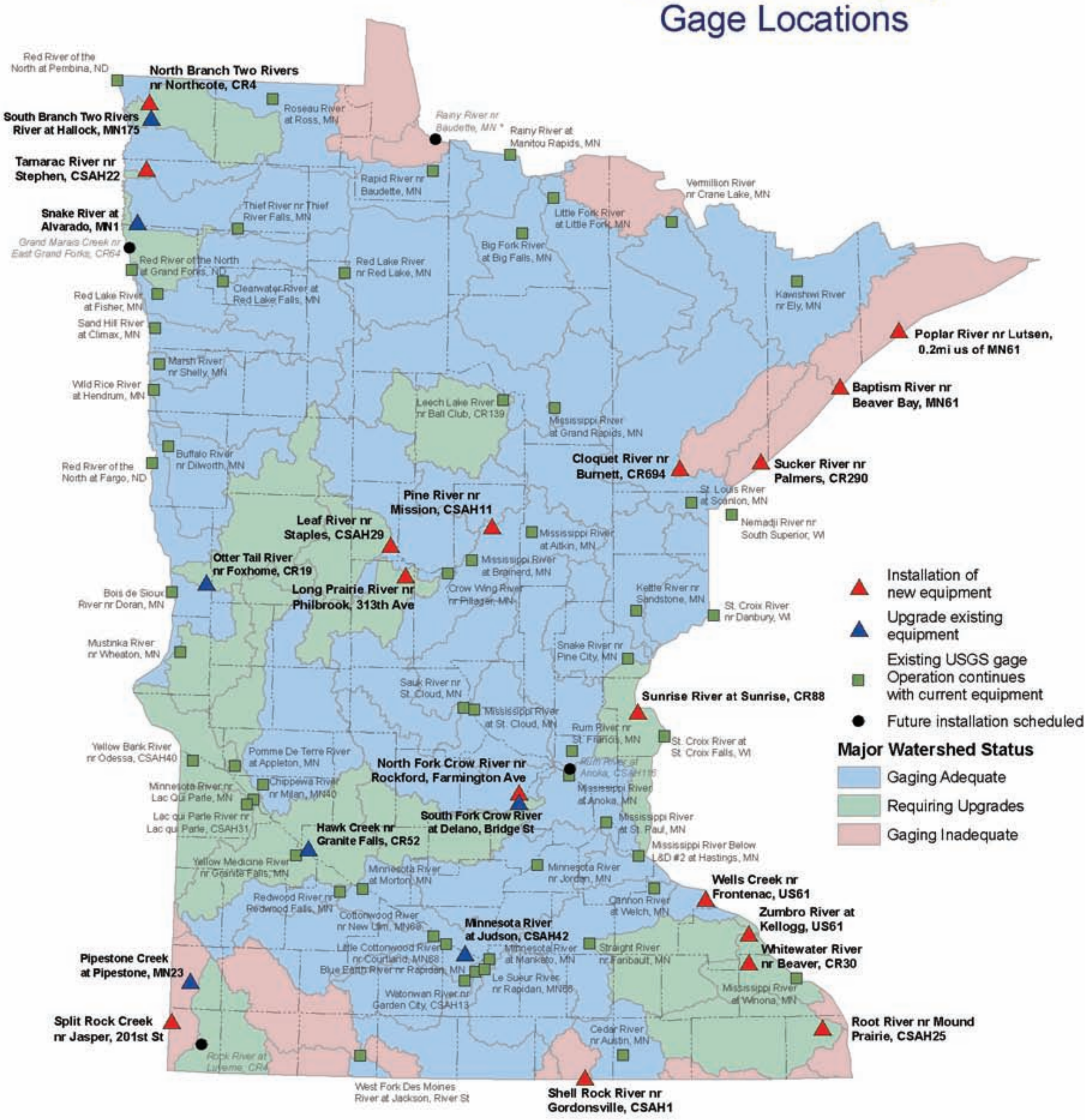


Figure 3

Clean Water Legacy Gage Locations



DNR Gage Installations

Station ID	Station Name	Installation date
H01063003	Poplar River nr Lutsen, 0.2mi us of MN61	08/13/2008
H01092001	Baptism River nr Beaver Bay, MN61	08/15/2008
H02031001	Sucker River nr Palmers, CR290	09/25/2008
H04048001	Cloquet River nr Burnett, CR694	09/25/2008
H11051001	Pine River nr Mission, CSAH11	07/02/2008
H13058001	Leaf River nr Staples, CSAH29	10/23/2008
H14034001	Long Prairie River nr Philbrook, 313th Ave	10/22/2008
H18088001	North Fork Crow River nr Rockford, Farmington Ave	07/23/2008
H19001001	South Fork Crow River at Delano, Bridge St	
H25037001	Hawk Creek nr Granite Falls, CR52	
H28054001	Minnesota River at Judson, CSAH42	
H37030001	Sunrise River at Sunrise, CR88	05/29/2008
H38006002	Wells Creek nr Frontenac, US61	06/12/2008

Station ID	Station Name	Installation date
H40016001	Whitewater River nr Beaver, CR30	06/03/2008
H41043001	Zumbro River at Kellogg, US61	
H43007002	Root River nr Mound Prairie, CSAH25	10/09/2008
H49009001	Shell Rock River nr Gordonsville, CSAH1	09/11/2008
H56066001	Otter Tail River nr Foxhome, CR19	
H67014001	Grand Marais Creek nr East Grand Forks, CR64	
H68006001	Snake River at Alvarado, MN1	
H69051001	Tamarac River nr Stephen, CSAH22	06/18/2008
H70018001	South Branch Two Rivers River at Hallock, MN175	
H70021001	North Branch Two Rivers nr Northcote, CR4	06/17/2008
H82015001	Split Rock Creek nr Jasper, 201st St	09/04/2008
H82035001	Pipestone Creek at Pipestone, MN23	
H83016001	Rock River at Luverne, CR4	

Water Year - 2007

In the fall of 2006 (the 2007 Water Year began October 1, 2006), stream flow conditions were low (or below the Q75 exceedence value) in the north-central to northeast part of the state. The remainder of the state was in a normal flow range (Q25-Q75) with a few pockets of higher flows in the west-central part of the state.

While a storm in November brought significant snowfall to the south and southeast, the snow was not sustained throughout the winter. December's above average temperatures caused precipitation to fall as rain, which helped bring low-flow rivers up to normal rankings. Warm temperatures during the beginning of January 2007 and a concurrent "snow drought" reduced remaining snow pack for much of the state. The end of February and beginning of March brought very cold temperatures and a couple of large snowstorms that would affect river levels. Although snow levels were lower than normal for the state overall for the 2006-07 winter, these late snowstorms coupled with quickly rising March temperatures were enough to cause spring runoff flooding problems in western Minnesota.

By early April rivers in the southern two-thirds of the state were open and running at high levels, or above the Q25 exceedence flow. By mid-April, most rivers were ice-free and returning to normal April flows (Q25-Q75). Rivers in the north-central and northeast part of the state that were low in the fall remained lower than those in the south. The spring runoff allowed the northern 1/3 of the state to recover to normal flows conditions.

While many rivers dropped into normal or even low flows in May, the rivers of west-central and southwest Minnesota continued to flow at or above their Q25 exceedence value. This high flow condition rapidly declined as the summer progressed with much of the state slipping into drought conditions.

Throughout May and June, the state began to show a large gap in precipitation distribution. Large rainstorms caused rivers in western Minnesota to swell while other areas of the state saw a shortage and hints of the drought to come.

Below average precipitation in July caused rivers to drop to the Low and Critical Flow range in a band through the northeast, central and south-central part of the state. Western and southeastern Minnesota rivers remained at normal flows levels.

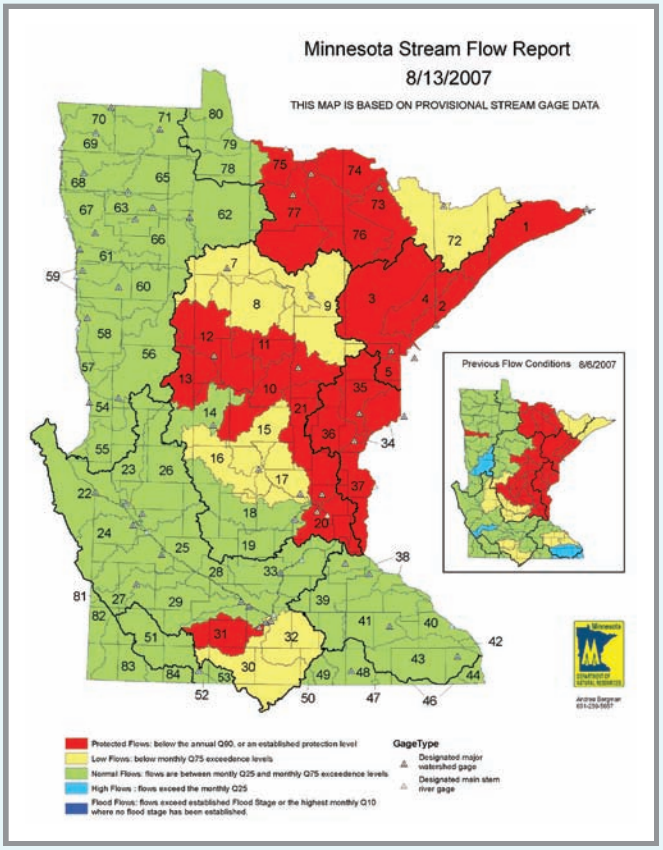
This separation between Normal and Critical Flow levels increased into August with central and northeast rivers falling to very low levels. By mid-August, much of the state was in drought or near-drought conditions. That all changed in southern Minnesota when a storm event on Sunday, August 19th brought up to 18 inches of rain in a matter of hours. Many watersheds quickly flipped from drought to flooding. Rivers in the southeast reported floods at 500-year event (which has a 0.2% chance of occurring in any given year) magnitudes. Severe flooding, mudslides, and damage occurred in many southeast counties (see special section on page 27).

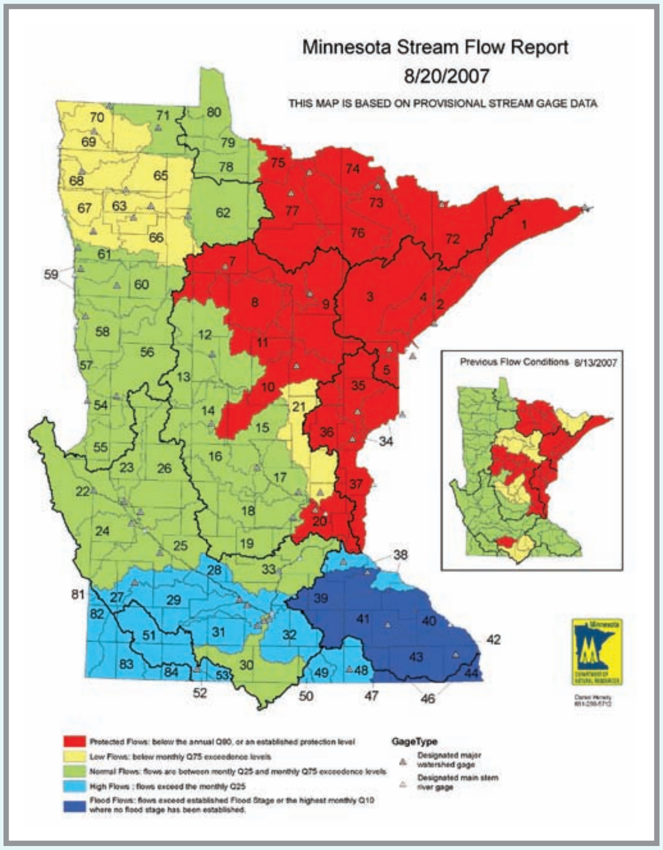
EXCEEDENCE VALUE

An exceedence value is a statistical parameter, based upon historical discharge records, and is the probability of stream flow exceeding a certain value. A 50% exceedence value (Q50) indicates that the discharge at that reporting station has been equalled or exceeded 50% of the time during a specific period. Exceedence values can be calculated on a daily, monthly or annual basis.

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

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





September rainfall was higher than normal, welcome in some parts of the state, not so in others. Rivers in the northern part of the state slowly recovered from drought conditions that had plagued them for most of the summer. These rains were unwelcome in southern watersheds where residents were still recovering from the August torrent.

The 2007 Water Year ended with rivers in the arrowhead region and southern Minnesota remaining at the Q25 exceedence level while the rest of the state recovered from drought conditions. Part of north central Minnesota remained below the Q75 exceedence level, while the rest of the state's watersheds were classified


Michele Hanson

Figure 4

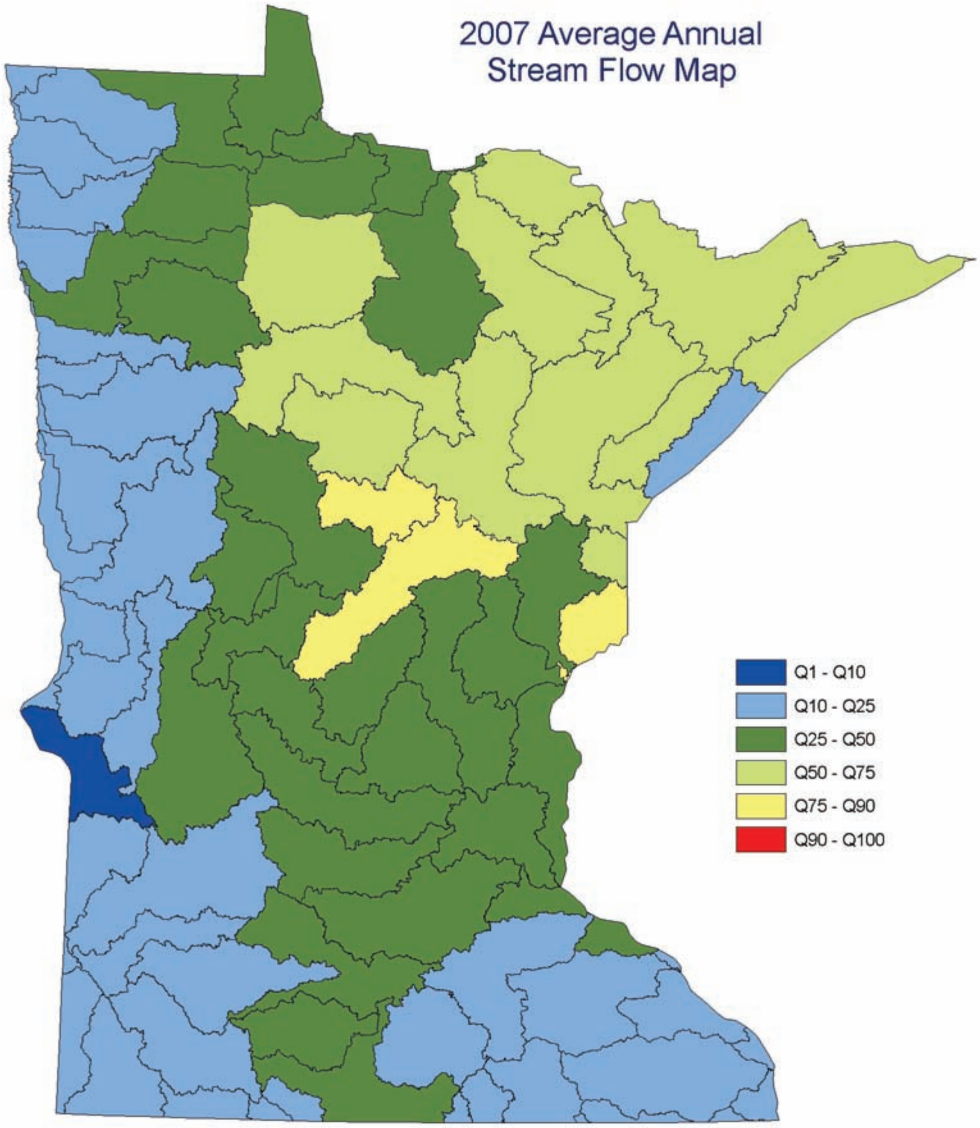
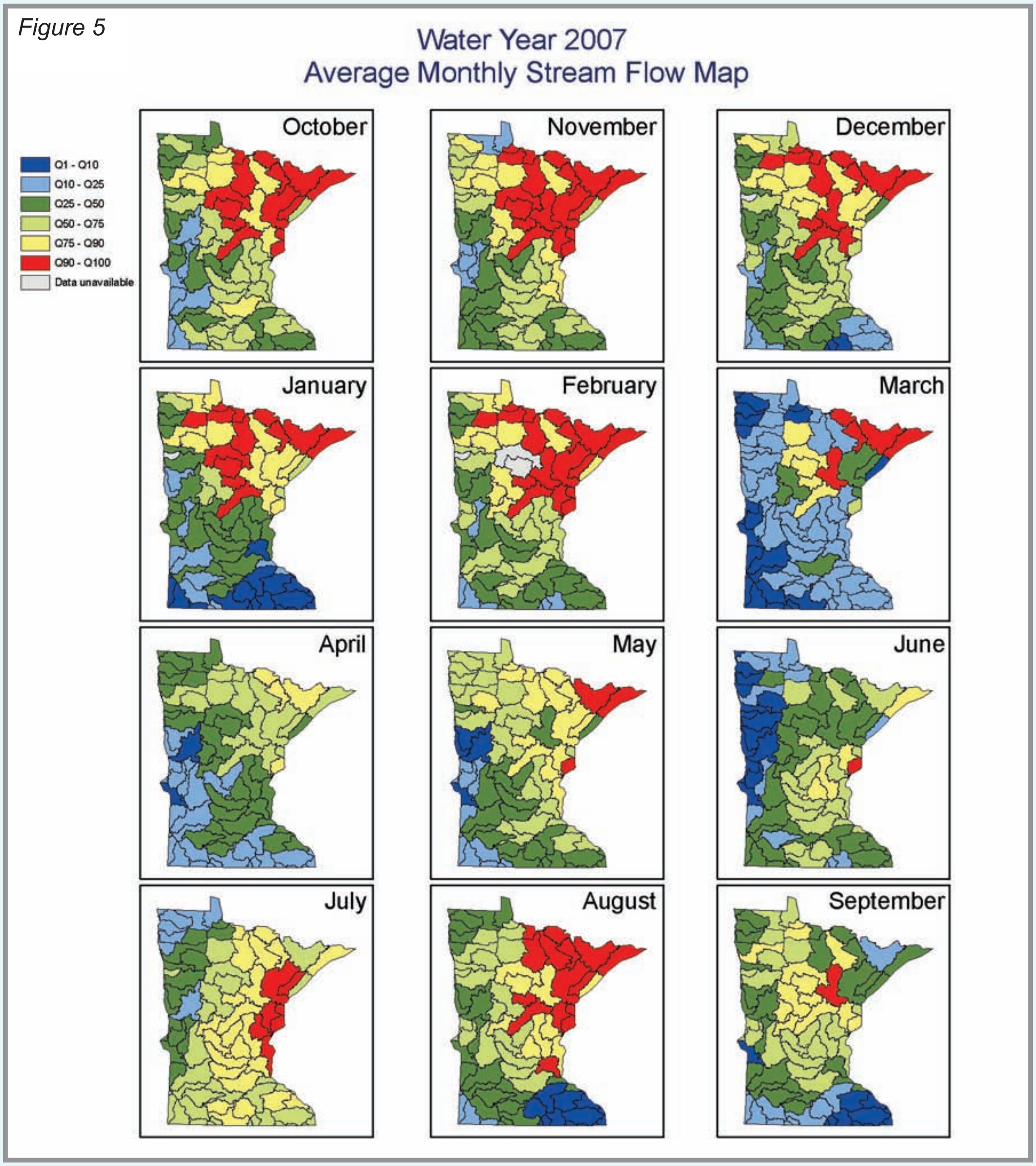


Figure 4 shows the 2007 Average Annual Stream Flow Map. Statewide, most watersheds had an annual average flow greater than the historic average or normal flow.


Clint Little


Peter Leete

Figure 5

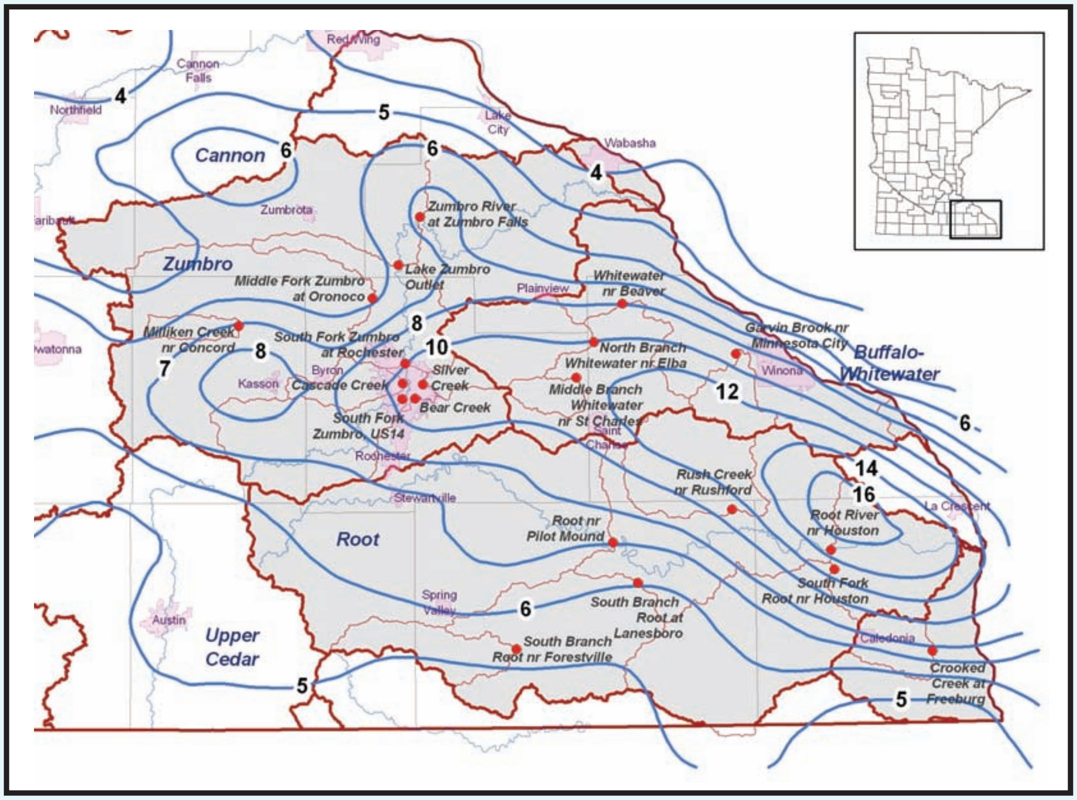



Woodbury Sinkhole

Dale Homuth


Rush Creek Flood Damage, Winona Co.

Jeff Green



(Data from State Climatology office)

When the rains came on the evening of August 18, 2007, they covered much of southeast Minnesota in record amounts. Rainfall totals ranged from an impressive 6 to a devastating 18 inches over the course of the event.

This event obviously caused a rapid rise in rivers, especially in that part of the state is where geographic relief tends to produce fast flowing, flashy streams. Some streams received such a volume of water, an entirely re-shaped river channel was left in its wake.

Crews from the DNR, USGS, National Weather Service, and Army Corps of Engineers were out collecting data and making stream flow and high water measurements in order to capture this record event. Due to the timing (early Sunday morning) speed and intensity of the event hydraulic models, high water marks and other survey information were used after the flooding to reconstruct the event at many locations where crews were unable to make measurements.

Measured and estimated discharges for affected watersheds:

Watershed	Event magnitude	Event note
Zumbro River Watershed	5-25 year event	
Whitewater River Watershed	500 year event (approximate)	Flood of record
Garvin Brook Watershed	500 year event (approximate)	Flood of record
Root River Watershed	100-200 year event (Houston)	Flood of record
Rush Creek Watershed	200-year event (approximate)	Flood of record

Water Year - 2008

Stream flows were high at the start of WY 2008 due to the flooding and above average precipitation in August and September of 2007. These higher flows continued into October, as precipitation was above average statewide.

Although November was dry, flows were sustained as ice formed and winter 2008 began with higher than normal snowfall amounts in December. However, by January and February, snowfall had dropped to below normal. Low snowfall totals produced a mild spring snowmelt season with no significant flooding events related to spring runoff. Temperatures during this period were also below normal, delaying the spring thaw. It wasn't until late April that most rivers were ice-free. Once the rivers were free of ice they swelled to high flows, at or above Q25 exceedence values, due to significant snow and rain events in April. These high flows did not cause nearly the flood damage seen in the spring of 2007 or other years.

With continued rainfall in May, many watersheds across the state quickly reached Q25 exceedence values by the middle of the month. The remainder of the month was dry and river levels quickly dropped to normal flows. June brought heavy rains to much of the state and caused another rise in stream flows for many watersheds. Two major rain events in the southeast in early June brought about severe flooding and damage. This event was not nearly as significant as the flooding event in August of 2007, but some communities were affected by both major events. By mid-June, most of the rivers in the state flowed at the Q25 exceedence value.

Rainfall dropped off in July and flows declined to Q75 exceedence values. This trend continued into August as watersheds began to dry up, again starting in northeast and east-central Minnesota. The state descended into yet another period of low flow and drought conditions. While considered a drought, it was not nearly as severe as in 2007. Water Year 2008 closed out with dry conditions persisting in the northeast and east-central watersheds, with the remainder of the state in normal flow conditions.

Figure 6

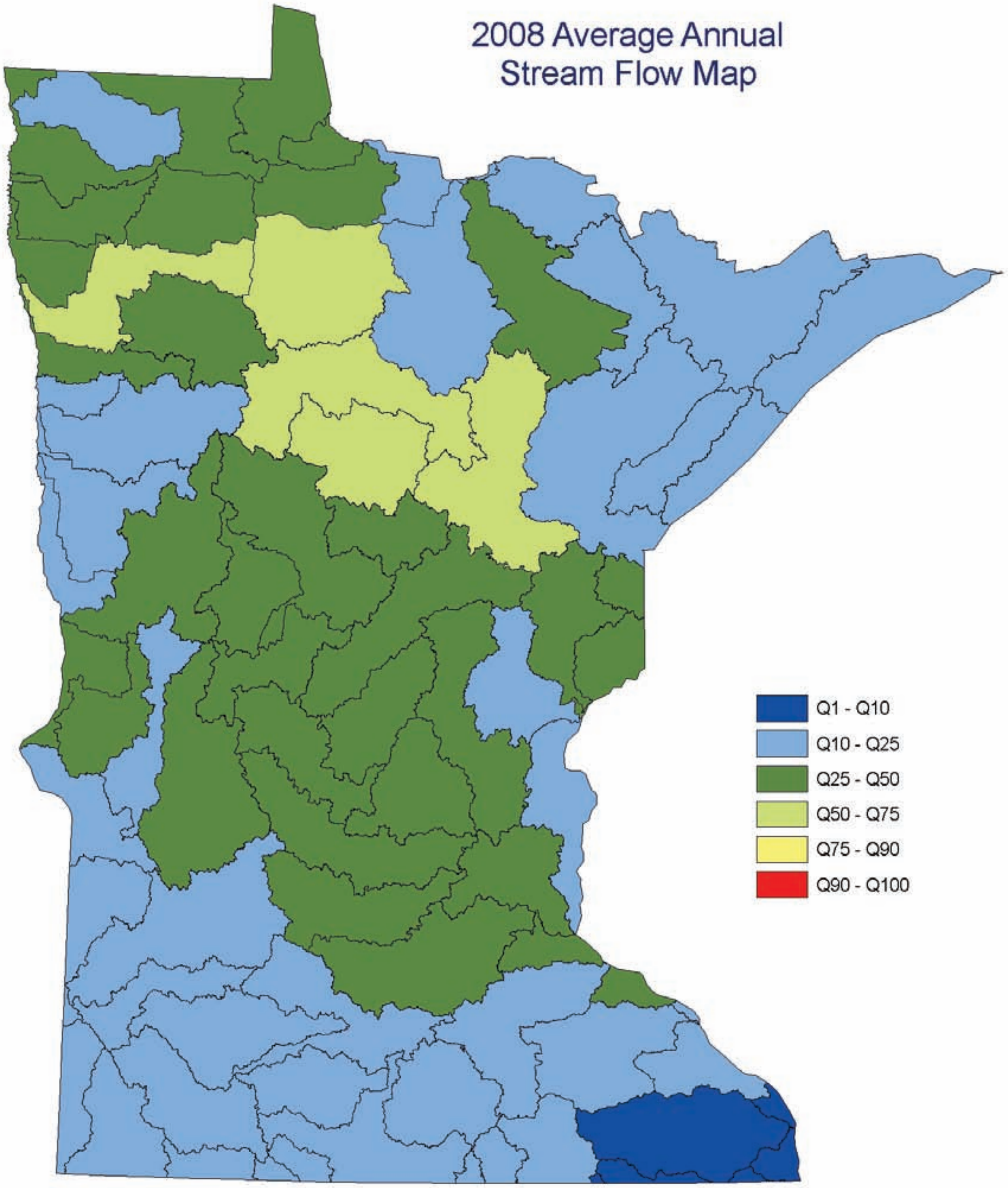
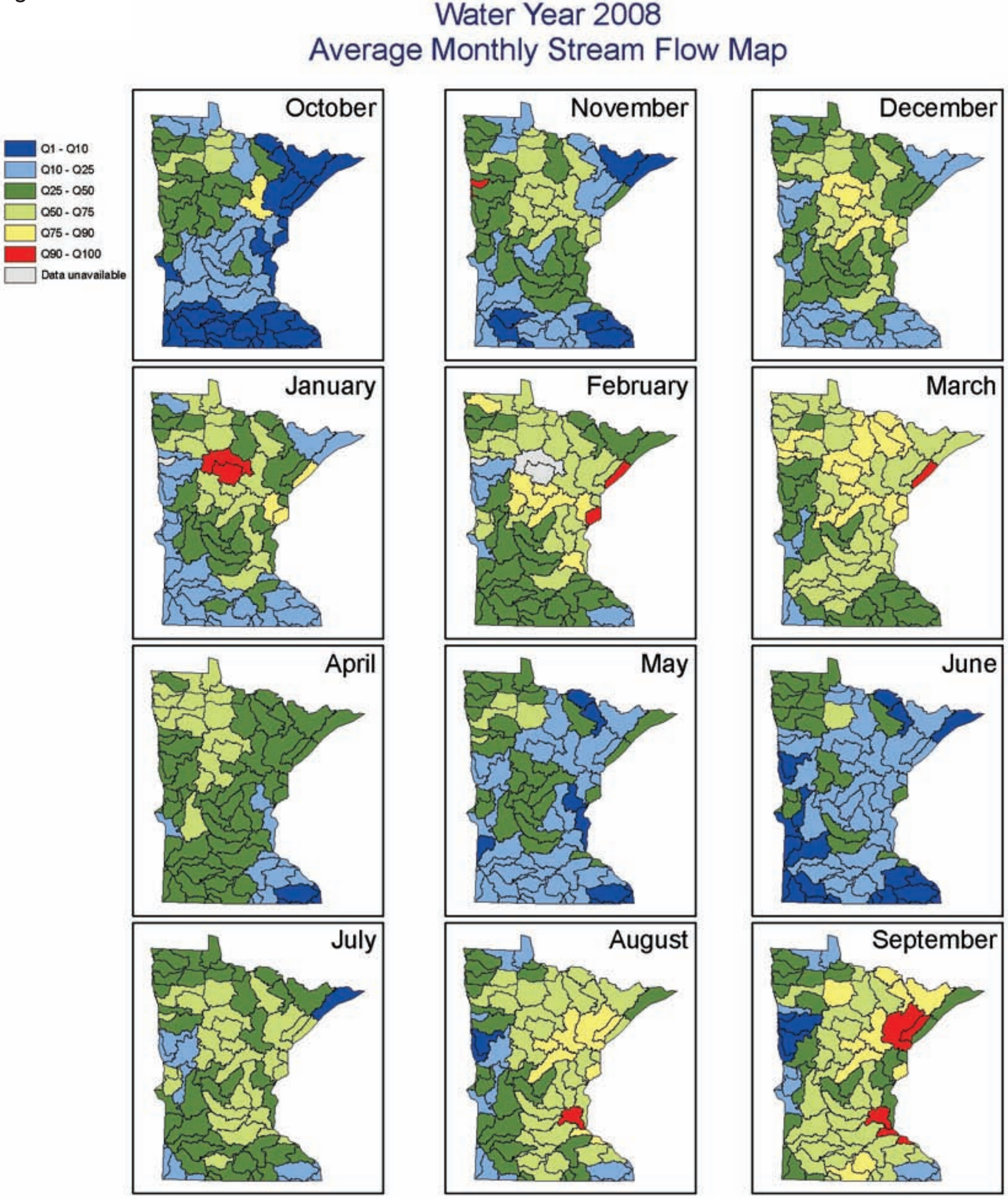


Figure 6 shows the 2008 Average Annual Stream Flow Map. Similar to 2007, watersheds had an annual average flow greater than the historic average or normal flow.

Figure 7

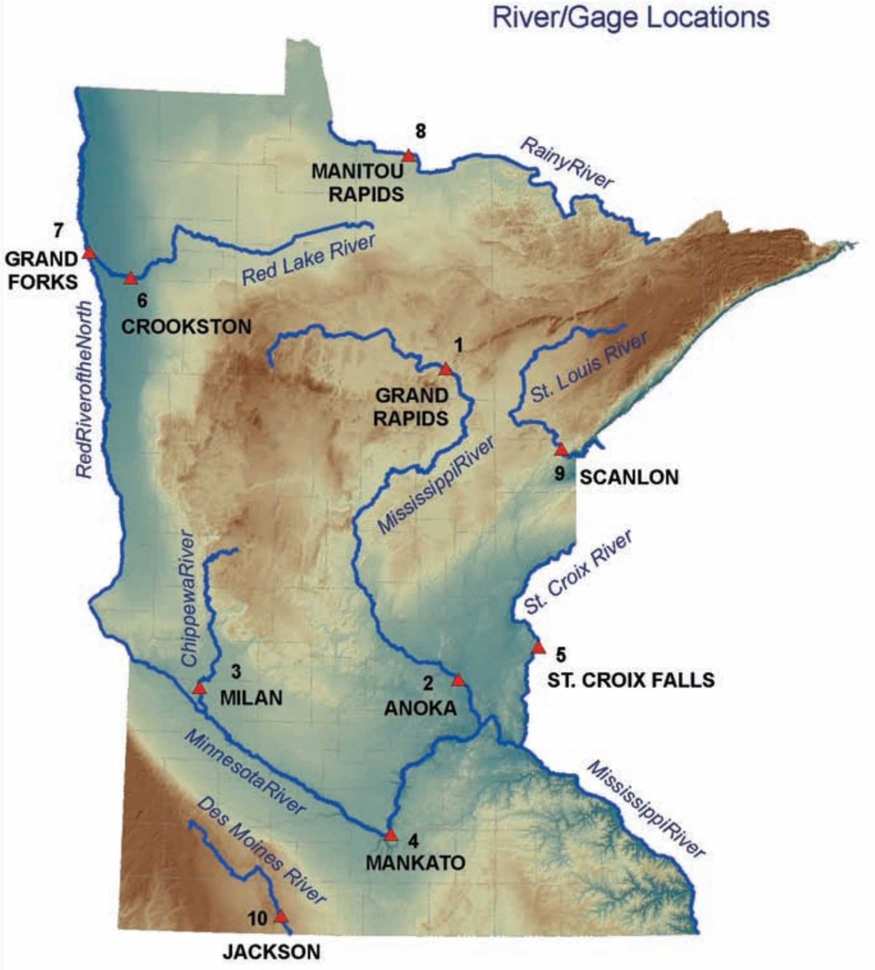


Skip Wright

Molly Shodeen

Hydrographs

Figure 8



Gage Name (USGS ID)

1) Mississippi River at Grand Rapids, MN (05211000)
2) Mississippi River near Anoka, MN (05288500)
3) Chippewa River near Milan, MN (05304500)
4) Minnesota River at Mankato, MN (05325000)
5) St. Croix River at St. Croix Falls, WI (05340500)
6) Red Lake River at Crookston, MN (05079000)
7) Red River of the North at Grand Forks, ND (05082500)
8) Rainy River at Manitou Rapids, MN (05133500)
9) St. Louis River at Scanlon, MN (04024000)
10) Des Moines River at Jackson, MN (05476000)

To give a general summary of flow conditions around the state for the 2007 and 2008 Water Years, discharge hydrographs were created for 10 selected streams. These streams and their locations are shown in Figure 8.

For these 10 selected streams, mean daily discharges are shown in Figures 9 and 10 (pages 32 and 33). Included on those figures are the daily Q25 and Q75 exceedence values and the Q90 Protected Flow.

Figures 11 and 12 (pages 34 and 35) show the mean annual discharge for each of the 10 selected sites. In these figures, the graphs, by water year, extend from 1900 to 2010. As with the other figures, the Q25 and Q75 exceedence values are included. Note, however, that these exceedence values are based on average annual flows and are different than the Q25 and Q75 values calculated from daily flows. Also included on the graphs is the 30-Year Moving Average, showing the general flow trend.

Figure 9

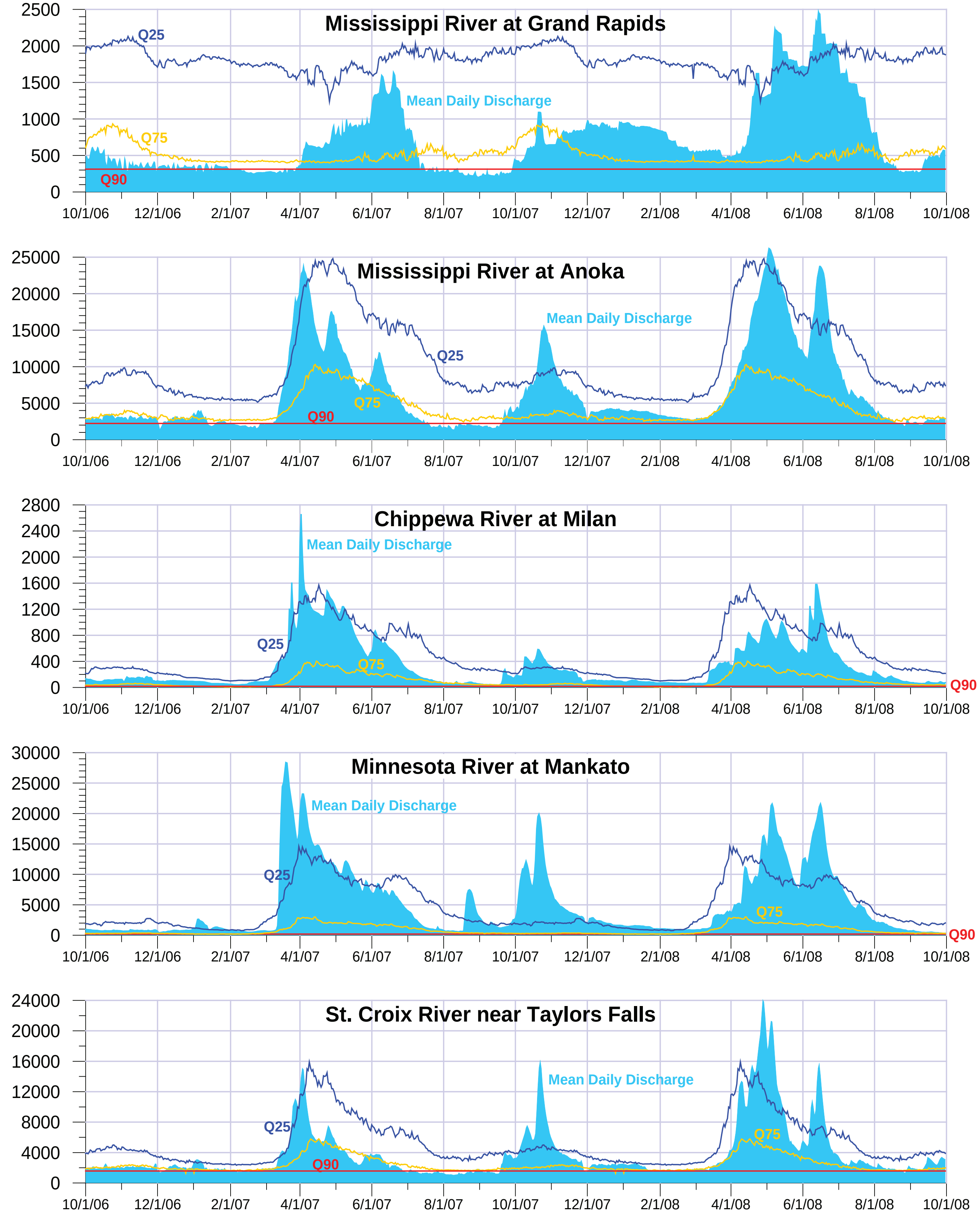

Mississippi River at Grand Rapids
2500
2000
1500
1000
500
0
Q25
Q75
Q90
Mean Daily Discharge
10/1/06
12/1/06
2/1/07
4/1/07
6/1/07
8/1/07
10/1/07
12/1/07
2/1/08
4/1/08
6/1/08
8/1/08
10/1/08
Mississippi River at Anoka
25000
20000
15000
10000
5000
0
Mean Daily Discharge
Q25
Q75
Q90
Chippewa River at Milan
2800
2400
2000
1600
1200
800
400
0
Mean Daily Discharge
Q25
Q75
Q90
Minnesota River at Mankato
30000
25000
20000
15000
10000
5000
0
Mean Daily Discharge
Q25
Q75
Q90
St. Croix River near Taylors Falls
24000
20000
16000
12000
8000
4000
0
Mean Daily Discharge
Q25
Q75
Q90

Figure 10

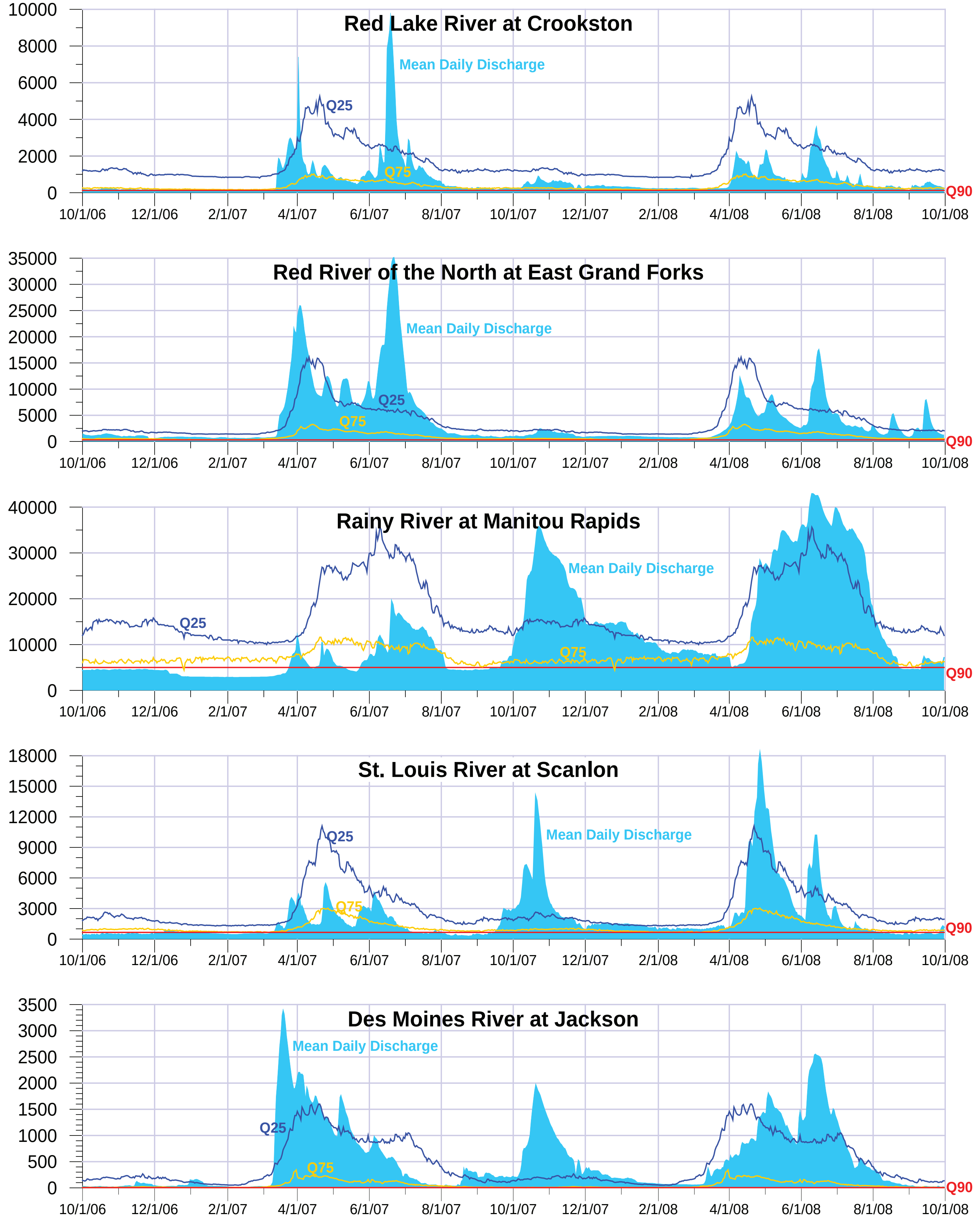

Red Lake River at Crookston
Mean Daily Discharge
Q25
Q75
Q90
10000
8000
6000
4000
2000
0
10/1/06
12/1/06
2/1/07
4/1/07
6/1/07
8/1/07
10/1/07
12/1/07
2/1/08
4/1/08
6/1/08
8/1/08
10/1/08
Red River of the North at East Grand Forks
Mean Daily Discharge
Q25
Q75
Q90
35000
30000
25000
20000
15000
10000
5000
0
Rainy River at Manitou Rapids
Mean Daily Discharge
Q25
Q75
Q90
40000
30000
20000
10000
0
St. Louis River at Scanlon
Mean Daily Discharge
Q25
Q75
Q90
18000
15000
12000
9000
6000
3000
0
Des Moines River at Jackson
Mean Daily Discharge
Q25
Q75
Q90
3500
3000
2500
2000
1500
1000
500
0

Figure 11

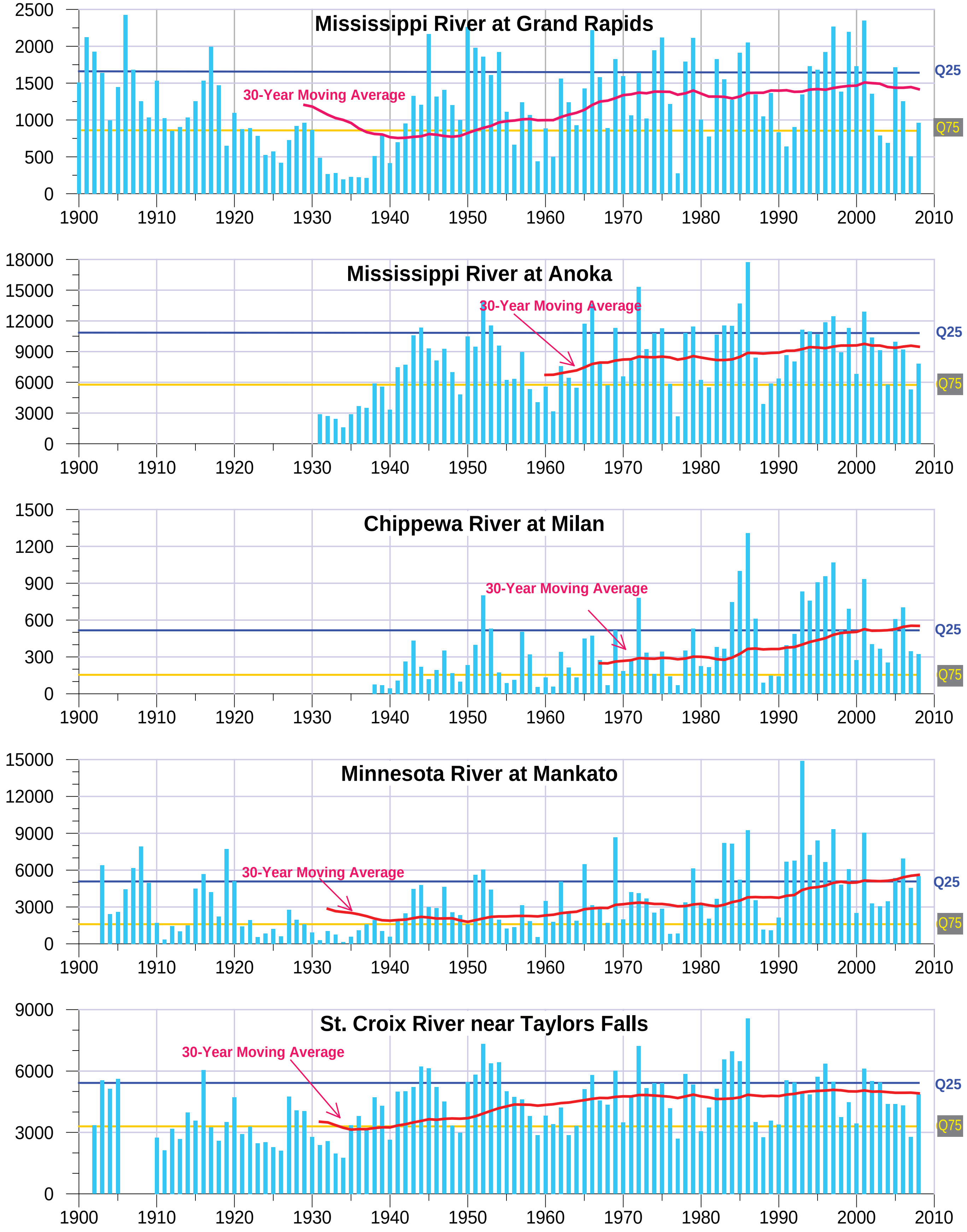
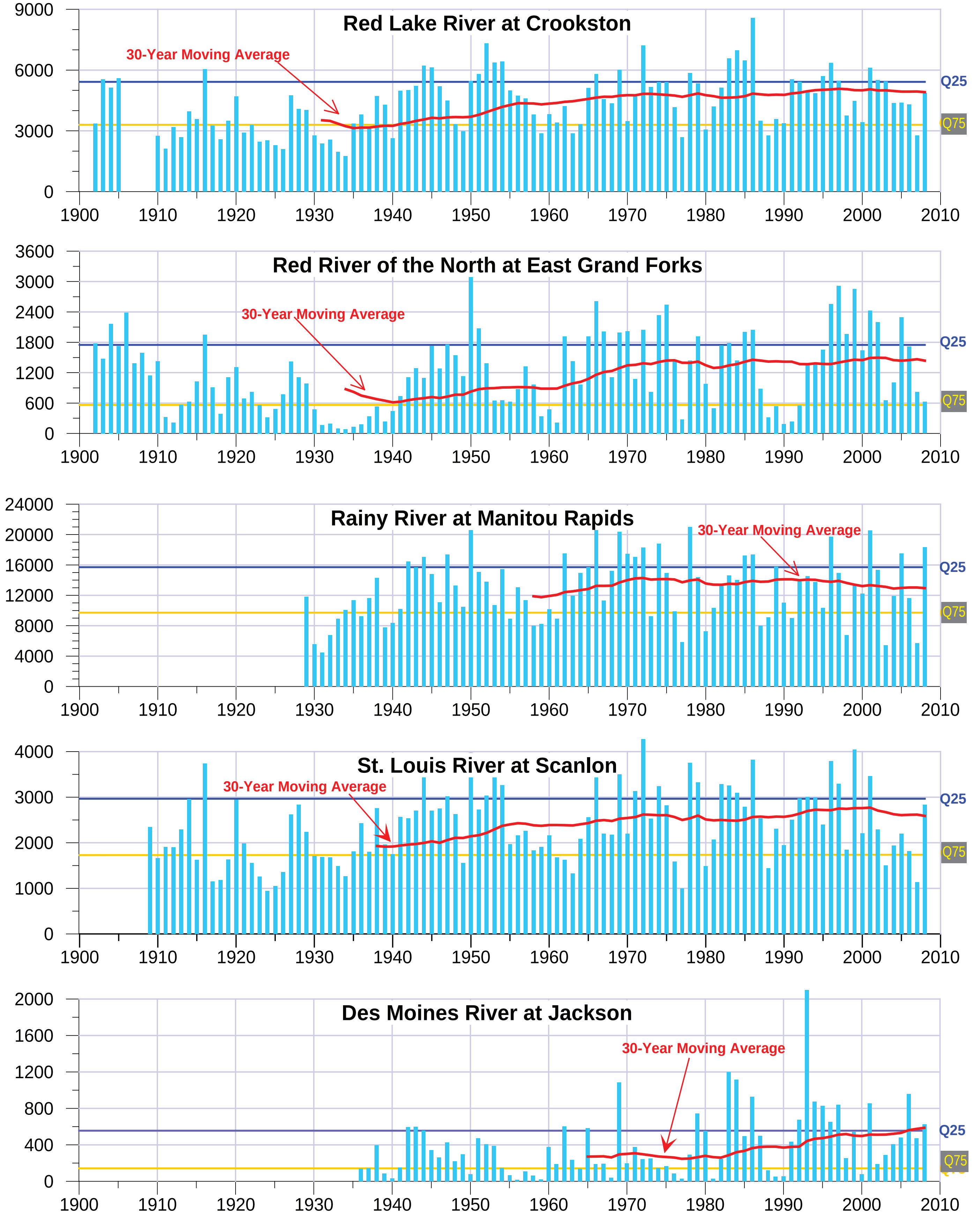

Mississippi River at Grand Rapids
2500
2000
1500
1000
500
0
30-Year Moving Average
Q25
Q75
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
Mississippi River at Anoka
18000
15000
12000
9000
6000
3000
0
30-Year Moving Average
Q25
Q75
Chippewa River at Milan
1500
1200
900
600
300
0
30-Year Moving Average
Q25
Q75
Minnesota River at Mankato
15000
12000
9000
6000
3000
0
30-Year Moving Average
Q25
Q75
St. Croix River near Taylors Falls
9000
6000
3000
0
30-Year Moving Average
Q25
Q75

Figure 12


Red Lake River at Crookston
30-Year Moving Average
9000
6000
3000
0
Q25
Q75
Red River of the North at East Grand Forks
30-Year Moving Average
3600
3000
2400
1800
1200
600
0
Q25
Q75
Rainy River at Manitou Rapids
30-Year Moving Average
24000
20000
16000
12000
8000
4000
0
Q25
Q75
St. Louis River at Scanlon
30-Year Moving Average
4000
3000
2000
1000
0
Q25
Q75
Des Moines River at Jackson
30-Year Moving Average
2000
1600
1200
800
400
0
Q25
Q75
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010

Lake Levels

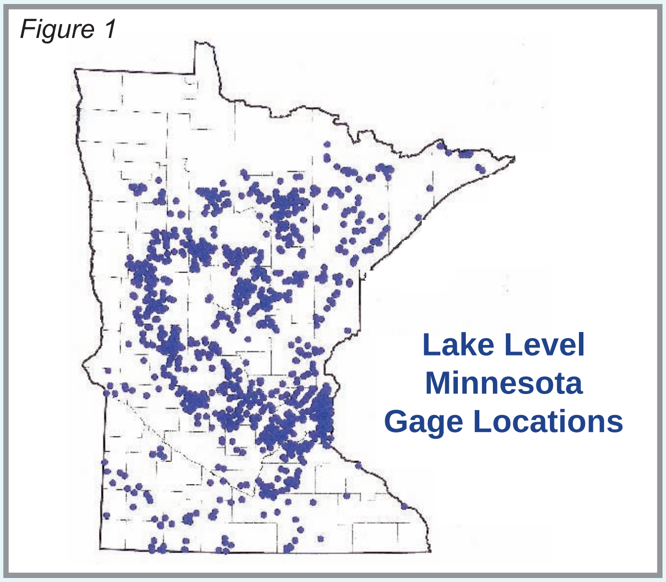
Introduction

The Lake Hydrology Program exists to support the DNR Waters director and staff by collecting and providing data on lake levels and other lake characteristics that are needed to effectively carry out DNR Waters' statutory responsibilities and management programs.

Lake Level Minnesota

A key component of the Lake Hydrology Program is the development and maintenance of the Lake Level Minnesota Monitoring Program. The Lake Level monitoring program primarily uses both temporary (movable) and permanent lake gages as indicators for measuring and determining the water surface level of certain lakes. A network of about 1000 lake gages is currently managed (Figure 1). The program relies on over 800 citizen volunteers and local government partners who record lake levels on a regular basis and submit the data to DNR Waters. Approximately 25% of the monitoring sites are managed currently under oral cooperative agreements with governmental units.

Figure 1



Sandy Fecht

Data Uses

Water level data are used by DNR field staff as rationale for decision making in the public waters permit program and appropriations permit program. The records are used as supporting data for establishing ordinary high water levels and historic high water elevations, which are also the foundation for setbacks within the land use management programs. Lake level data support many DNR Waters hydrologic and hydraulic analyses. A consistent record of lake levels provides a long-term indication and understanding of the hydrology of the lake, watershed, and the relation between surface water and ground water. The information is crucial to surface water and ground water interaction studies for appropriations decisions. Long-term records show normal fluctuations, as well as the extreme highs and lows. Data are used to calibrate hydrologic models, especially applications for flood levels and lake outlets.

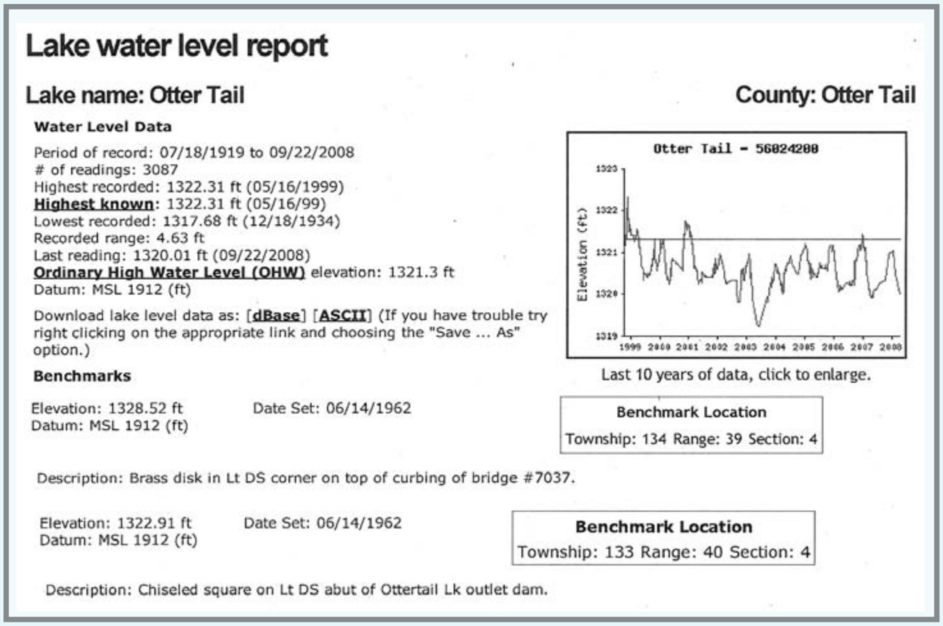
The data are used by local zoning officials for platting, locating structure sites, and for establishing low floor elevations for new construction. Watershed managers and planners use historical lake level data while preparing local water management plans and modeling lake water quality characteristics. Fisheries staff use data as one variable in studying impacts on habitat. Other researchers use the data for climate change studies. Water level data are used for decisions by lakeshore owners on dock location/timing, vegetative shoreline protection, and understanding the natural fluctuations of a lake.

Information Management

All lake level readings received are entered into Lakes-DB©, a database program for storing and retrieving a variety of information on Minnesota's lake basins. Over the last few years, the millions of items of information have been migrated from a stand-alone database to an updated web application.

The DNR Lake Finder web site is the best means for the public to access available data on more than 4,500 Minnesota lakes relating to lake water levels, fisheries information, lake area and maximum depth, depth maps, water quality and clarity, air photos, and topographic maps. After searching by county, lake name, or identification number for a particular lake, a click on the word, "go," below "lake water levels/ruler" displays the Lake Water Level Report page. This report contains information, including:

- reported historical and current lake levels
- period of record and number of readings
- highest recorded lake level
- highest known lake level
- lowest recorded lake level
- recorded range
- ordinary high water level [also shown as the red line on the 10-year graph]
- datum of the majority of elevations
- benchmarks
- most recent 10-year graph [X-axis Year tick mark references mid-year]



Lake water level report

Lake name: Otter Tail

County: Otter Tail

Water Level Data

Period of record: 07/18/1919 to 09/22/2008
# of readings: 3087
Highest recorded: 1322.31 ft (05/16/1999)
Highest known: 1322.31 ft (05/16/99)
Lowest recorded: 1317.68 ft (12/18/1934)
Recorded range: 4.63 ft
Last reading: 1320.01 ft (09/22/2008)
Ordinary High Water Level (OHW) elevation: 1321.3 ft
Datum: MSL 1912 (ft)

Download lake level data as: [**dBase**] [**ASCII**] (If you have trouble try right clicking on the appropriate link and choosing the "Save ... As" option.)

Last 10 years of data, click to enlarge.

Benchmarks

Elevation: 1328.52 ft
Datum: MSL 1912 (ft)
Date Set: 06/14/1962

Benchmark Location
Township: 134 Range: 39 Section: 4

Description: Brass disk in Lt DS corner on top of curbing of bridge #7037.

Elevation: 1322.91 ft
Datum: MSL 1912 (ft)
Date Set: 06/14/1962

Benchmark Location
Township: 133 Range: 40 Section: 4

Description: Chiseled square on Lt DS abut of Ottertail Lk outlet dam.

Over 1,300 of the lakes have a historical record of more than 100 water level readings. In addition to the summary information, a Lake Finder user can retrieve and view all the reported lake elevations for a specific lake via the download of lake level data as dBase or ASCII from the center of the Lake Water Level report page.

Clicking on ASCII is the most common method used to view the water surface elevations and the date of the readings. The chronological water surface elevation data can then be viewed, saved, or highlighted and copied into a computer software spreadsheet for sorting and graphing. Check out how the levels of a chosen lake compare to other historic drought or wet years or other lakes.

Lake Levels

The primary factor that affects water level changes is the quantity and distribution of precipitation. Other factors that contribute to water level changes are soil moisture conditions, runoff, evapotranspiration, outlet conditions, beaver dams, human-made dams, ground water movement, and watershed characteristics and size (Figure 8, page 48).

Jerry Angst

The water levels of all lakes fluctuate dependent on their unique water budget - some more than others. A water budget is the sum of "incoming" resources minus "outgoing" resources. It is an estimation of the water resources available to "spend" or "save" and must take into account all available ground and surface water. Water enters the lake as precipitation, surface-water inflow, and ground-water inflow. Water leaves the lake as evaporation, surface-water outflow, and ground-water outflow *(see Hydrologic Cycle, page iv)*.

In a prolonged dry cycle, runoff and rain may be absorbed first by the soil and not contribute to lake levels. Knowing, understanding, and accepting the history of water level fluctuations can help lake users deal with expectations and problems associated with the changing levels.

Drought

"Pulled dock out August 28 - lake too low to get boat near."

"Water is 3 feet away from the lake gage."

"I haven't seen the lake this low since 1976."

"Super dry based on my 30 years of volunteer gage reading."

"Funny how we got rain, but it didn't seem to do as much as I thought it would have. No runoff from our watershed went into the lake."

"Think rain!!"

Comments like these from our volunteer readers illustrate the widespread drought in 2007 for the second summer in a row (Figure 2, page 40).

Rainfall totals for the summer were far short of the historical average in some locations in west central and central locales. In response to the lack of precipitation in 2007 and the effects of the drought of 2006, many lakes receded to low water levels. The list of counties with large areas reporting over 150 of their lowest lake levels by the end of Water Year 2007 grew longer and longer: Aitkin, Carlton, Carver, Cass, Hennepin, Kandiyohi, McLeod, Pine, St. Louis, Scott. Over 35 gaged lakes in Washington County reached their all-time lowest reported levels by the end of summer in 2007. Crow Wing and Itasca County lakes had the next highest number of gaged lakes with lowest reported levels in 2007. A number of gages had to be reset one to three times over the summer in deeper locations in order to capture any water level readings.

Water Year 2008 saw a prolonged dry spell for the third summer in a row for southern Minnesota, the Mississippi Headwaters, and parts of the northeast (Figure 3, page 41). Lakes in concentrated areas in Cass, Hubbard, Itasca, Washington, and Martin Counties reached their lowest historic lake level in the summer of 2008.

The 2008 drought areas were lessened by lowered temperatures in the summer, holding evaporation rates close to normal. Remarks by our volunteer readers were few compared to the previous two years of impacts on many gaged lakes. Less than 60 lakes reported their lowest lake level during the summer of 2008, a sharp contrast to the large numbers in 2006 and 2007.

Lake Level Responses

In contrast to the drought and areas of normal precipitation, other areas' significant rainfalls were reflected in lake level increases during the 2007-2008 Water Years (Figure 4, page 42). Rapid snow melt followed by above average precipitation for the first half of 2007 saturated the region in west central and northwestern Minnesota. A dozen lakes in Otter Tail County reported their highest water levels in Spring 2007. Only scattered lakes in the state reached their highest waters during that time, reflecting the effects of the drought. By the end of August 2007, many locations in the southern third of the state set all-time monthly rainfall records which helped restore low lake levels. One Twin Cities gage reader wrote, “Water, water everywhere! What happened to the drought?”

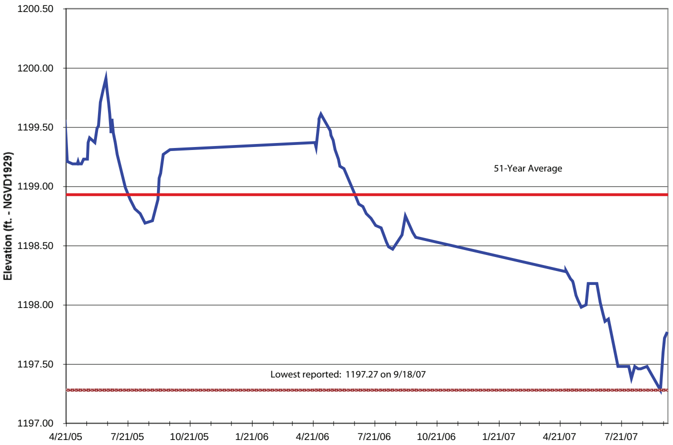
A strong weather system in early September 2007 dropped over six to nine inches of rain in the Arrowhead region, tripling historical averages for the month. Many of these same locations in the northeastern counties also had one of their wettest Octobers ever with similar precipitation totals. These cumulative rain events spiked lake levels to a number of highest reported levels in St. Louis County. A volunteer reported, “My dock is under water, and the lake is still rising.”

(photo at left: Poplar Lake, Rockwood Lodge & Canoe Outfitters)

One of the most interesting fluctuations over a year came from our volunteer readers on Poplar Lake in Cook County. In May 2007, they apologized [without need!]for missing taking a gage reading during the Ham Lake fire. Early May had brought weather conditions that were highly conducive to dry conditions and spreading wildfire potential. There was some June recharge of their lake, but the lake levels quickly dropped below the gage by the end of August. The lake then received the double impact from historic rainfalls in both September and October as seen in the hydrograph in Figure 4 (page 42).

The influence of the Fall 2007 rains carried over into high lake levels for many St. Louis County lakes in Spring and Summer 2008. Climatology Office maps showed this area with more than 175% of normal precipitation through mid-June 2008. Lakes were kept high as that trend continued with close to 100% precipitation by the end of the summer.

Long Lake (77-0027), Todd County



Gilbert Lake (18-0320), Crow Wing County

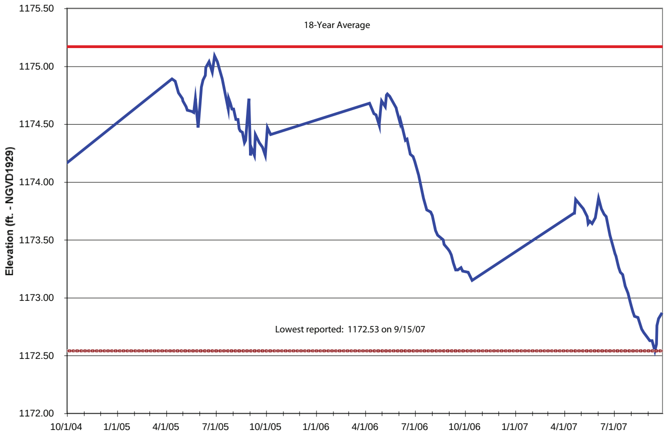
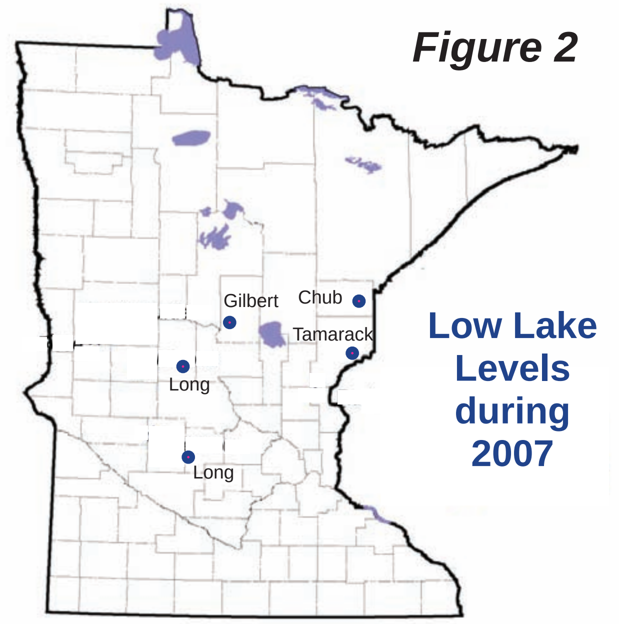
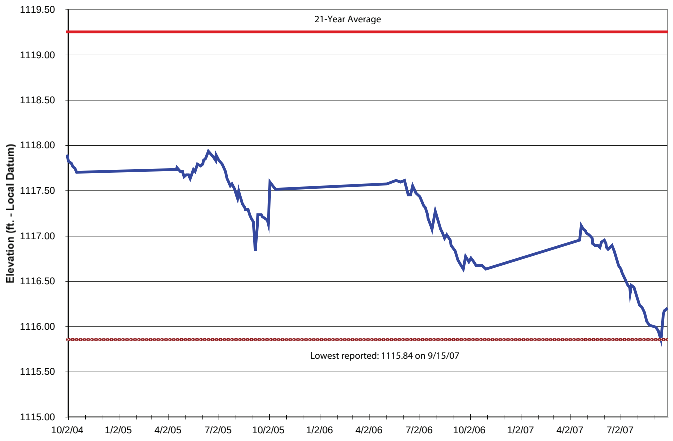


Figure 2

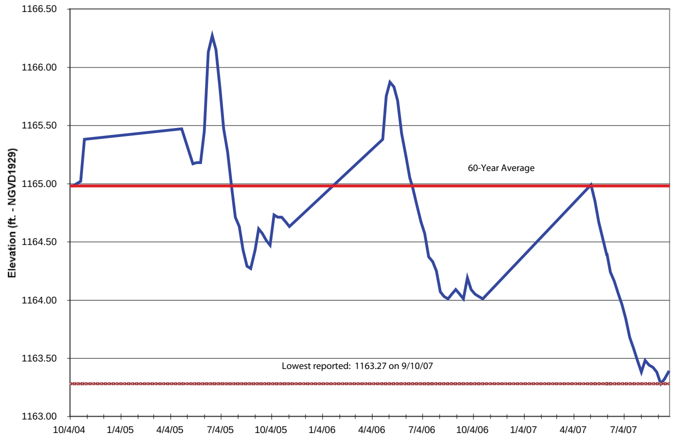


Low Lake Levels during 2007

Chub Lake (09-0008), Carlton County

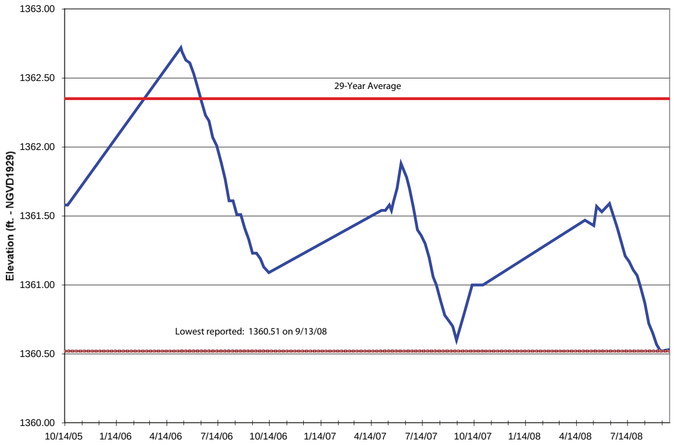


Long Lake (47-0177), Meeker County

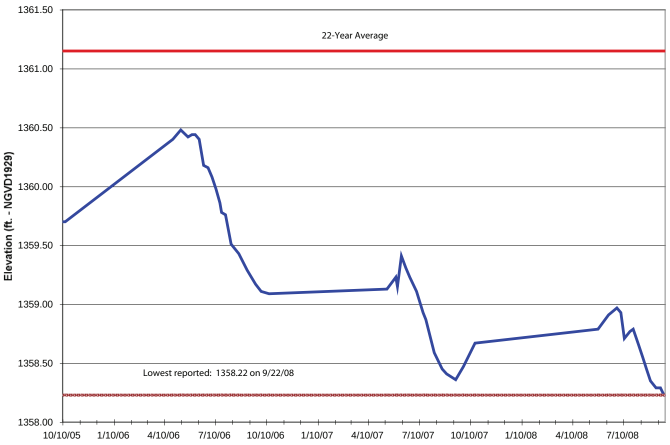


Tamarack Lake (58-0024), Pine County

Johnson Lake (31-0586), Itasca County



Sand Lake (31-0438), Itasca County



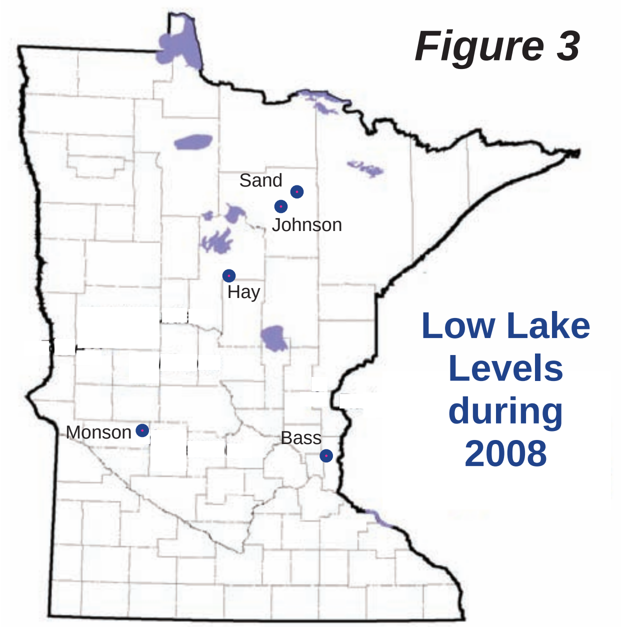
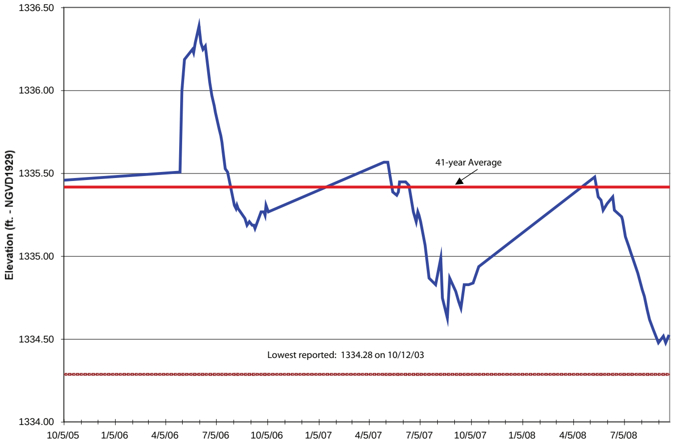


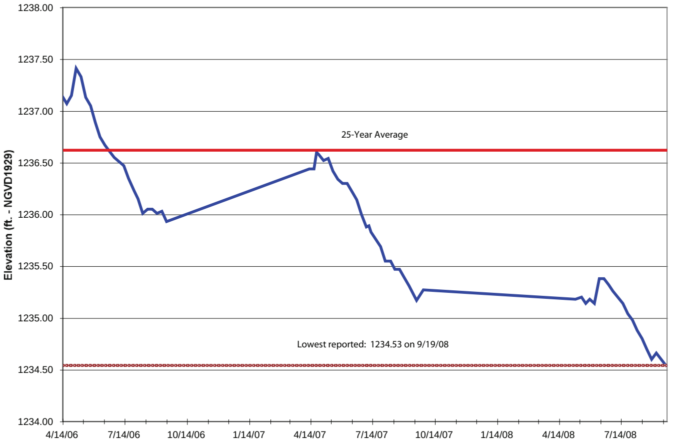
Figure 3

Low Lake Levels during 2008

Hay Lake (11-0199), Cass County

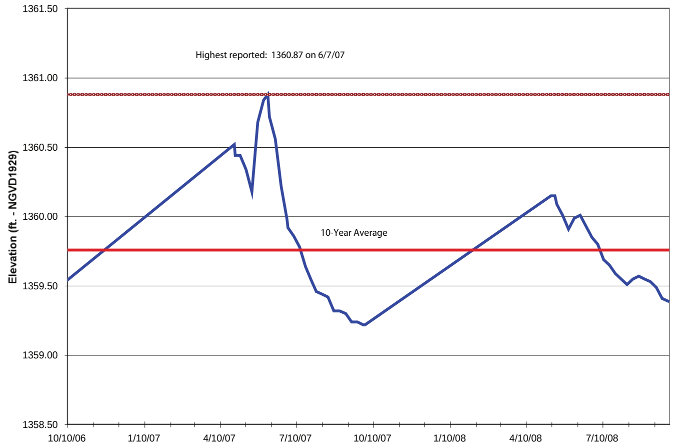


Monson Lake (76-0033), Swift County

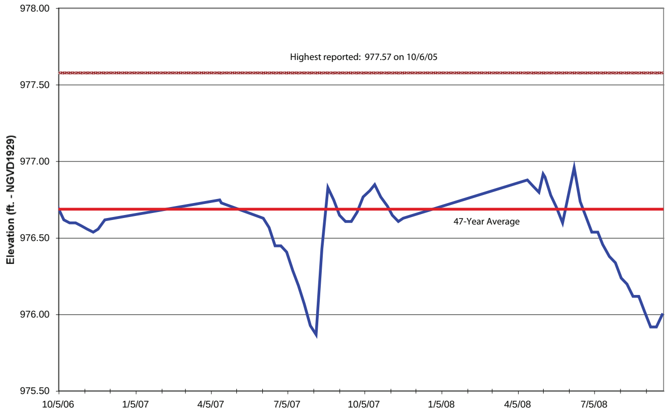


Bass Lake (82-0123), Washington County

Leek (Trowbridge) Lake (56-0532), Otter Tail County
Spring 2007



Orchard Lake (19-0031), Dakota County
Summer 2007



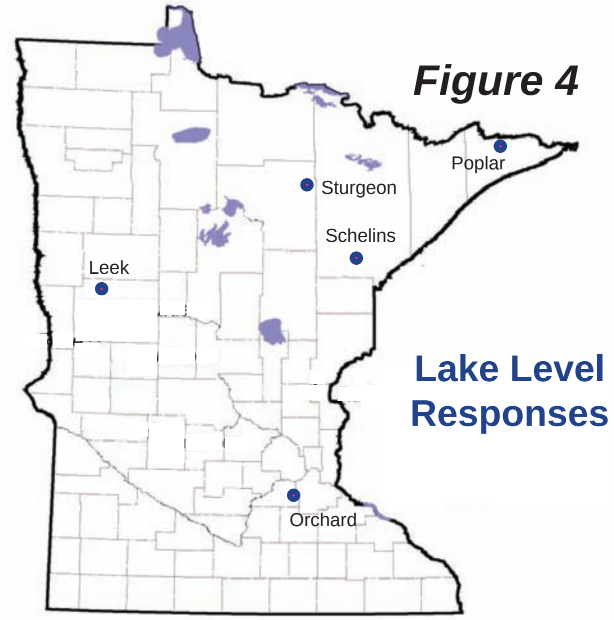
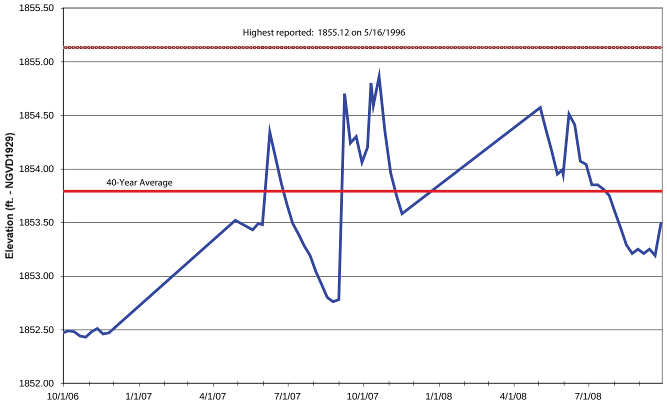


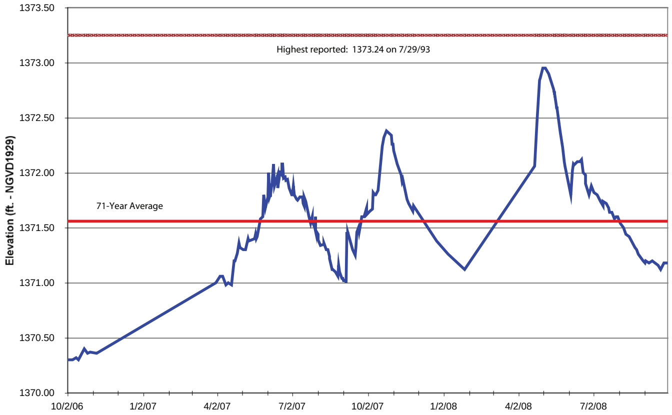
Figure 4

Lake Level Responses

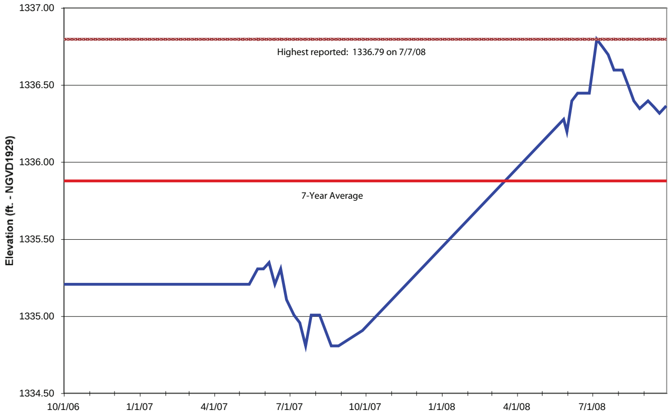
Poplar Lake (16-0239), Cook County
Fall 2007



Sturgeon Lake (69-0939), St. Louis County
Spring 2008

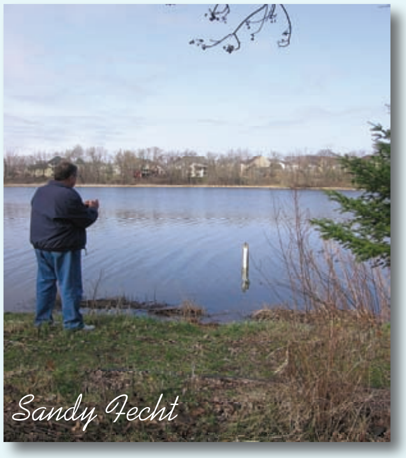


Schelins Lake (69-0624), St. Louis County
Summer 2008



Ten-Year Trends

Information has been collected and reported over a period of more than ten years for many of the lakes that are currently monitored. A ten-year average may be used as a point of reference when comparing water year data to a shorter or longer time period, or a ten-year climate cycle. It may be useful in discerning trends for an individual basin.



Sandy Fecht

A selection of lakes is shown in Figures 5 (page 45) and 6 (page 46). Lake Vermilion reflected the high precipitation for the Northeast in Fall 2007 and Spring 2008. Reported lake levels in May 2008 were some of the highest reported for Vermilion in our 58 years of records. Comparable spring levels can only be found in 1970 and 2001.

For these selected lakes, one lake remained below average during Water Year 2007 and most of Water Year 2008. Three of the lakes remained below their average throughout both Water Years 2007 and 2008. In Fall 2008, White Bear Lake reported its lowest level for the last 17 years. For more information from a past study of lake-ground water interaction at White Bear Lake following a drought, see this link.

Landlocked Basins

A landlocked lake has no regularly-functioning surface outlet channel, and usually a small watershed. These types of lakes typically experience large, long-term water level fluctuations. The importance of ground water contributions to a landlocked lake can make the lake a good indicator of local ground water levels and movement. Examples of landlocked basins are shown in Figure 7 (page 47). Some of these lakes also reflect responses to the dry conditions of 2007 and 2008.

Velma Wesloh

Annual Lake Level Fluctuation

Minnesota lakes typically fluctuate one to two vertical feet in a given year, but historical fluctuations have been recorded in excess of ten feet. Assessing the annual fluctuation can be done by looking at the changes from one Water Year to the next. Another primary evaluation tool is the "starting point," i.e. the elevation of the lake in spring, and how that compares to the end of the open water season and how that year compares to the "starting point," "end point," and pattern of other years. The lake levels and their patterns can then be evaluated in the context of historic climate data.

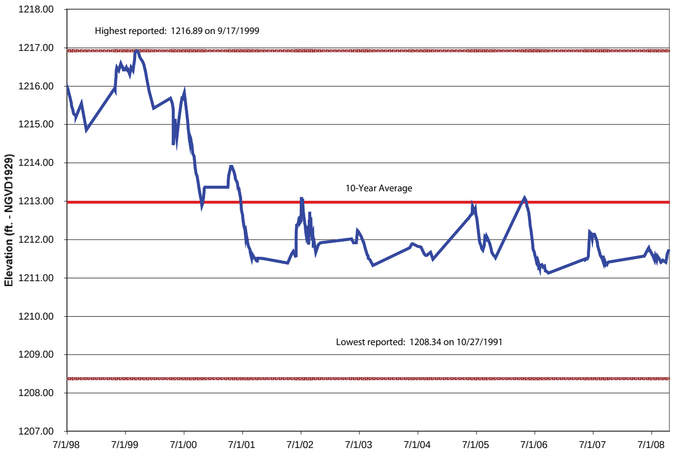
The statewide average fluctuation for Water Year 2007 was 1.24 feet, but decreased to 1.14 feet for the statewide average during Water Year 2008. Average fluctuations for the past ten Water Years are shown in the table on the next page. Link here to tables which display fluctuations, spring and fall elevations, ranges, reported highest and lowest lake levels and their dates, and averages for selected lakes grouped by county.

Additional summary information, ten-year trend graphs, and a comprehensive list of all reported lake levels for an individual lake may be found on the DNR Lake Finder web site.

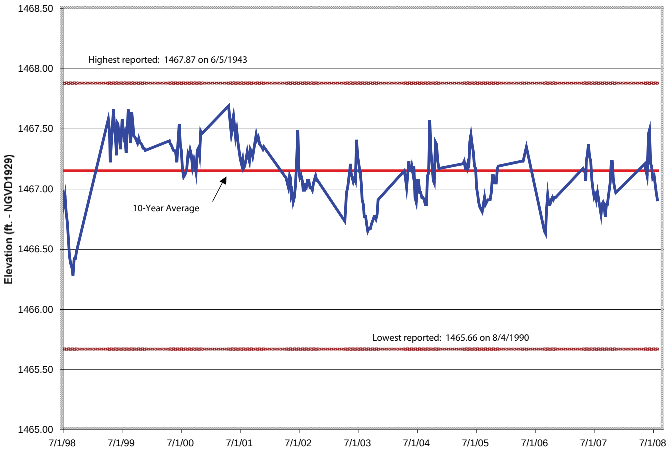
Water Year	Average Fluctuation Statewide (ft.)
1999	1.24
2000	1.05
2001	1.97
2002	1.33
2003	1.42
2004	1.24
2005	1.07
2006	1.29
2007	1.24
2008	1.14

Sandy Fecht

Union Lake (60-0217), Polk County



Lake Itasca (15-0016), Clearwater County



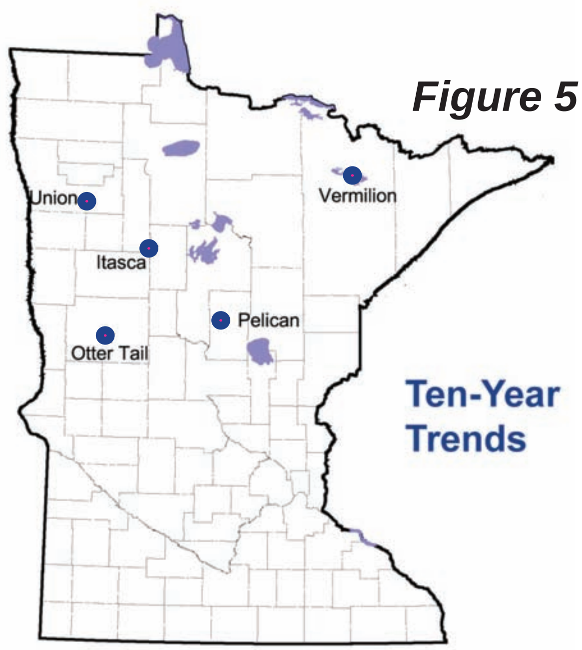
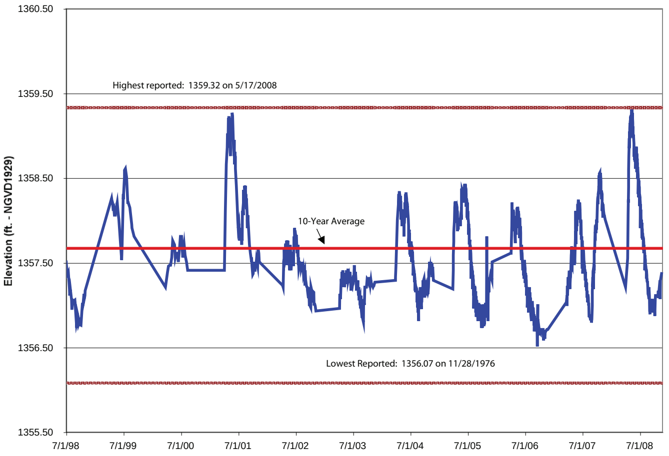


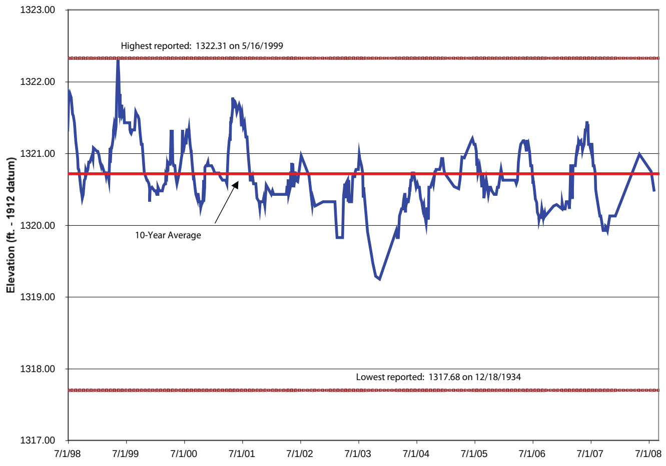
Figure 5

Ten-Year Trends

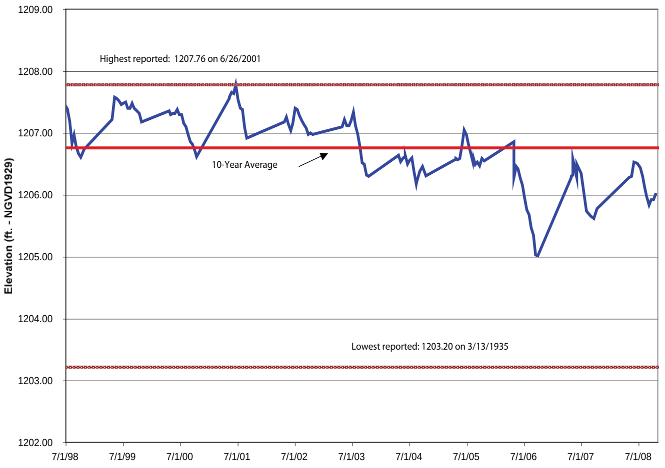
Vermilion Lake (69-0378), St. Louis County



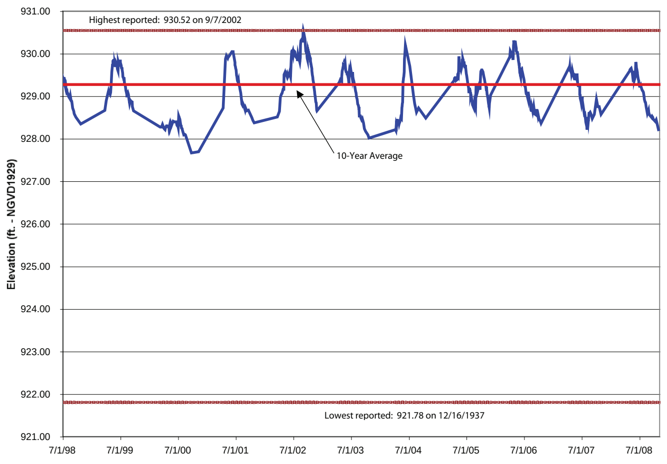
Otter Tail Lake (56-0242), Otter Tail County



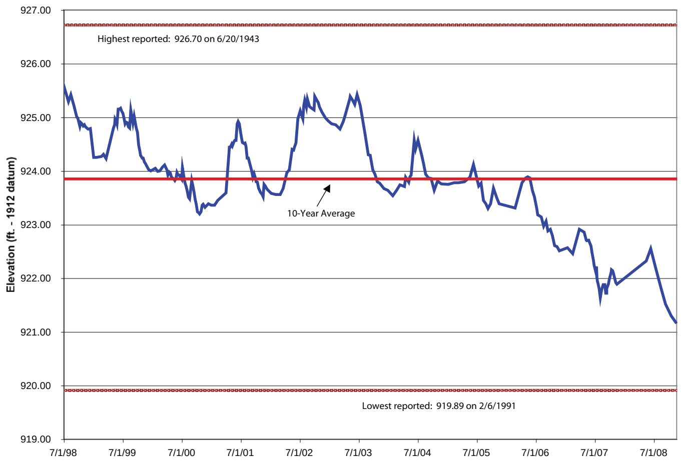
Pelican Lake (18-0308), Crow Wing County



Lake Minnetonka (27-0133), Hennepin County



White Bear Lake (82-0167), Washington County



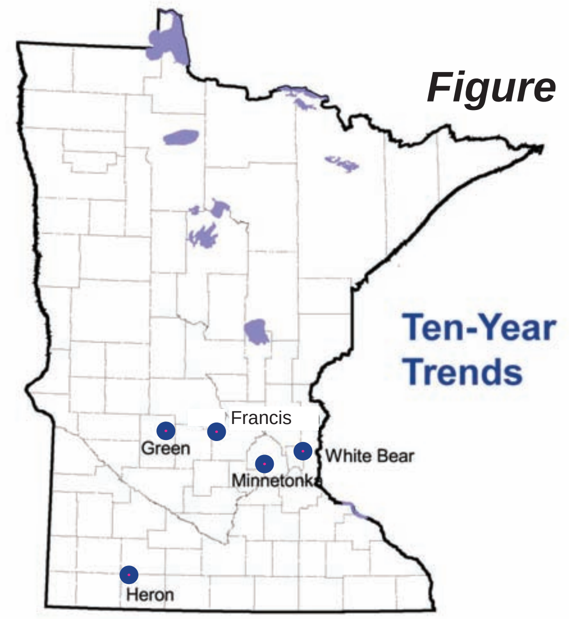
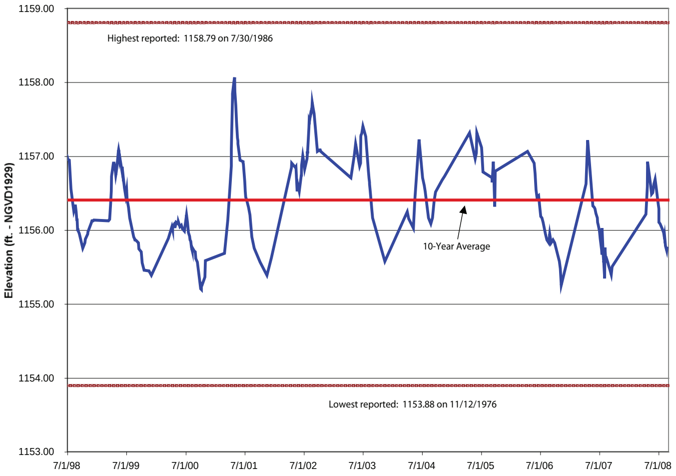


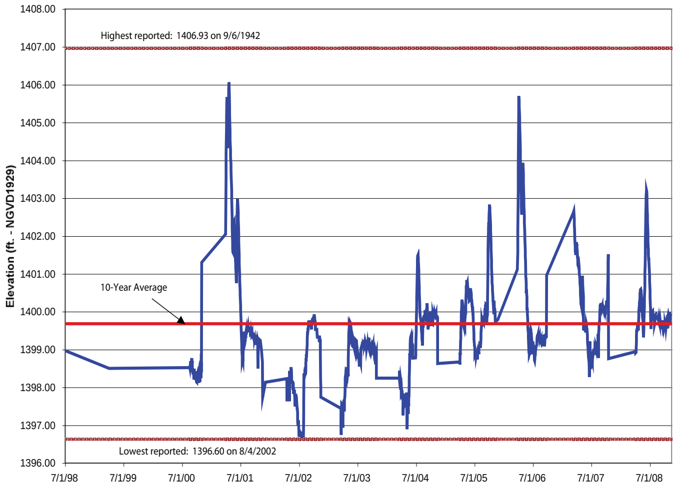
Figure 6

Ten-Year Trends

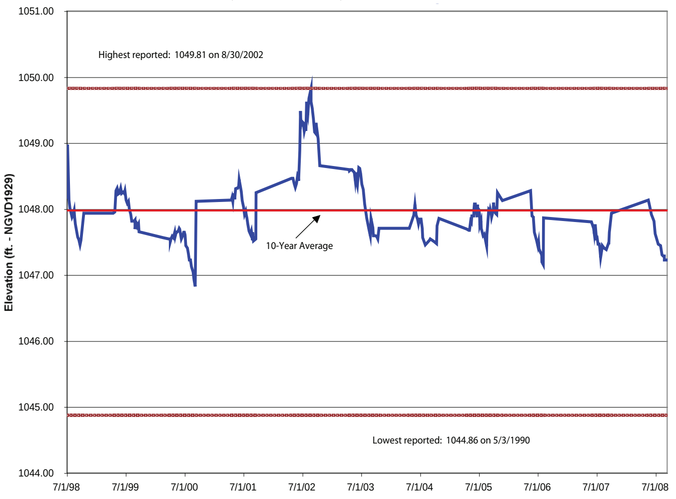
Green Lake (34-0079), Kandiyohi County



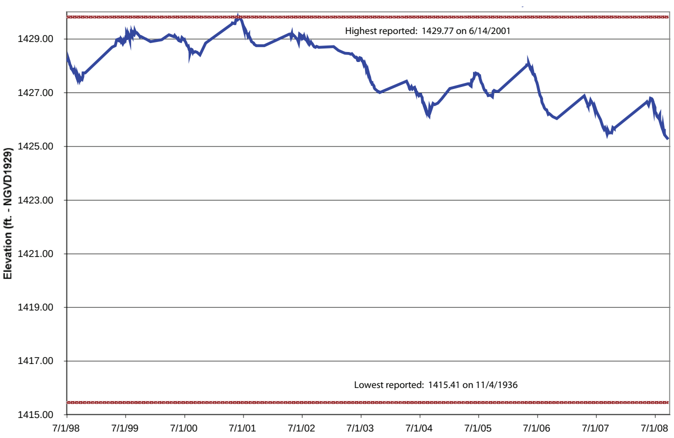
Heron Lake (32-0057-01), Jackson County



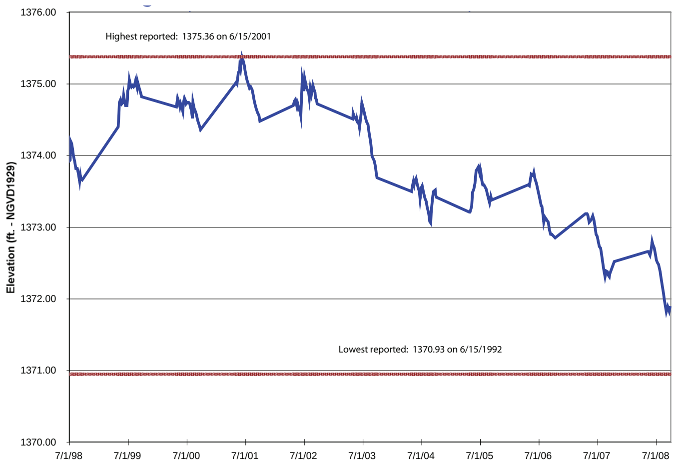
Francis Lake (47-0002), Meeker/Wright Cos.



Belle Taine Lake (29-0146), Hubbard County



Stony Lake (11-0371), Cass County



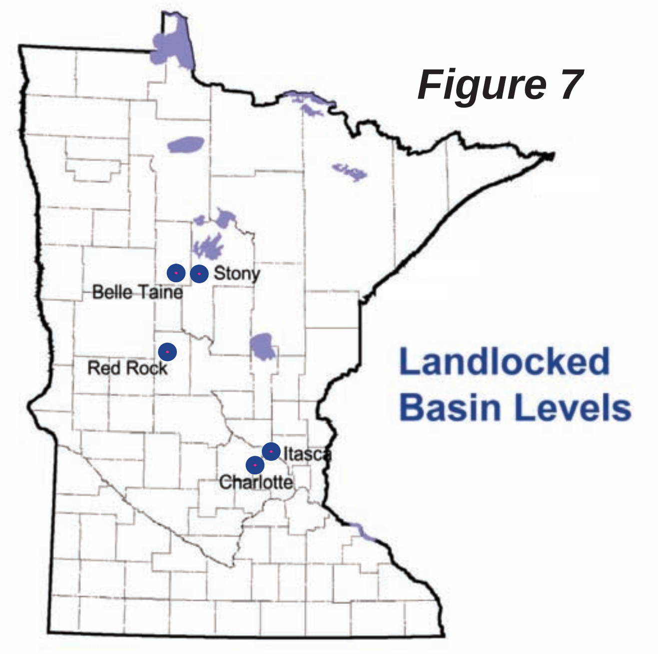
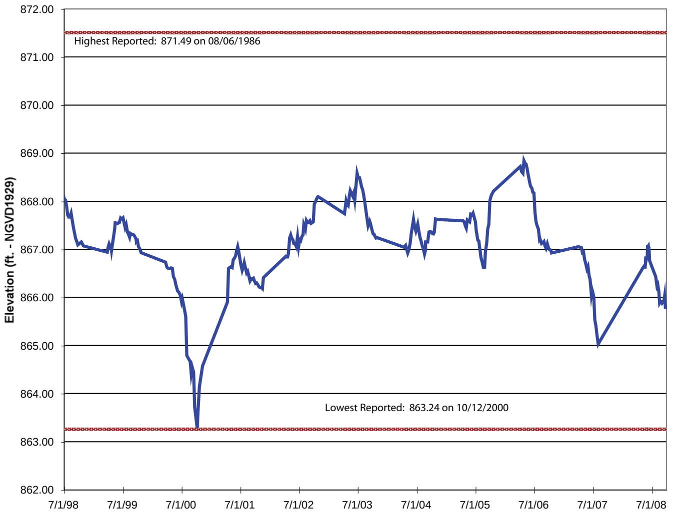


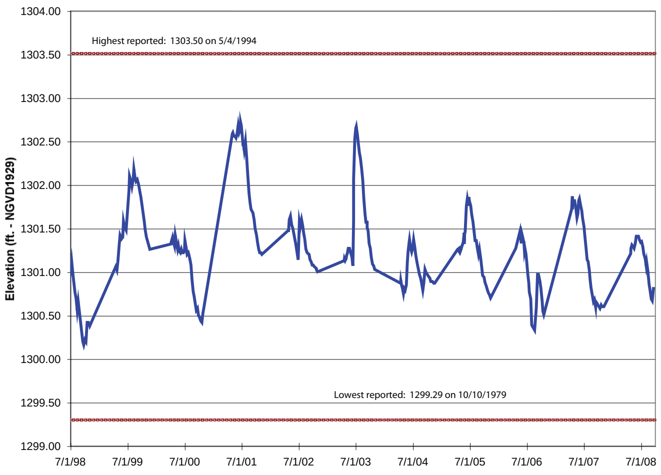
Figure 7

Landlocked Basin Levels

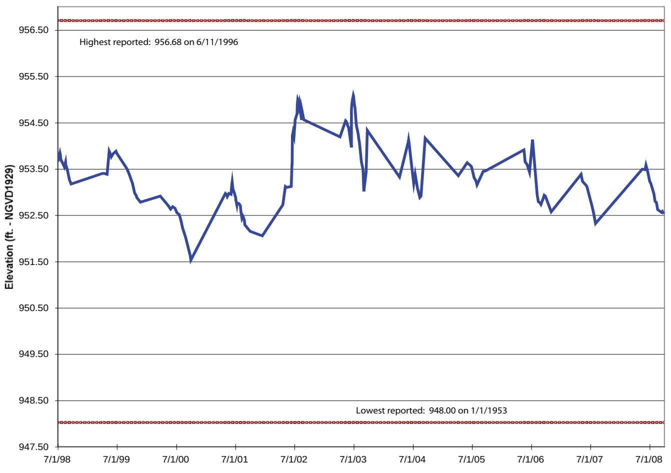
Itasca Lake (02-0110), Anoka County



Red Rock Lake (21-0291), Douglas County

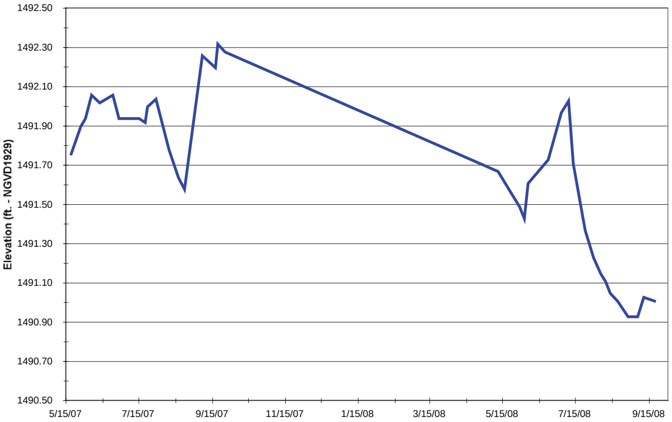


Charlotte Lake (86-0011), Wright County



Eagles Nest #1 Lake (69-0285-01), St. Louis County

Beaver dams removed mid-July 2008



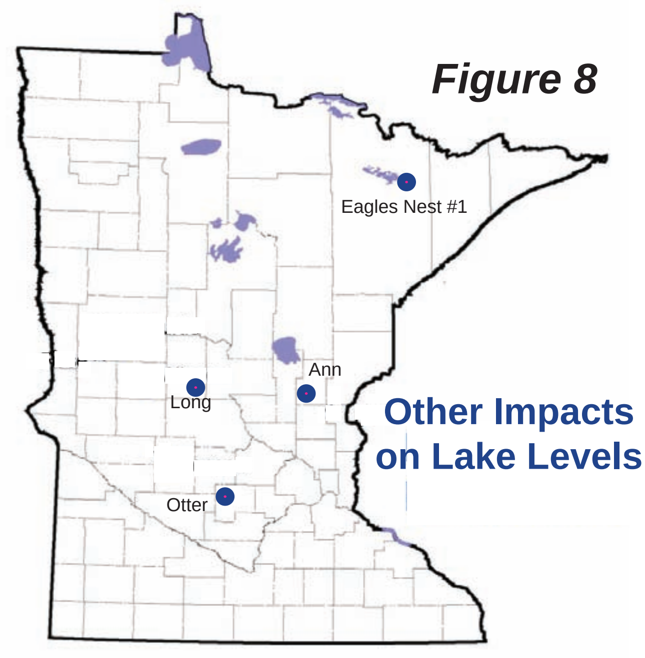
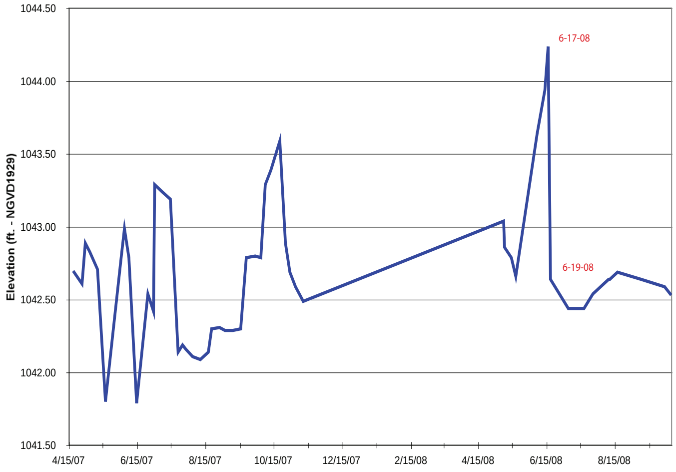


Figure 8

Other Impacts on Lake Levels

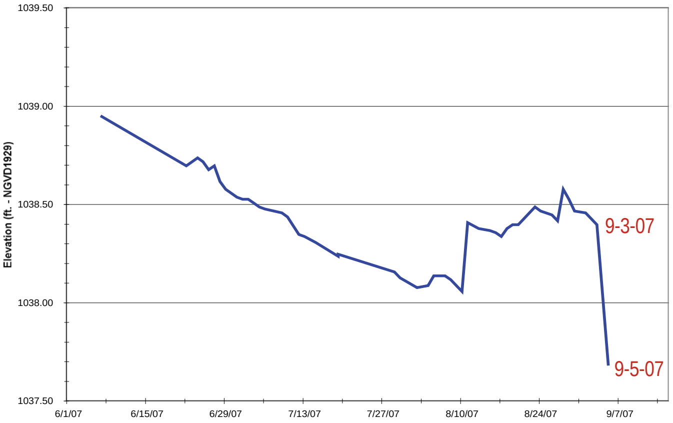
Ann Lake (33-0040), Kanabec County

Bog removed June 2008



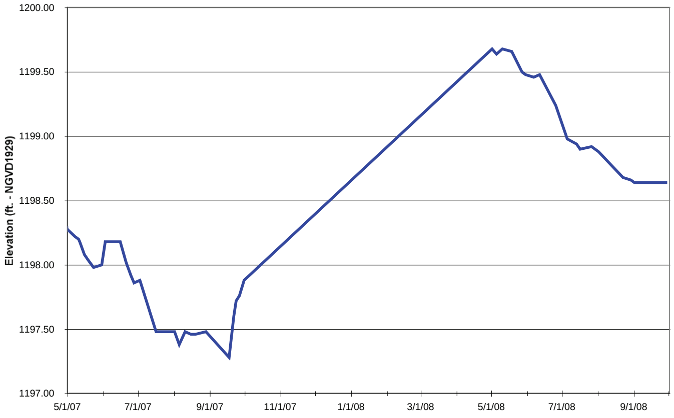
Otter Lake (43-0085), McLeod County

Dam opened September 4, 2007 at noon



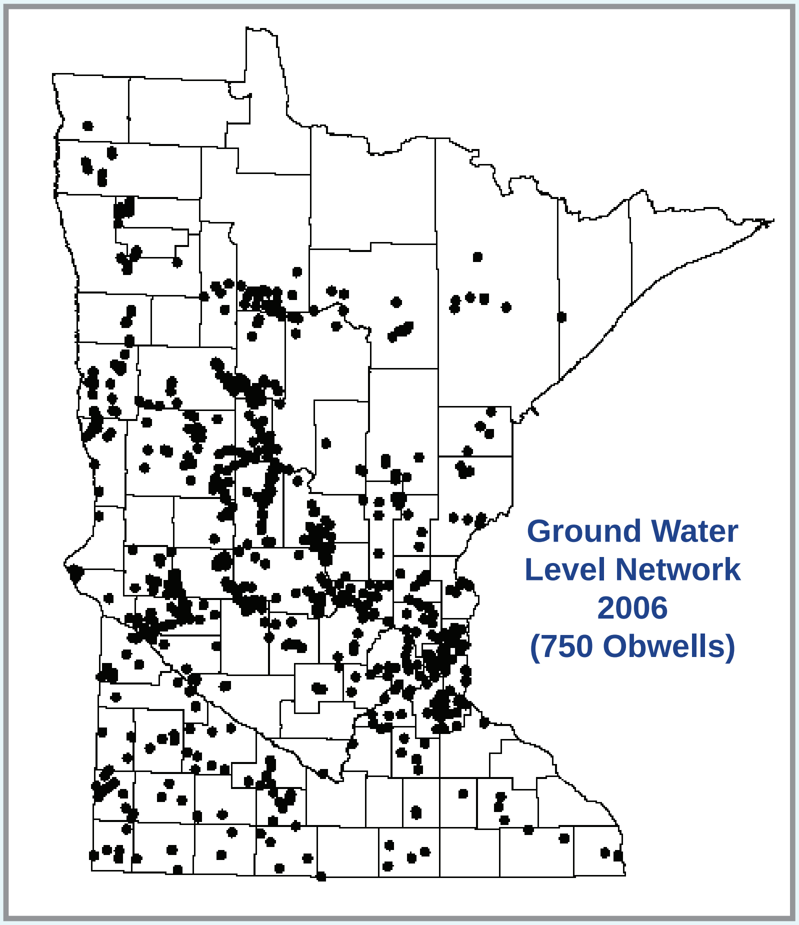
Long Lake (77-0027), Todd County

Heavy Rains during Fall 2007 & Outlet Plugged



Chapter 3 Ground Water

Michael MacDonald


Ground Water
Level Network
2006
(750 Obwells)

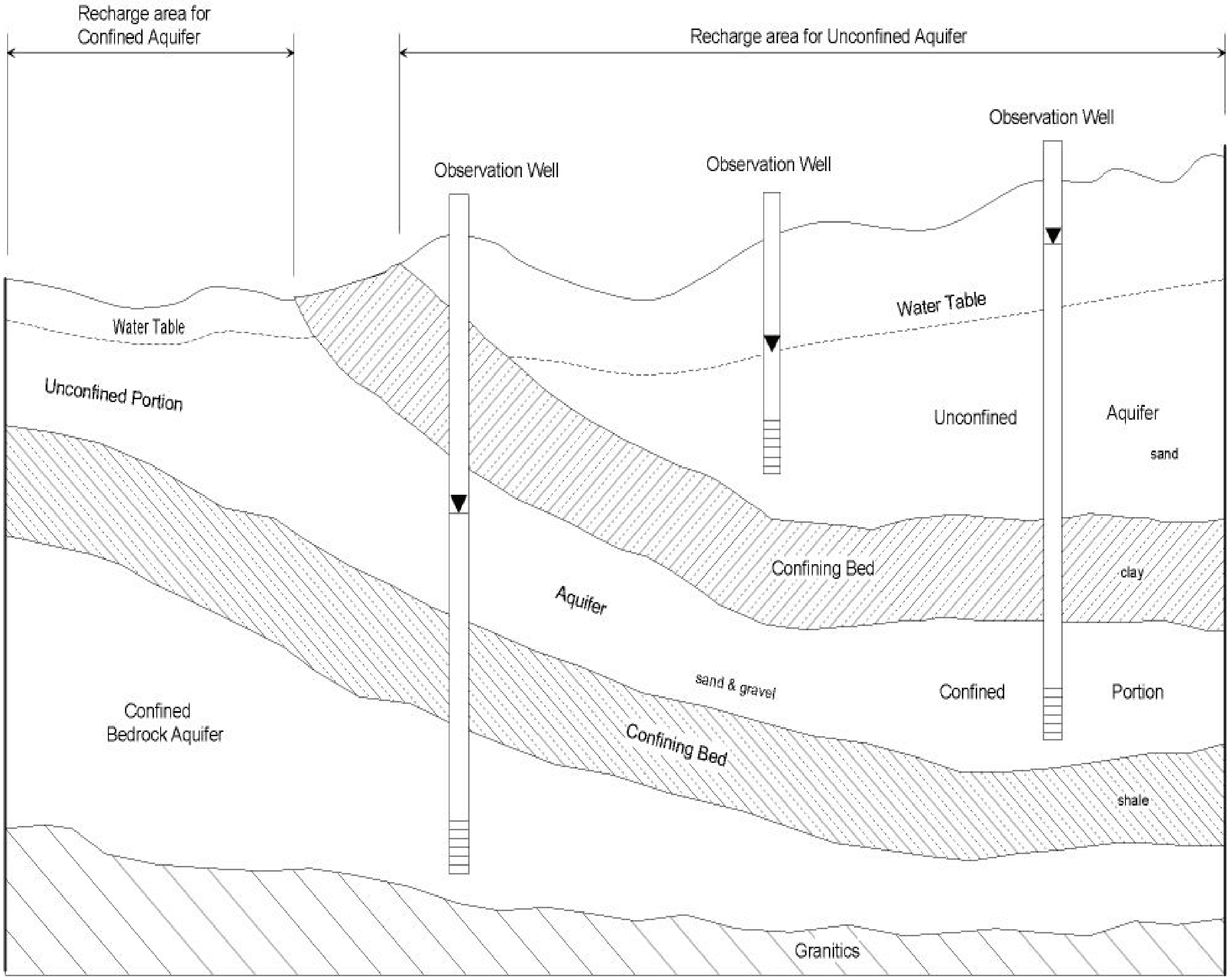

Michael MacDonald

Introduction

Ground water level monitoring began in Minnesota in 1942. In 1947, it was expanded with a cooperative program between the DNR and the United States Geological Survey (USGS). The number of wells monitored has increased since 1942 and now approximately 750 observation wells (obwells) are measured. Data from these wells are used to assess ground water resources, determine long-term trends, interpret impacts of pumping and climate, plan for water conservation, evaluate water conflicts, and otherwise manage the water resource. Soil and Water Conservation Districts (SWCD) and other cooperators under agreement with DNR Waters measure the wells monthly and report the readings to DNR Waters as part of the Ground Water Level Monitoring Program. Readings are also obtained from volunteers and electronically at other locations. Figure 1 presents a generalized ground water system showing the different types of aquifers and wells.

Figure 1

Hypothetical Unconfined and Confined Aquifer Systems



Aquifers

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

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

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

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

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

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

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

Statewide Summary

Currently, the DNR monitors water levels in approximately 750 wells. Water levels are usually recorded monthly from March through November. For this report, water levels from representative monitoring wells from each region of the state and from four aquifer systems are presented. The aquifer systems are: the unconfined (water table) aquifer, the buried drift aquifer, the Prairie du Chien and Jordan aquifers, and the Mt. Simon aquifer. Figures 2, 3, 4, and 5 present the locations of the wells in each of the aquifer systems. Hydrographs of the water levels in these wells are presented at the end of this chapter. The hydrographs present the water levels for the length of record for each obwell. The current water year water levels are shown in red on the hydrograph. These hydrographs and the data for all past and present DNR obwells are accessible **here**.

Several parts of the state have experienced dry conditions during the Water Years 2003, 2004, 2005. In Water Year 2006 (WY06), the state experienced a statewide drought. In Water Year 2007 (WY07), the drought continued during the summer but was reduced in late summer and fall by above average rainfall including floods in southeastern Minnesota. The trend of low precipitation continued into Water Year 2008 (WY08) when there were drought conditions at various locations throughout the state during the summer. The impact of the reduced precipitation was lessened by average temperatures, which decreased evaporation and allowed the soil to retain its moisture.

The remainder of this chapter discusses the ground water levels in unconfined and confined aquifers during WY07 and WY08. This discussion focuses on a comparison of monitoring well (obwell) water levels in WY07 and WY08 to past water levels focusing on the past three to five years.

Unconfined Aquifers

Water Table

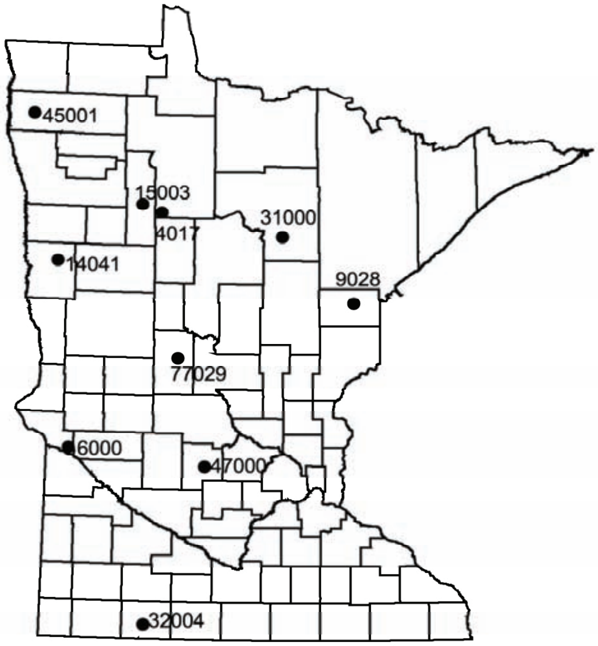
While drainage from an unconfined aquifer continues throughout the winter, recharge is restricted. In general, winter precipitation is stored as snowpack, and frozen soil prevents or slows the infiltration of spring snowmelt. By the end of winter, water tables would be expected to be at a low point. As the soil thaws and spring rains occur, the water table aquifers are recharged resulting in the higher water tables.

The locations of the water table wells used in this report are shown in Figure 2. Hydrographs for these wells are shown in Figure 6 (page 58).

In general, the water table in WY07 dropped to levels similar to those of WY06 but in WY08 the water table rose above the levels of WY06 and WY07. The hydrographs show that in the central, west, and north central parts of the state spring recharge in both WY07 and WY08 raised the water table to levels equivalent to or higher than in the preceding years. In the northwest, spring recharge in WY07 did not raise the water table to levels of previous years but in WY08, the water levels rose to those of past years. In the northeastern part of the state, the recharge did not raise the water levels to previous year levels.

Figure 2

Water Table Obwells



Because of continued summer drought conditions, water levels in the summer of WY07 declined to levels similar to or lower than those observed in WY06. In the summer of WY08, the water table levels were generally higher than in WY06 and in WY07 and were generally similar to or higher than the water levels in past years. In the northeast part of the state, the water levels are lower than have been seen since 1990. There is a small downward trend observed in water levels in some of the obwells in this part of the state.

In northwest Minnesota, as represented by the Clearwater County obwell, the low water table levels in both WY07 and WY08 were similar to or slightly above those in WY06 and appear to be showing an upward trend. In Central Minnesota the obwell in Todd County, situated in an area where the drought was severe in 2006, indicated that the water level in WY07 was lower than in WY06 but in WY08 the water levels were similar to the levels in WY06. The spring recharge in both years is similar to earlier years. There appears to be a slight upward trend in water levels from this obwell.

In southwest Minnesota, as represented by the Jackson County obwell, the WY07 summer water levels were lower than in WY06 but above historical lows. The summer water levels in WY08 were above those recorded in WY06 or WY07. The spring recharge levels are similar or above historical levels.

Confined Aquifers

Water levels in confined aquifers may respond to changes in precipitation patterns differently than they would in water table aquifers – the presence of an overlying confining bed inhibits the movement of rain or snowmelt downward into the confined aquifer thereby delaying the recharge of the aquifer. During dry periods, the demand for increased water use from a confined aquifer will be reflected in declining water levels. As the dry period ends and precipitation returns to normal, recovery of water levels will be delayed due to the slow movement of water into the confined aquifer. Recovery may take two or more years.

Likewise, wetter than normal periods may not cause a rise in water levels because of the retarded water movement through the confining layers.

Buried Drift Aquifers

Under confined conditions, these aquifers generally respond more slowly to seasonal inputs from snowmelt and precipitation than water table aquifers do. However, buried drift aquifers can be near the surface with their extent poorly defined and have some connection to adjacent unconfined aquifers. As a result, response of buried drift aquifers to recharge is determined by individual characteristics. The response is therefore difficult to predict.

The approximate locations of the buried drift wells used in this report are shown in Figure 3. Hydrographs for these wells are shown in Figure 7 (page 62).

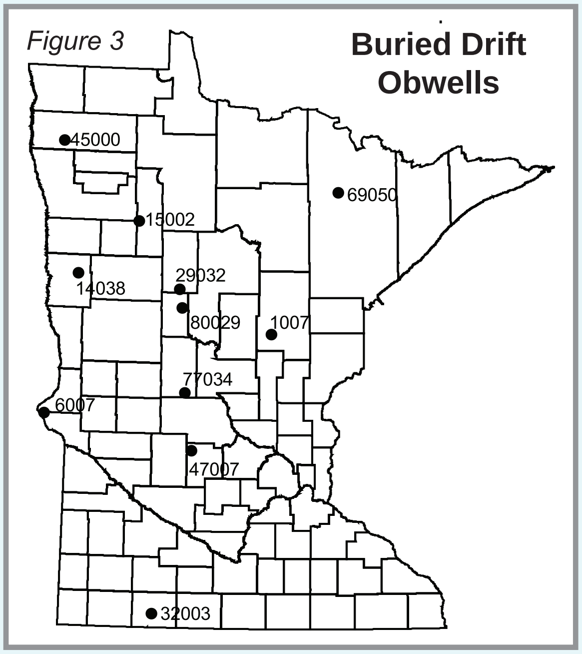


Figure 3

As in the case with water table wells, the buried drift hydrographs show that throughout the state, spring recharge in both WY07 and WY08 raised the water levels in the aquifers. The increases are not as large as those seen in WY06, so that the water levels at the beginning of the summer season were generally lower than those observed in WY05 and WY06.

In WY07, the summer water levels were similar to or lower than those observed in WY06. This may reflect the delay in recharge that is often seen in confined aquifer systems. In the summer of WY08, the water levels are generally higher than seen in the past few years. This may represent the delay expected in recharging confined aquifers. Of the wells presented here only two, in Marshall and Meeker counties, had water levels in the summer of WY08 similar to or lower than those recorded in WY06. The most dramatic increase in water levels between WY07 and WY08 occurred in Clay, Hubbard, St. Louis, and Todd Counties.

Nearly all of the buried drift aquifer hydrographs show a return to water levels similar to those before the onset of the WY06 drought.

Bedrock Aquifers

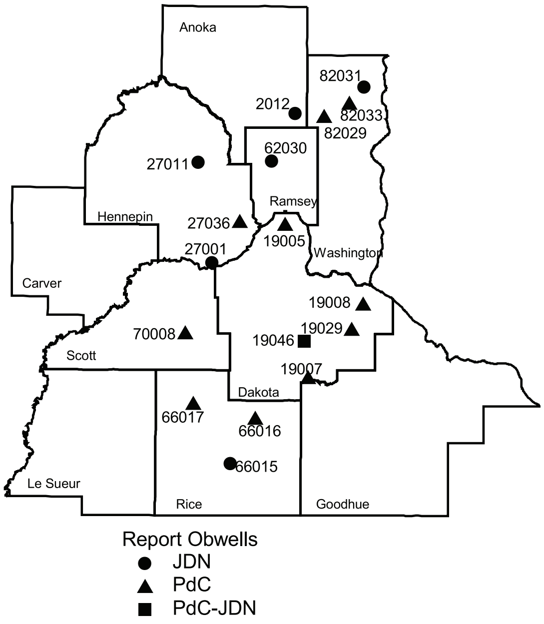
Jordan and Prairie du Chien Aquifers

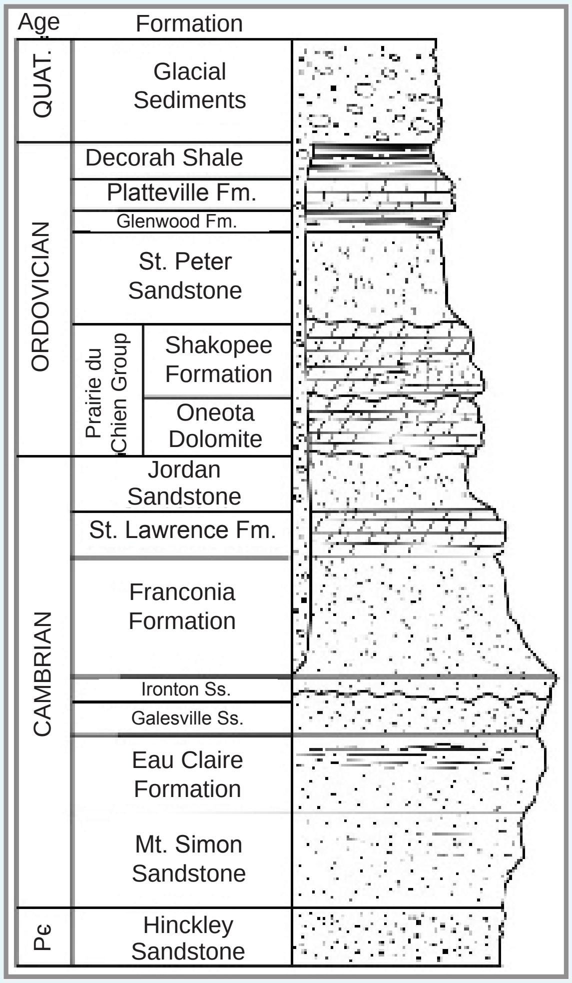
In past years, the Jordan and Prairie du Chien aquifers have been considered hydrologically linked and generally considered as one hydrologic unit. Conditions in the "Prairie du Chien/Jordan Aquifer" were considered to be to be represented by water level monitoring wells completed in the Prairie du Chien, the Jordan or in both the Prairie du Chien and Jordan formations.

Studies in recent years, especially those of the Minnesota Geological Survey (MGS), have begun to question the lumping of the two formations into one hydrologic unit. The information presented here relative to water levels in WY07 and WY08 is not meant to offer support for either the "lumping" or the "splitting" of these two geologic units. The water level measurements from WY07 and WY08 do not show clear evidence that the formations are one or two distinct aquifers. To continue the discussion as presented in the 2005-2006 Water Year Data Summary report, the formations are presented and discussed here as two separate units.

Figure 4

Jordan & Prairie du Chien Obwells





Example of a generalized geologic column for the 7-county metropolitan area.

Locations of the Jordan (JDN) and Prairie du Chien (PDC) wells used in this report are shown in Figure 4. Wells identified by number are those wells for which hydrographs are shown in Figures 8A (page 66) and 9A (page 69) that follow.

For this report there were adequate numbers of wells distributed around the metro area to allow the JDN and PDC aquifer levels to be looked at separately. One exception was in Dakota County where a distinct JDN well was not available. Looking at many of the wells completed in both the PDC and JDN in Dakota County, it appeared as if they were responding to climatic events in a manner similar to JDN wells. Consequently, in examining the Jordan aquifer levels in the metro area, one PDC/JDN well in southern Dakota County was included (Figure 9K, page 72).

Jordan Aquifer

Water levels in the Jordan aquifer system throughout the metro area generally show a decline in summer water levels below the WY06 levels in both WY07 and WY08. Most of these wells also have lower winter water levels then have been seen in the past few years. Only two wells, those in Olmstead and Ramsey Counties, showed an increase in water levels over the course of the past two water years. In general most of the Jordan aquifer wells are showing a declining water level since the drought of WY06.

Prairie du Chien

Water levels in the Prairie du Chien aquifer showed variable response to the conditions of WY07 and WY08. In Hennepin County, the summer water levels were lower than those in WY05 and WY06 but are not as low as those seen in 2003 and earlier years. In Scott County, the water levels have decreased since the levels observed in the summer of WY06 and the water levels at the end of WY08 are similar to those in the summer of WY05. This decrease is not observed in nearby obwells in Rice or Hennepin Counties.

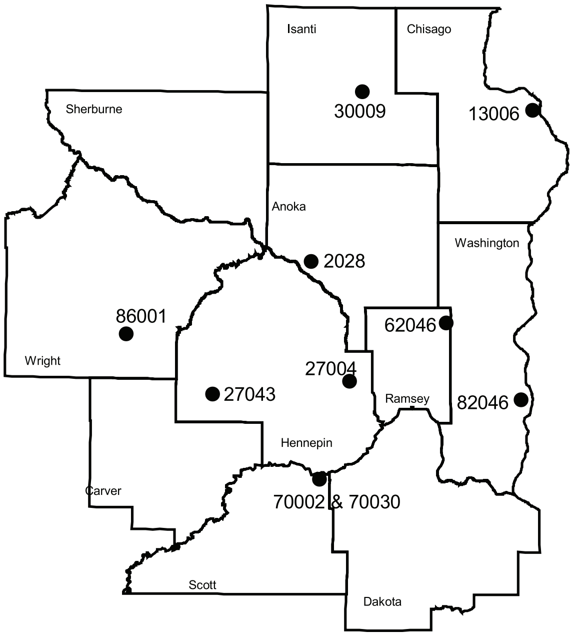
In Rice County there was a varied response to the conditions. In obwell 66016, water levels fluctuated in a manner similar to recent preceding years, with no appreciable declines in either water year. In obwell 66017, there are declining water levels in both water years with the WY08 summer levels comparable to the levels observed in 1993 and 2004.

Dakota County PDC obwells showed a lot of variation: obwell 19005 in the north looked like a continuation of recently increasing water level trends; obwells 19008 and 19029 continue to exhibit water level declines; and obwell 19007 showed a large decline in water level for summertime WY07 with a similar but smaller declines in WY08. This was in keeping with patterns of water levels from this well in recent years. The Dakota County obwell 19046, which is a Prairie du Chien/Jordan well, shows a small rise in water levels over the two water years. The hydrograph shows an unusual upward trend, which is resembles water level increases seen in the well periodically before about 1995.

In northern Washington County, water levels showed a decline similar to those in northern and eastern Dakota County. It is interesting to note that the hydrographs for PDC well 82033 and JDN well 82031 are similar. These two wells are located in close proximity and one would probably conclude that the two formations are functioning as one, interconnected aquifer.

Figure 5

Mt. Simon Obwells



Mt. Simon Aquifer

With some exceptions, the Mt. Simon aquifer is a confined aquifer. It may respond as an unconfined aquifer in the atypical instances where the aquifer is adjacent to unconfined materials, such as along deeply incised buried glacial valleys or at the outer edges of the formation.

Locations of the Mt. Simon wells used for this summary are shown in Figure 5. Hydrographs depicting representative water levels across the metro area are shown in Figure 10A (page 73).

Many of the Mt. Simon obwells have a fairly short period of record; consequently it is difficult to place the WY 07 and 08 readings in a long-term perspective. However, the data that are available provide a look at how the aquifer is responding to recent climate.

Generally the WY07 and WY08 Mt. Simon water levels fluctuated within the bounds of recent previous years and springtime high water levels were similar to preceding recent spring times.

A couple of exceptions did occur. In Hennepin County, the water level at the end of WY06 was at its lowest measured level since 1989. The spring recharge of the WY08 was higher than the levels in WY05 and 06 and the WY08 summer water levels were similar to


Steve Robertson, MN Dept of Health

WY05 levels. The Isanti County obwells shows a water level rise from the low levels measured in the summer of WY06 to levels comparable to those measured in WY05. In Ramsey County, the water level in the summer of WY07 was the lowest ever measured while the water levels measured in the spring of WY08 are comparable to levels from WY05 and earlier.

In the southern metro area, the Scott County obwell showed a situation where the summer water levels in WY08 were the lowest ever measured and continue a downward trend in water levels that began around 1980. No measurements were collected in WY07 because changes in DNR personnel did not allow for data collection.

One can also note on this Scott County hydrograph that the Mt. Simon aquifer water levels in the Savage area are continuing their long-term decline; while some of this is climatically induced, part of the decline must be attributed to pressures exerted on this aquifer by increasing development in the area.

Program Highlights

During the water years presented in this document, a number of activities were initiated or continued.

WY07

- Began work to assess the location and condition of the obwells in the state.
- Continued to manage and maintain the obwell network.

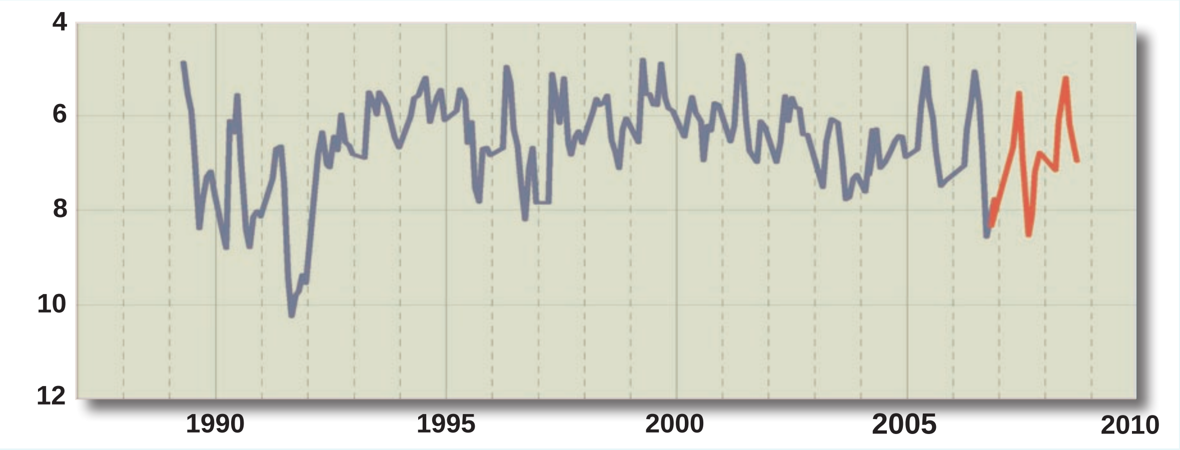
WY08

- Added two wells to the obwell network in cooperation with the Minnesota Geological Survey. These were deep, buried aquifer wells and the cost to install them was $11,200.
- Replaced three existing wells in the obwell network, which had been damaged or were no longer functioning properly. The wells were replaced using DNR personnel and equipment and cost approximately $5,000.
- Sealed three wells from the obwell network because of damage to the well or because the well was no longer functioning properly. The cost to seal the wells was approximately $2,500.
- Continued to work on the obwell assessment. By the end of WY08, the condition and validity of 279 obwells in 37 counties had been assessed.
- Began investigation work to determine the limits and conditions of the Mt. Simon aquifer in the south central and metropolitan parts of the state. This included drilling new wells and collecting geophysical data. Results of this work are expected to be available in WY10.
- Began work on upgrading the database system used to collect, store, and analyze the obwell groundwater data collected.
- Continued to manage and maintain the obwell network.


Michael MacDonald

Figure 6A

Beltrami County - Water Table #4017



Depth to Water below ground surface, ft.

Figure 6B

Big Stone County - Water Table #6000

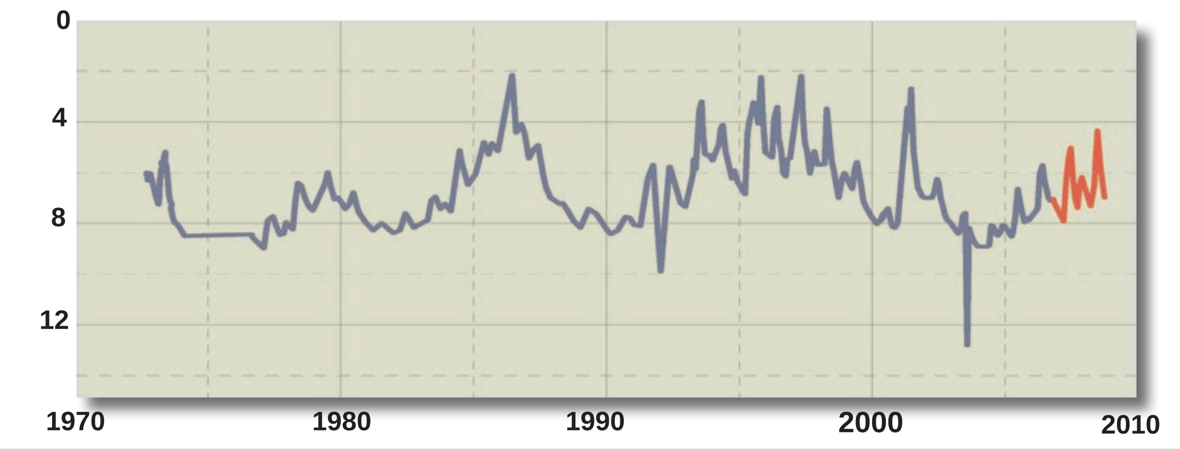


Figure 6C

Carlton County - Water Table #9028

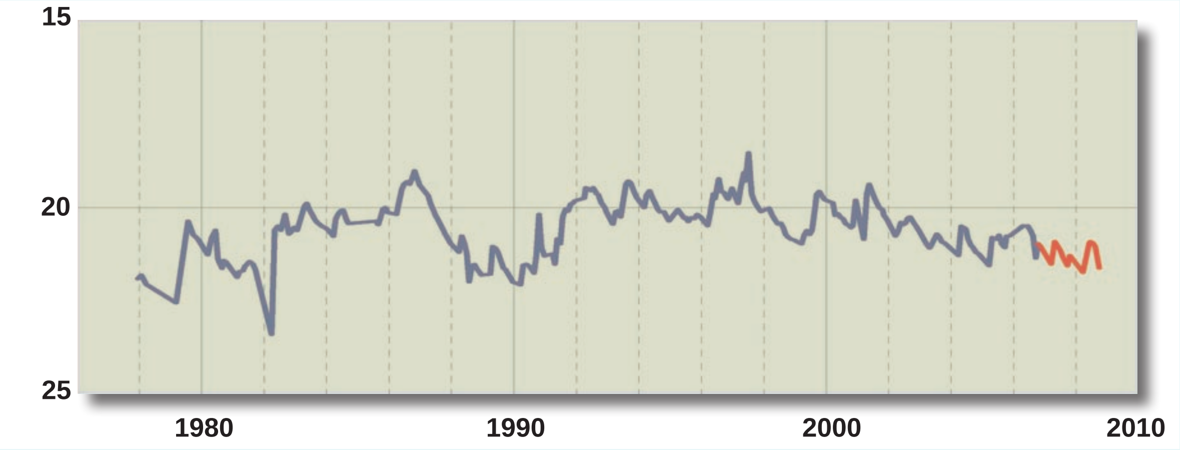


Figure 6D

Clay County - Water Table #14041

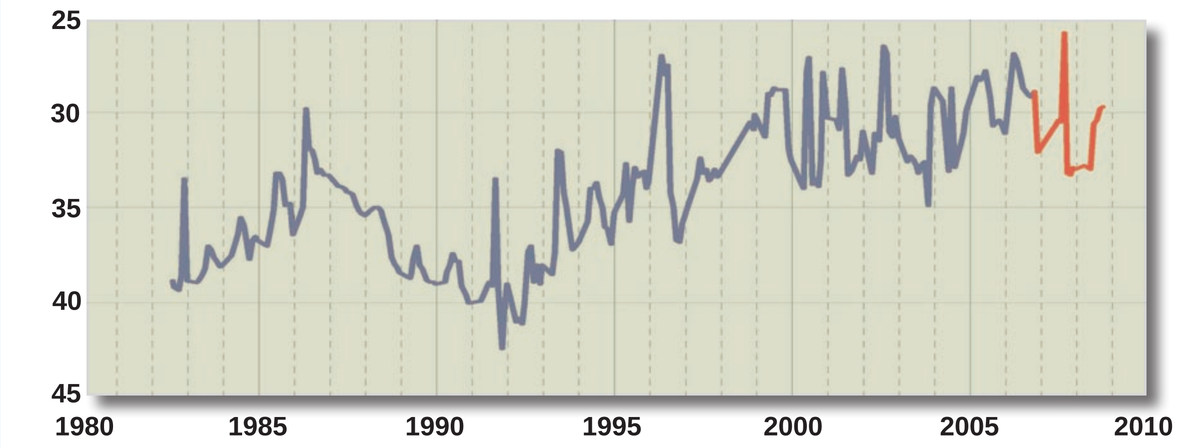


Figure 6E

Clearwater County - Water Table #15003

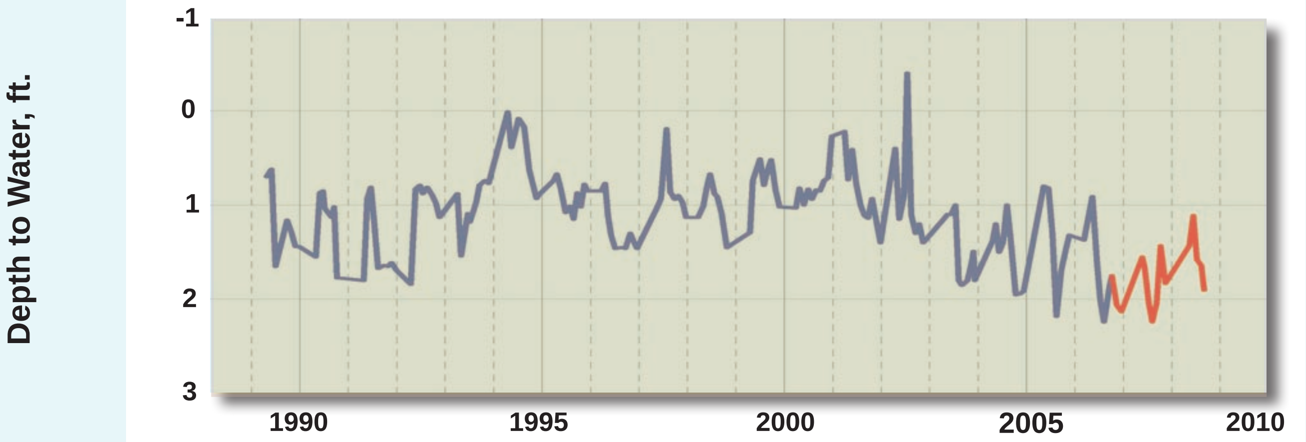


Figure 6F

Itasca County - Water Table #31000

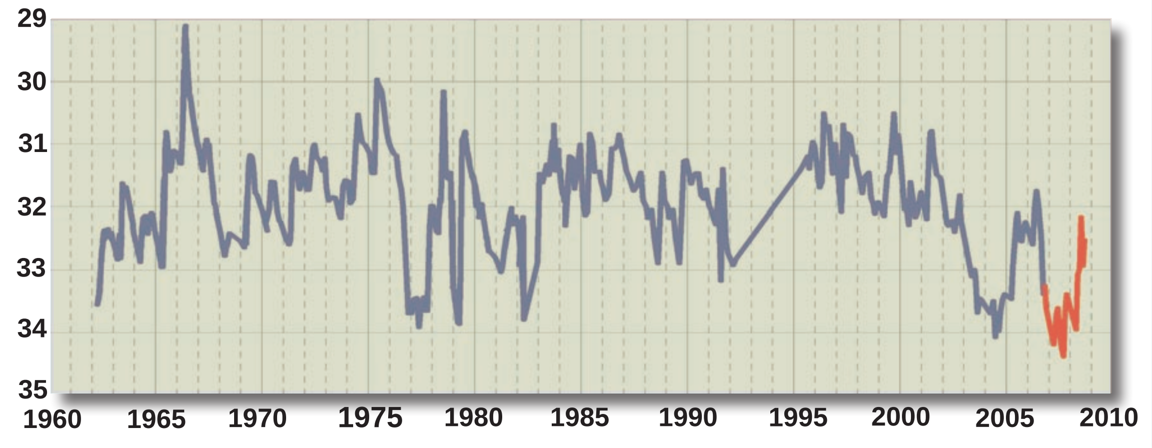


Figure 6G

Jackson County - Water Table #32004

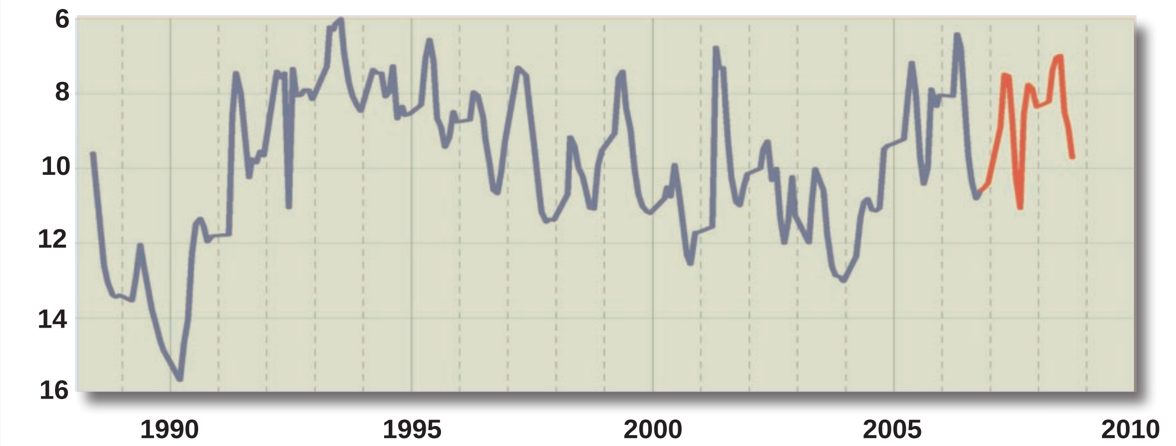


Figure 6H

Marshall County - Water Table #45001

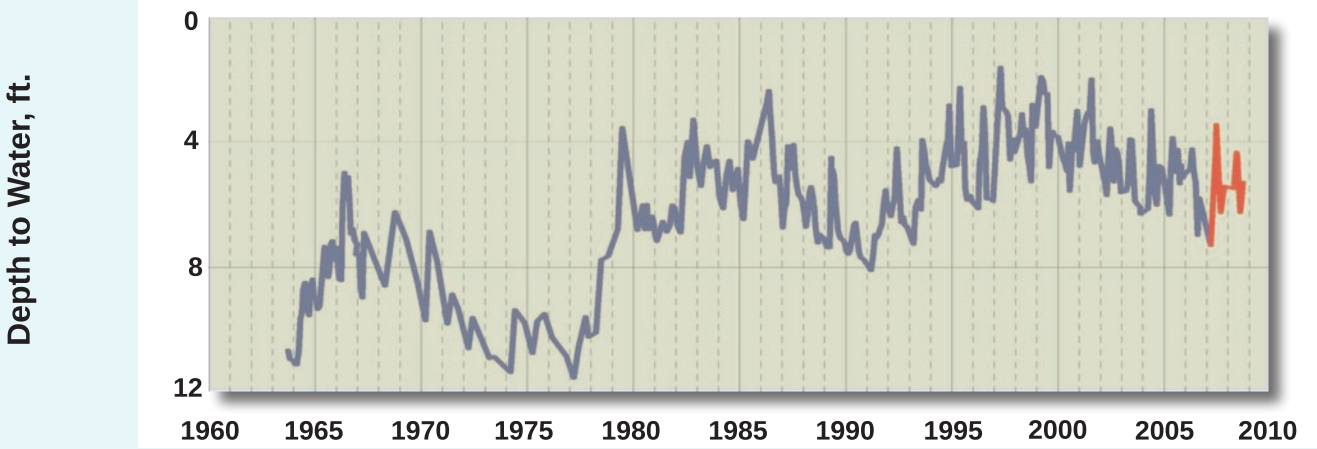


Figure 6i

Meeker County - Water Table #47000

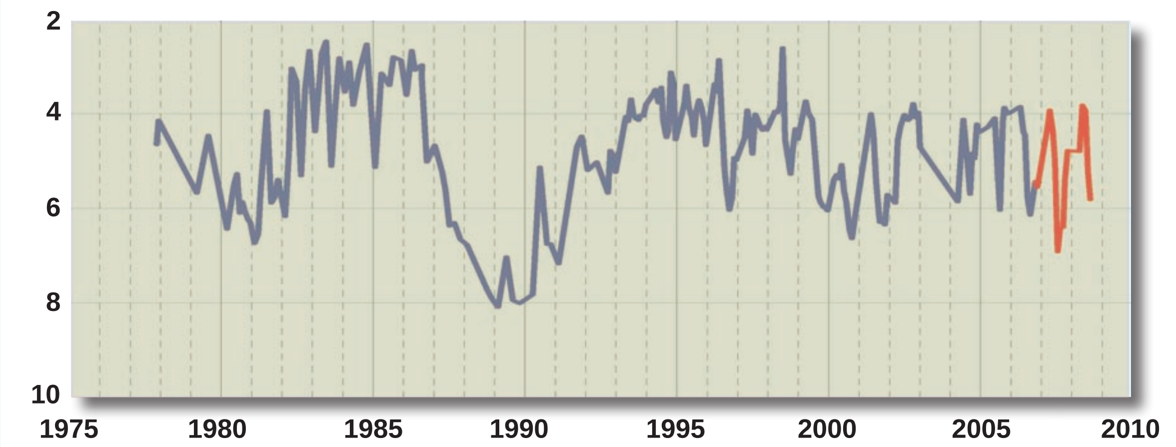


Figure 6J

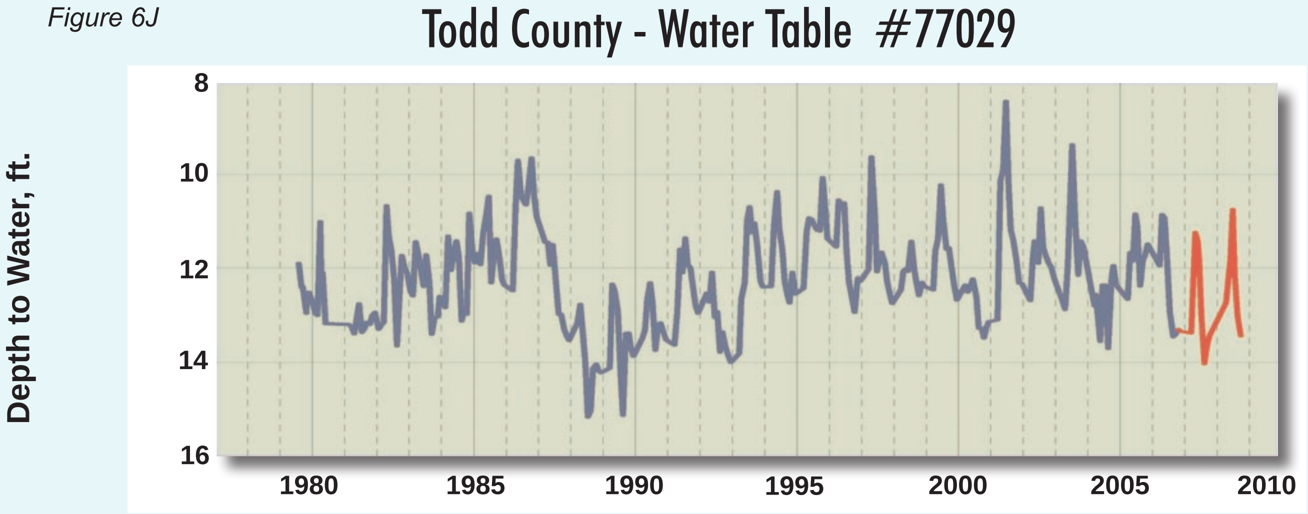

Todd County - Water Table #77029
Depth to Water, ft.
8
10
12
14
16
1980
1985
1990
1995
2000
2005
2010

Figure 7A

Aitken County - Buried Drift #1007

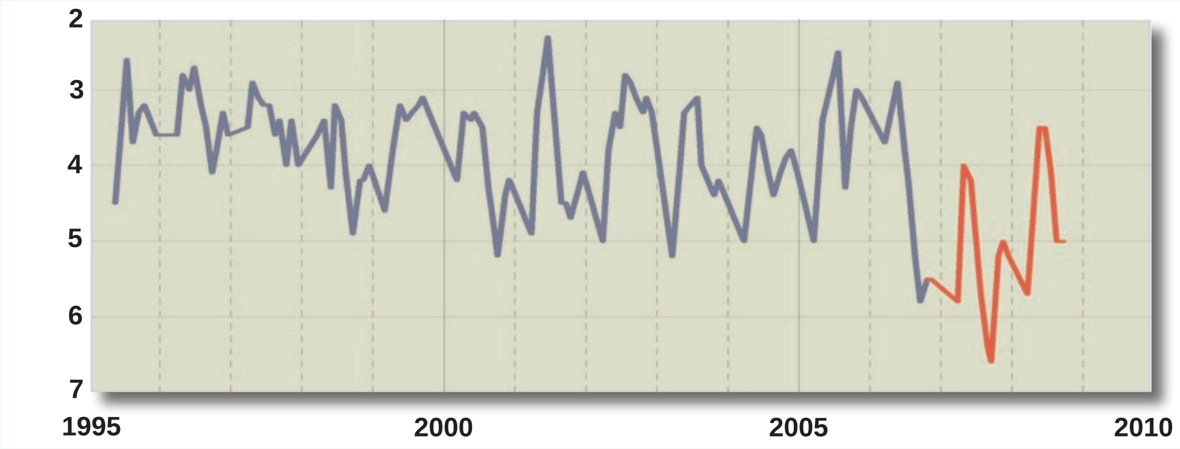


Figure 7B

Big Stone County - Buried Drift #6007

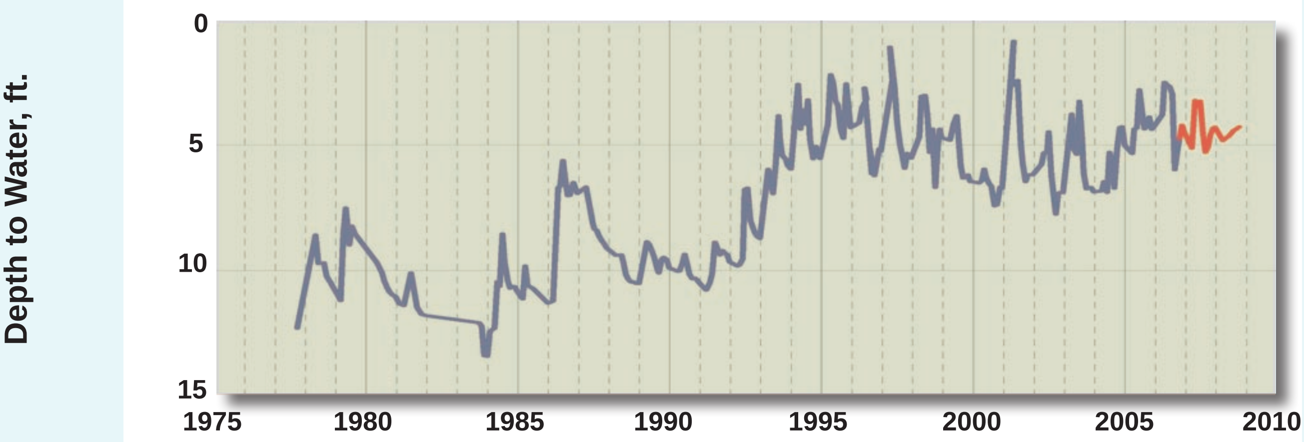


Figure 7C

Clay County - Buried Drift #14038

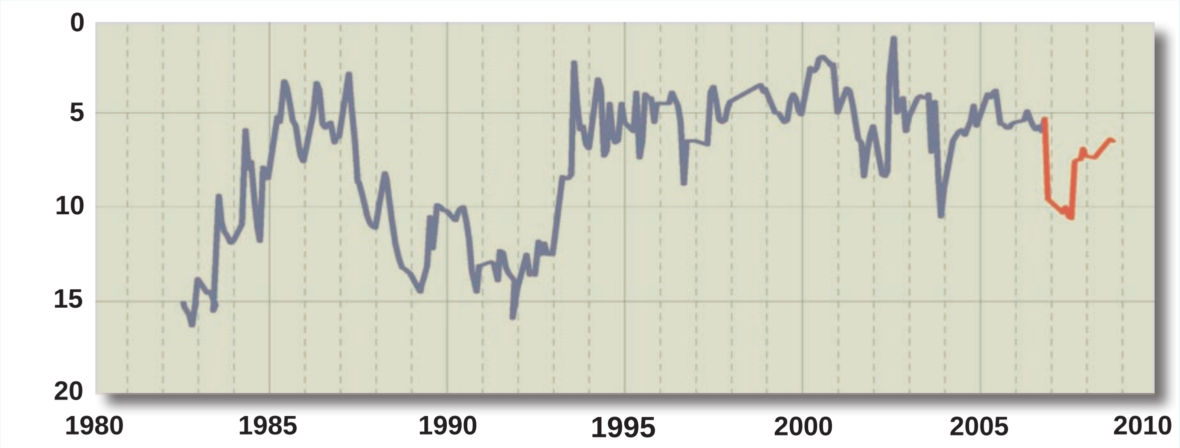


Figure 7D

Clearwater County - Buried Drift #15002

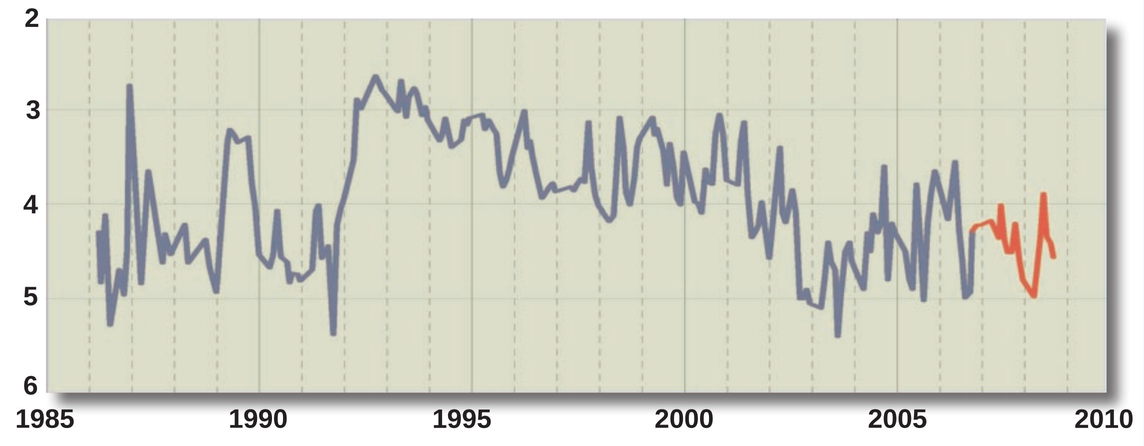


Figure 7E

Hubbard County - Buried Drift #29032

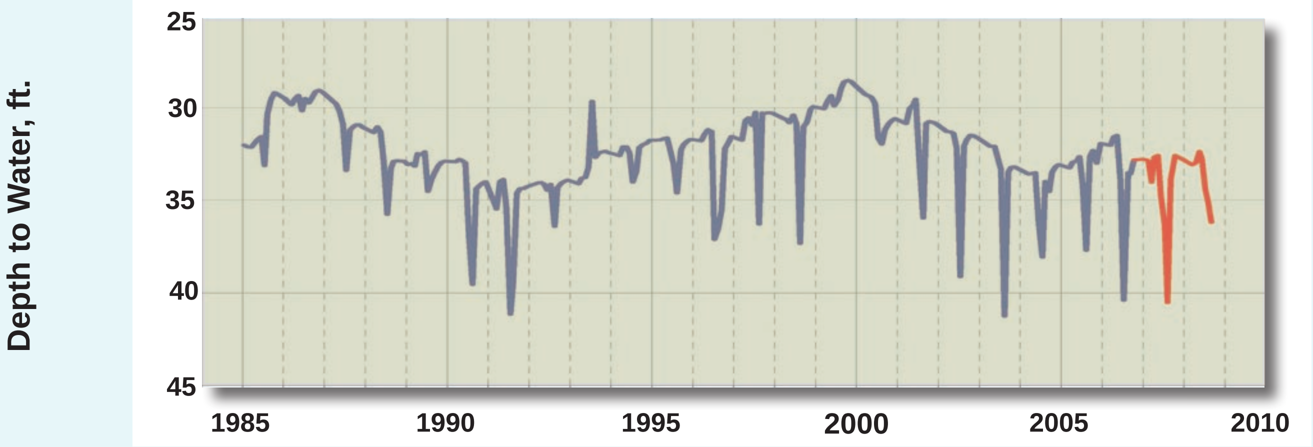


Figure 7F

Jackson County - Buried Drift #32003

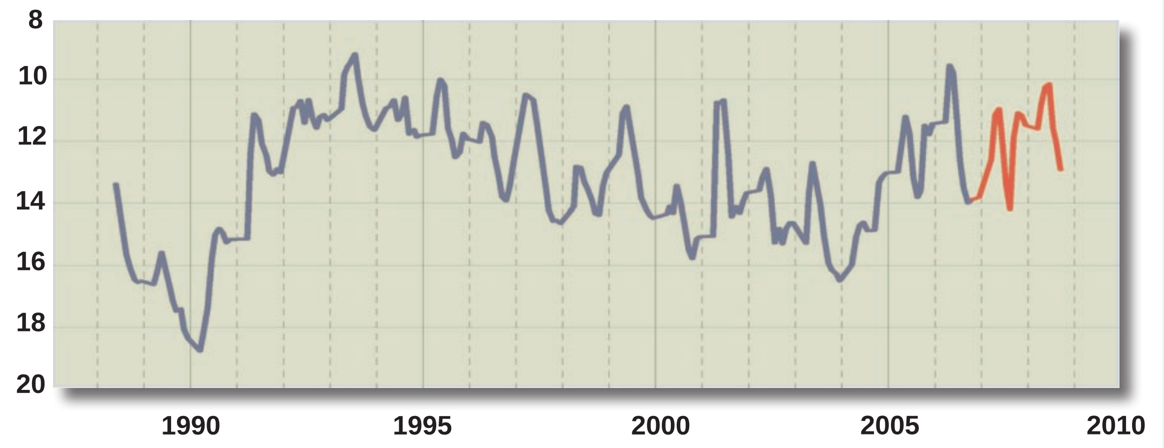


Figure 7G

Marshall County - Buried Drift #45000

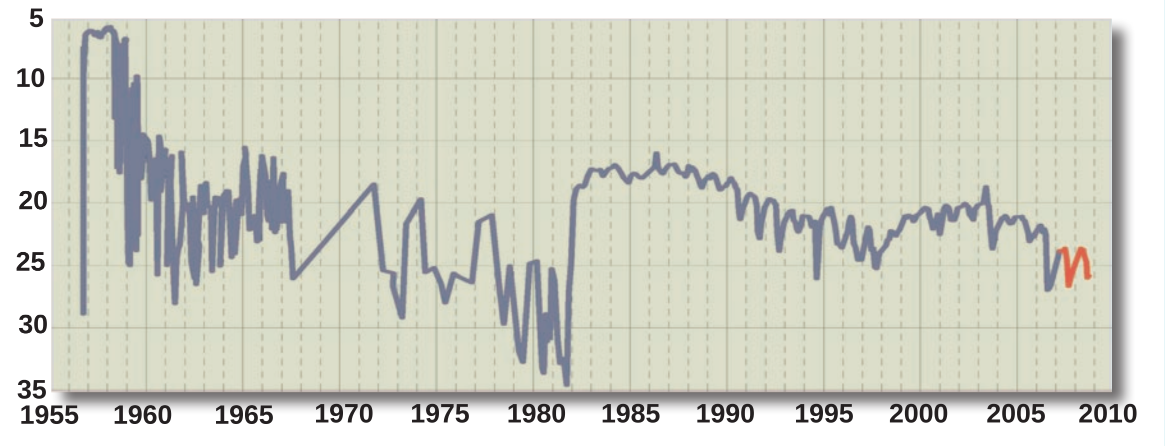


Figure 7H

Meeker County - Buried Drift #47007

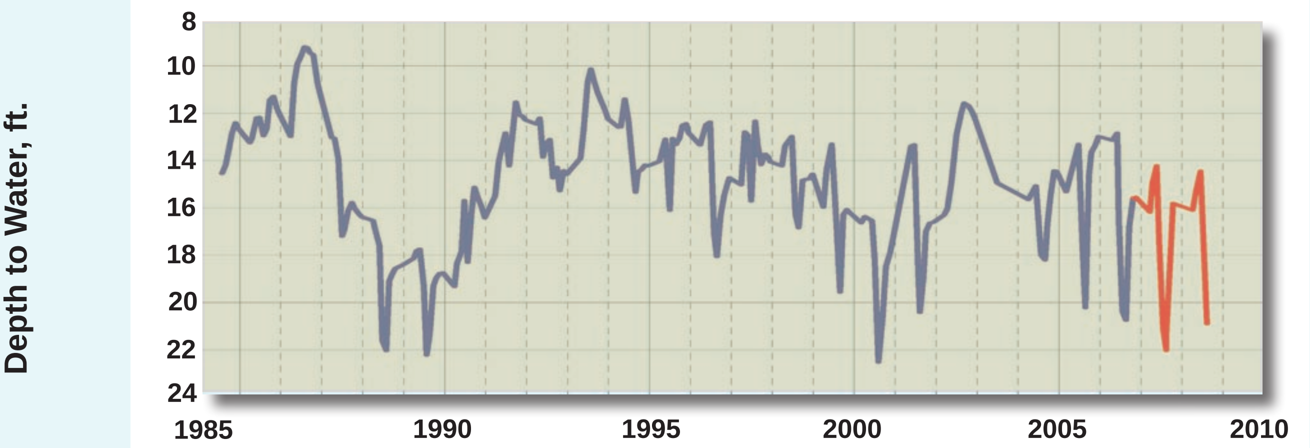


Figure 7i

North St. Louis County - Buried Drift #69050

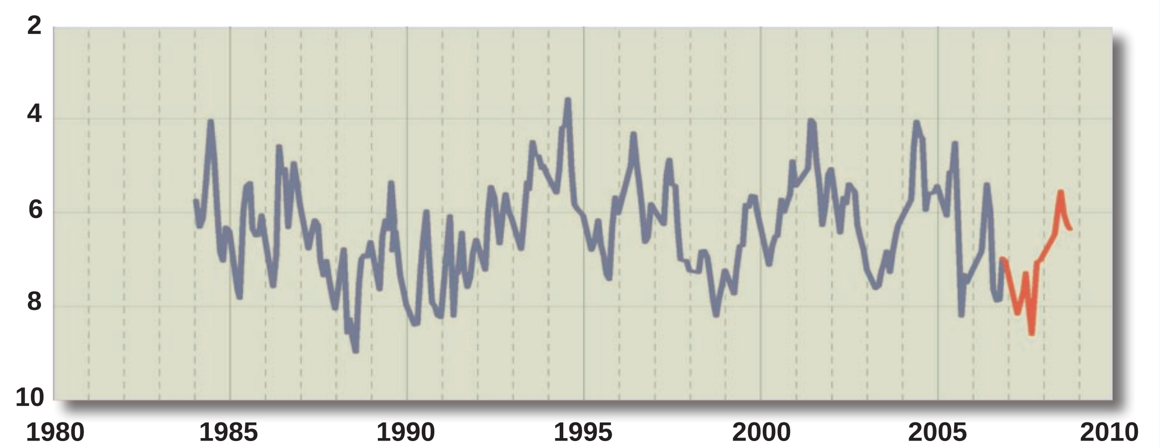


Figure 7J

Todd County - Buried Drift #77034

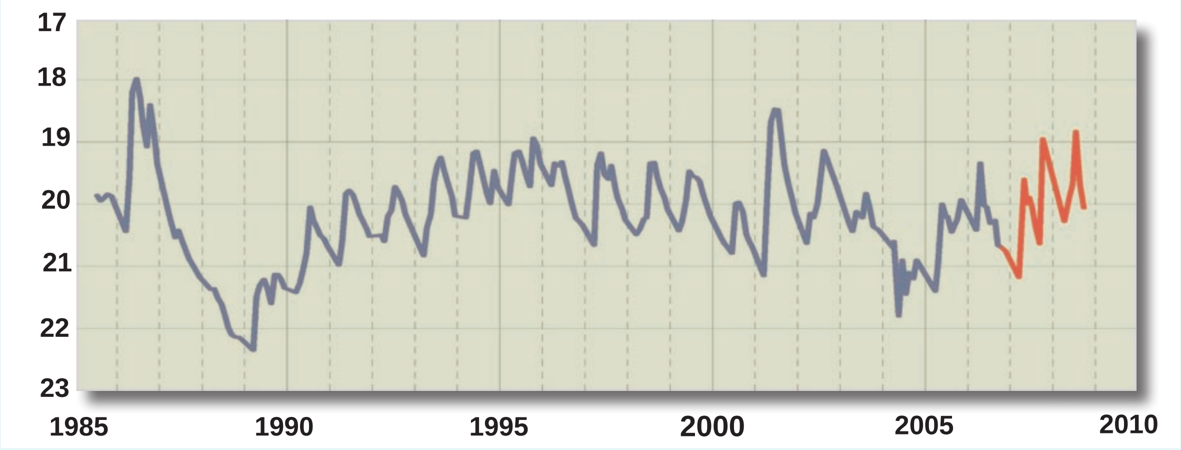


Figure 7K

Wadena County - Buried Drift #80029

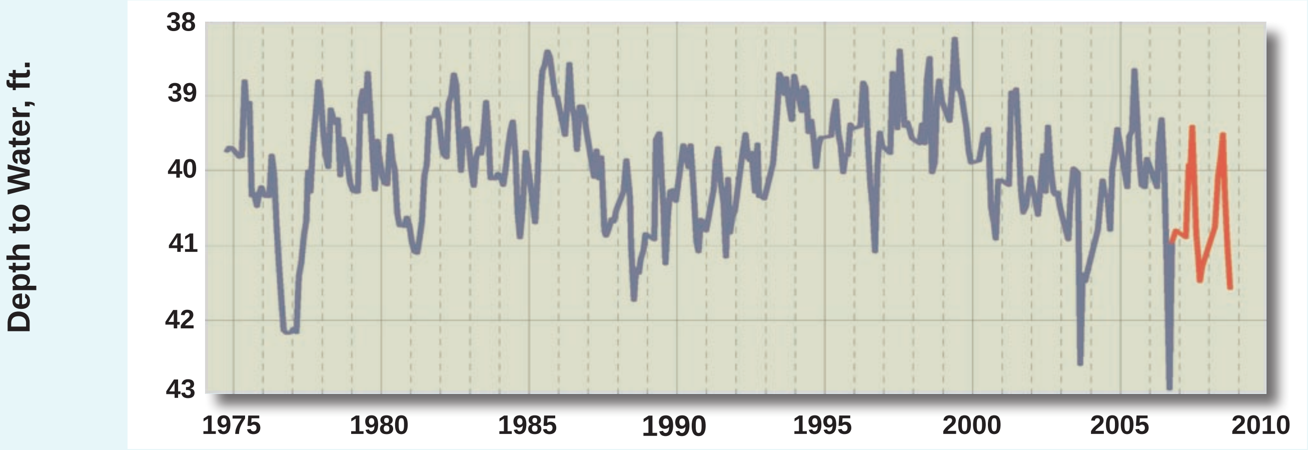


Figure 8A

Anoka County - Jordan #2012

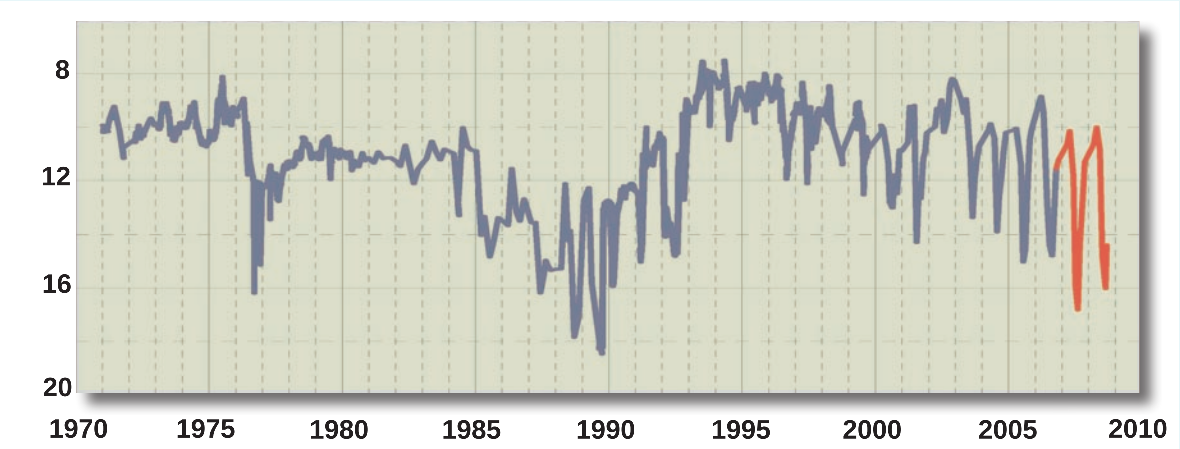


Figure 8B

Hennepin County - Jordan #27001

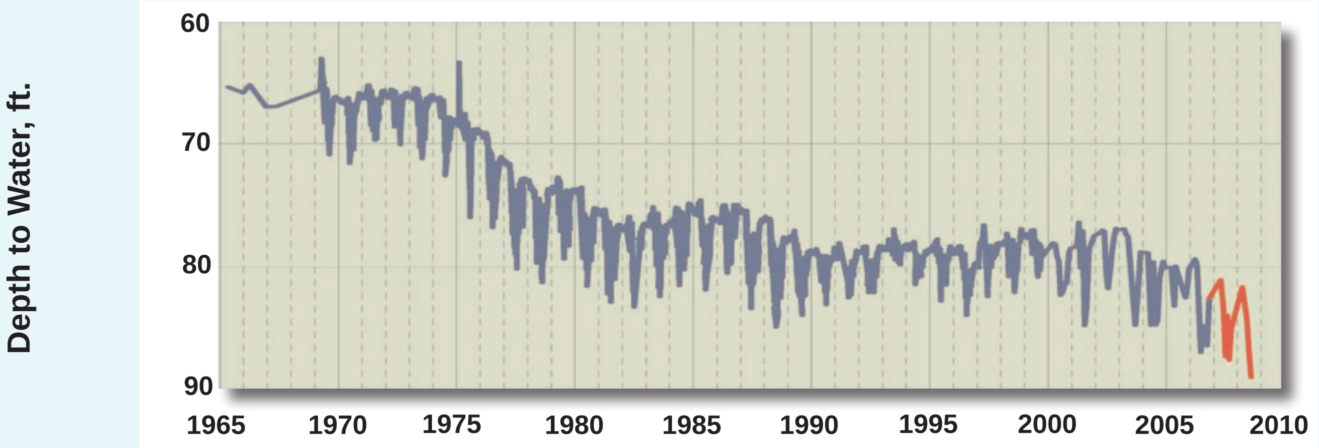


Figure 8C

Hennepin County - Jordan #27011

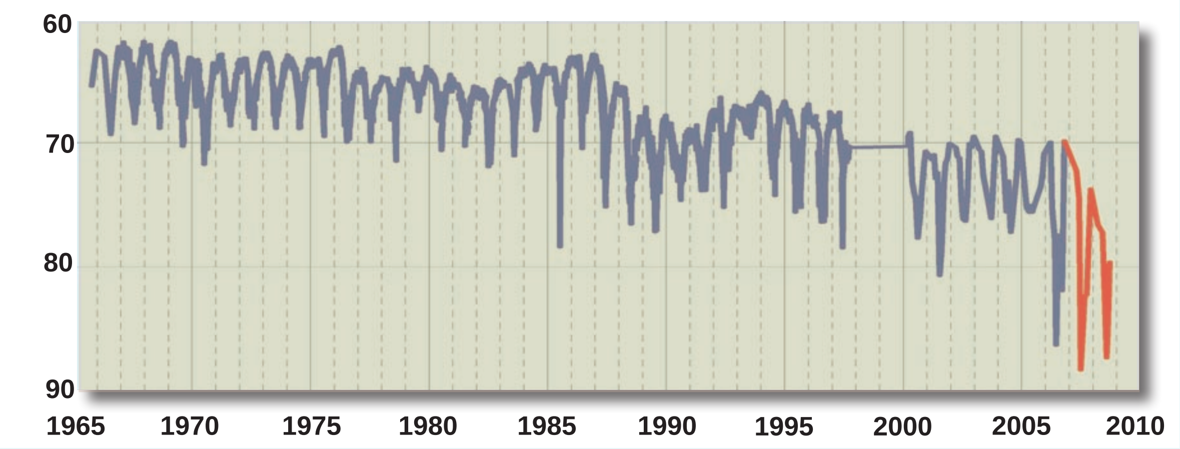


Figure 8D

Olmsted County - Jordan #55000

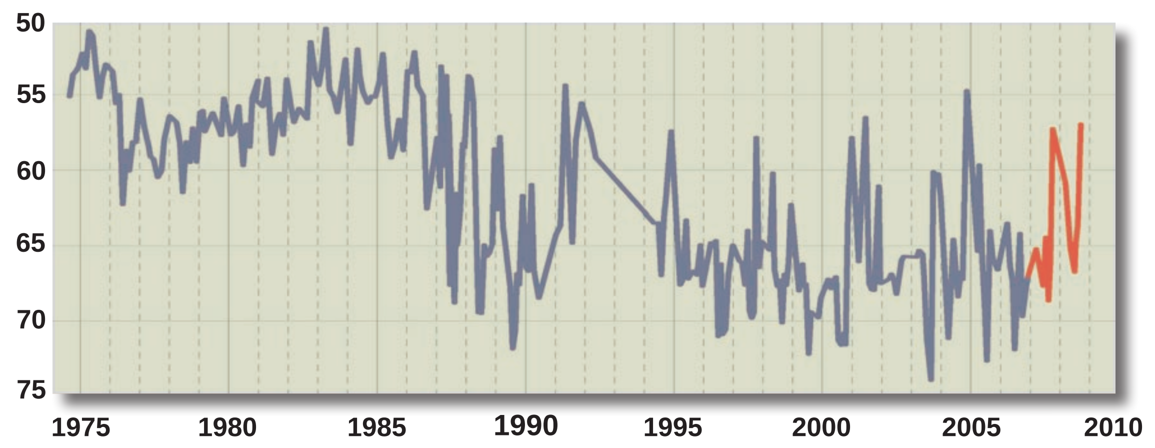


Figure 8E

Ramsey County - Jordan #62030

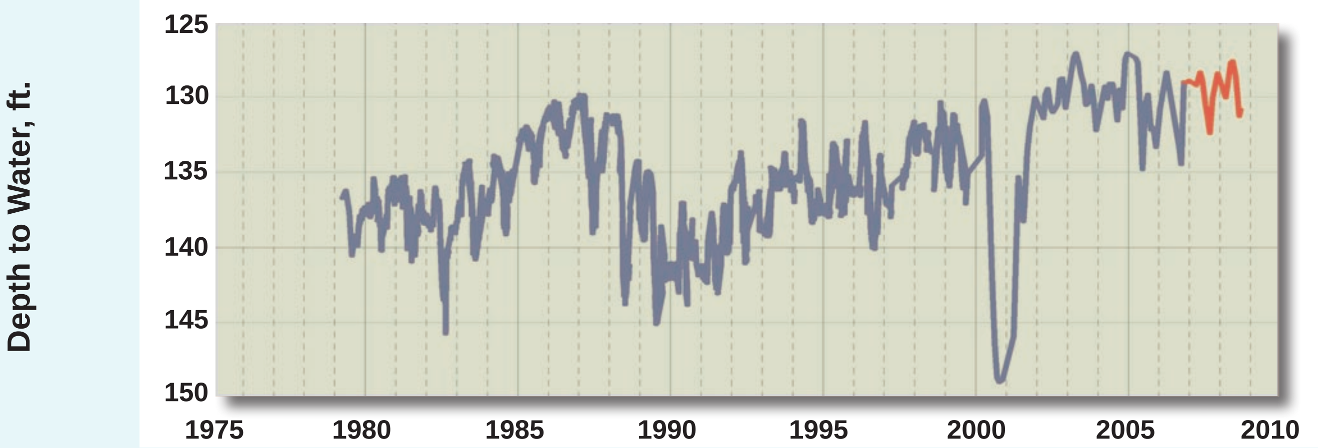


Figure 8F

Rice County - Jordan #66015

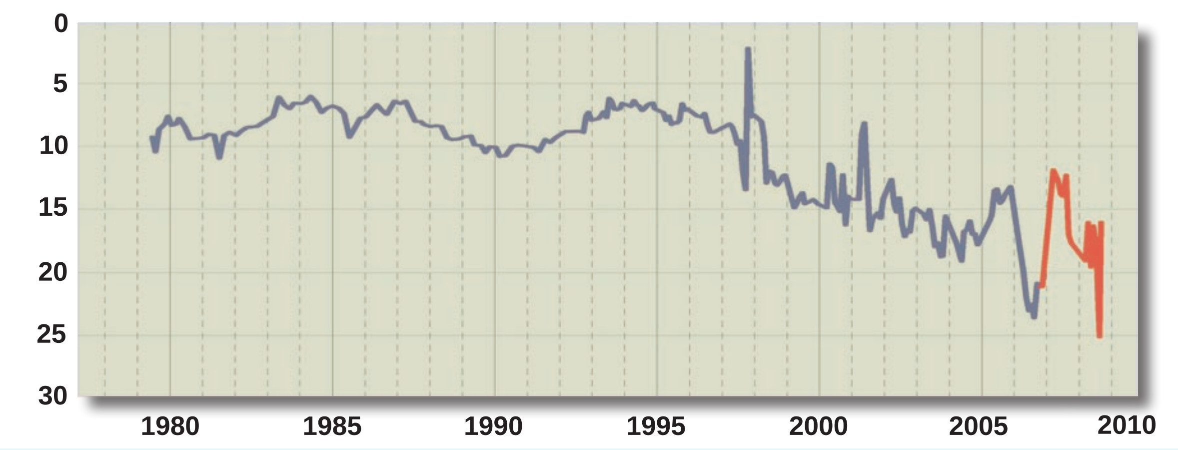


Figure 8G

Washington County - Jordan #82031

Figure 9A

Dakota County - Prairie du Chien #19005

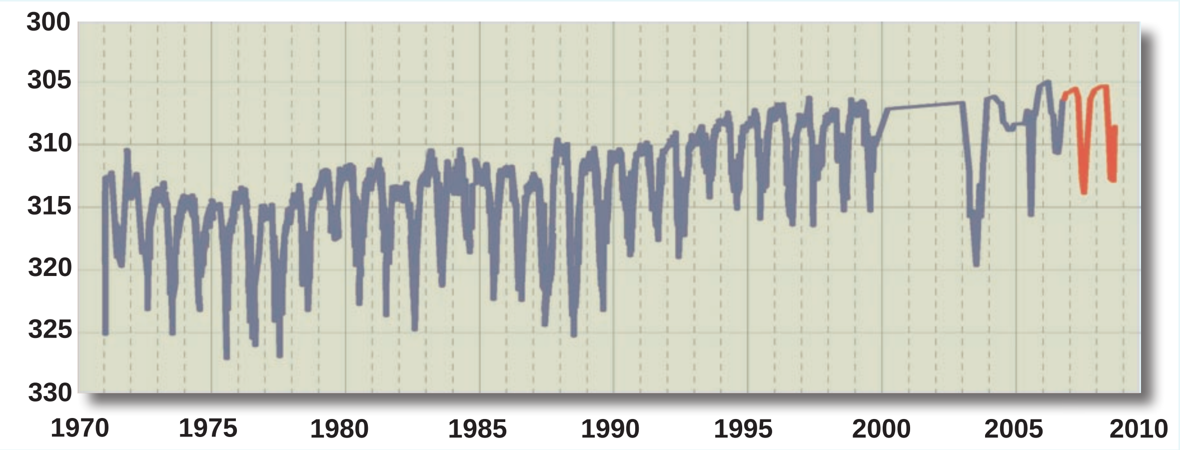


Figure 9B

Dakota County - Prairie du Chien #19007

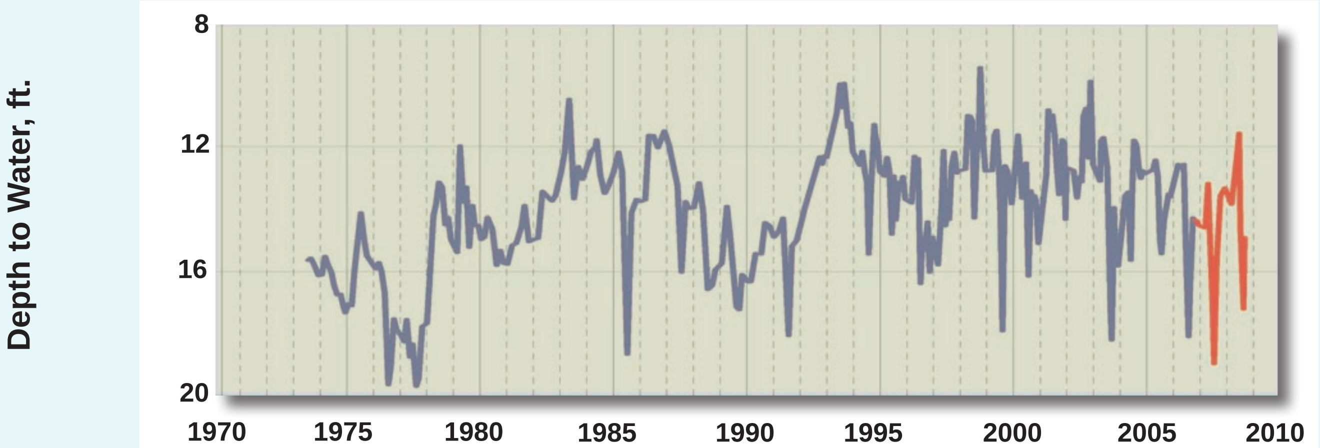


Figure 9C

Dakota County - Prairie du Chien #19008

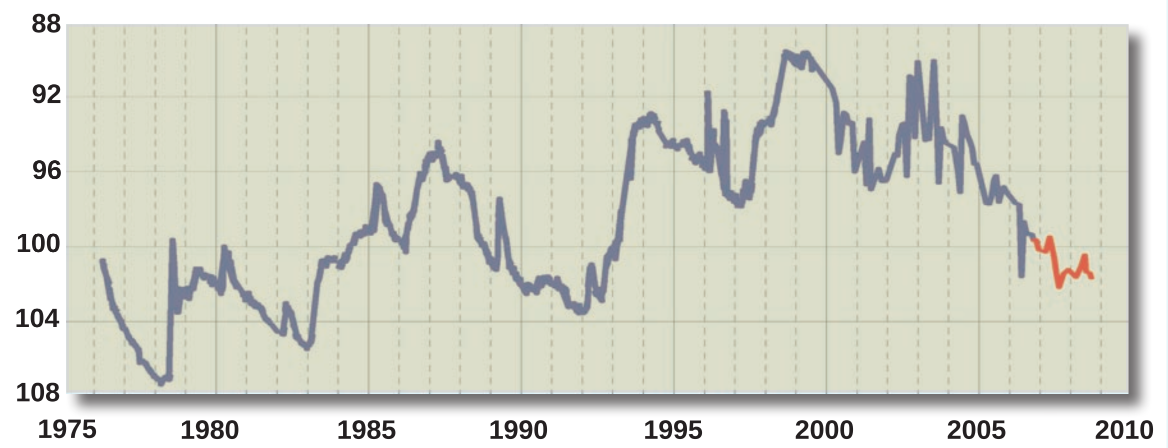


Figure 9D

Dakota County - Prairie du Chien #19029

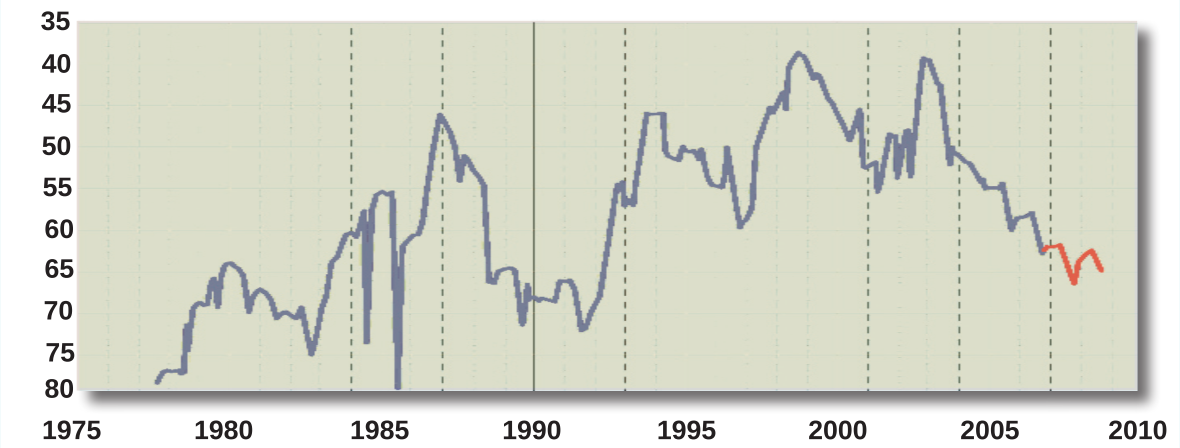


Figure 9E

Hennepin County - Prairie du Chien #27036

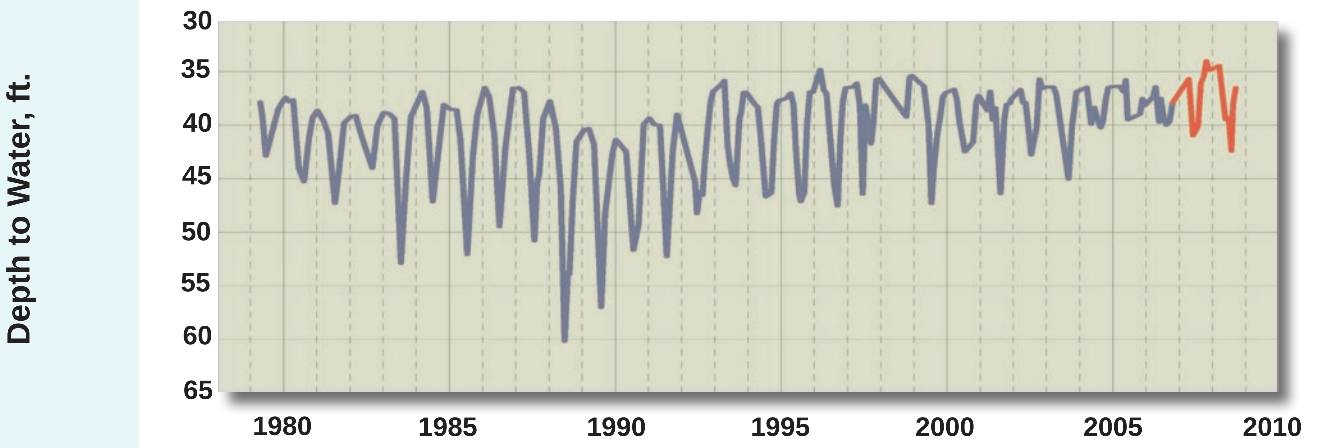


Figure 9F

Rice County - Prairie du Chien #66016

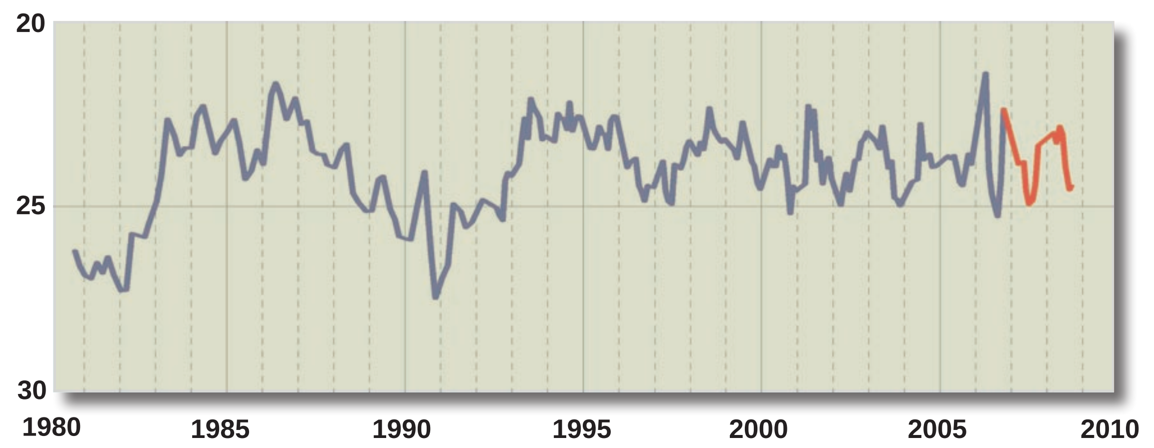
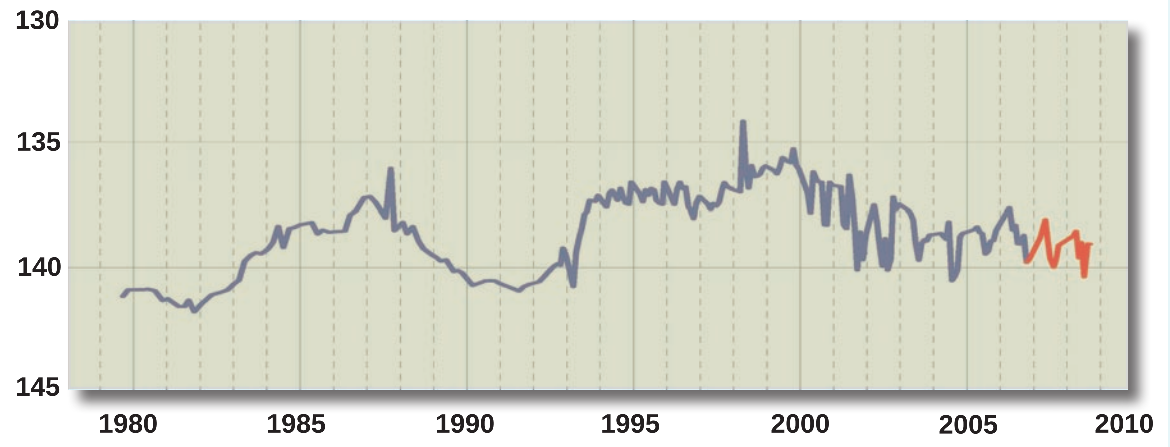
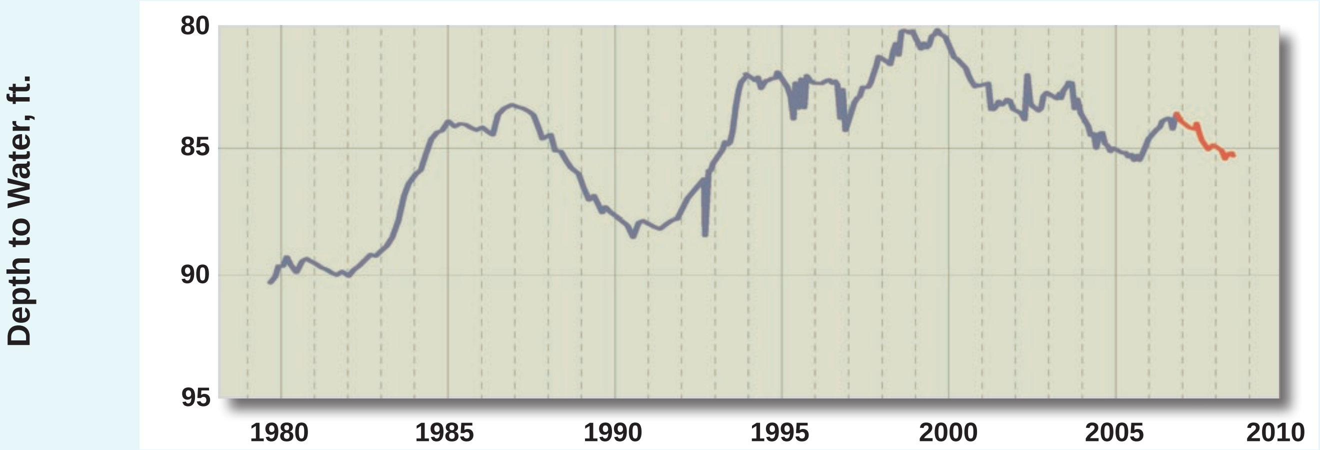


Figure 9G



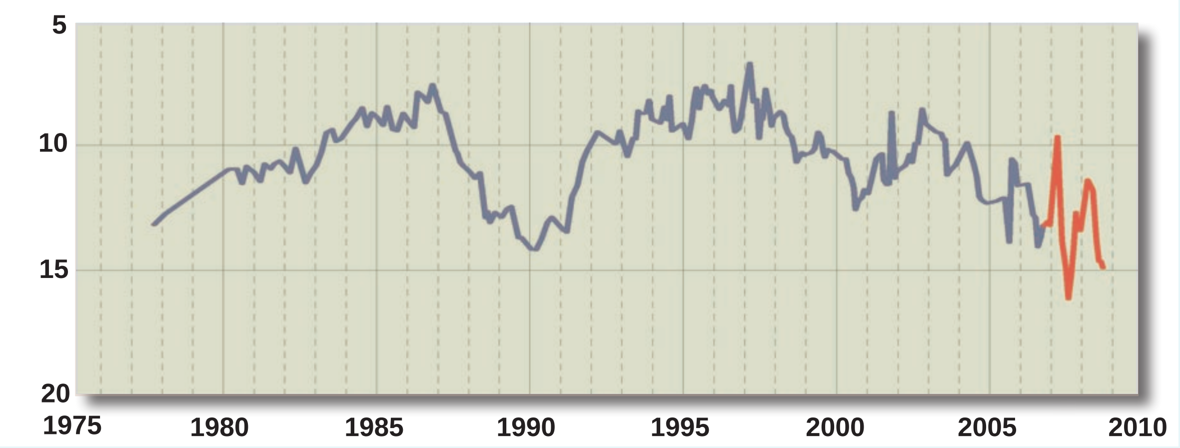
Rice County - Prairie du Chien #66017

Figure 9H



Scott County - Prairie du Chien #70008

Figure 9i



Washington County - Prairie du Chien #82029

Figure 9J

Washington County - Prairie du Chien #82033

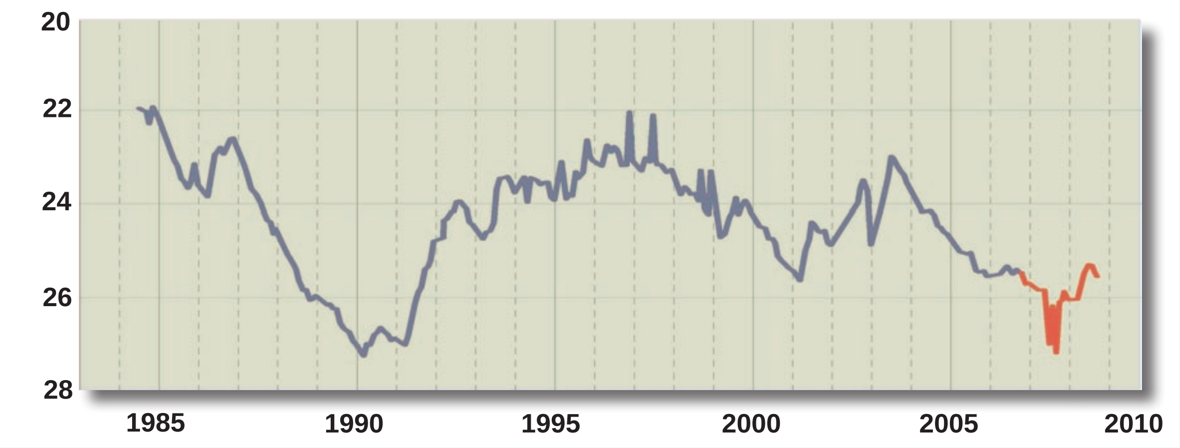


Figure 9K

Dakota County - Prairie du Chien/Jordan #19046

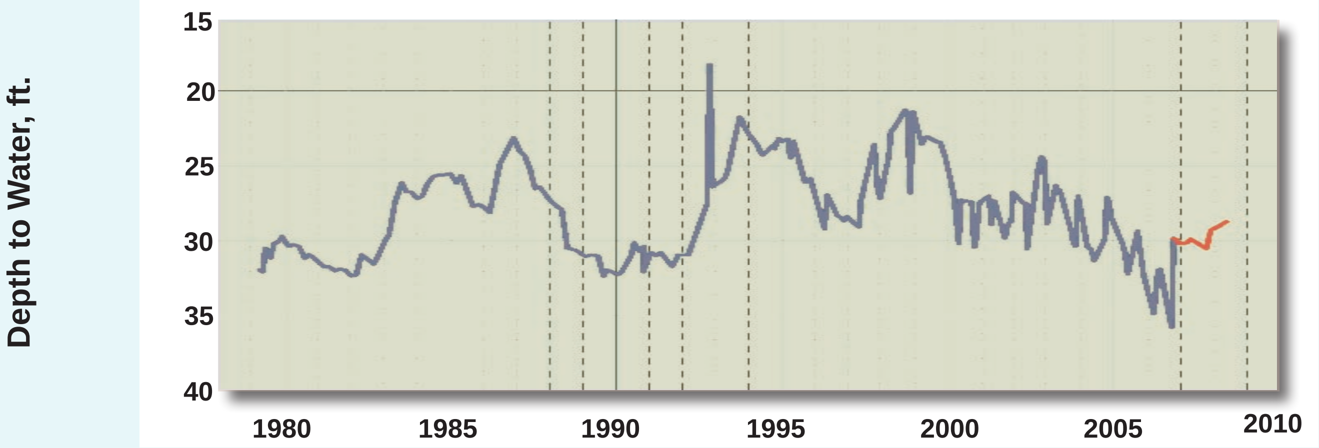


Figure 10A

Anoka County - Mt. Simon #2028

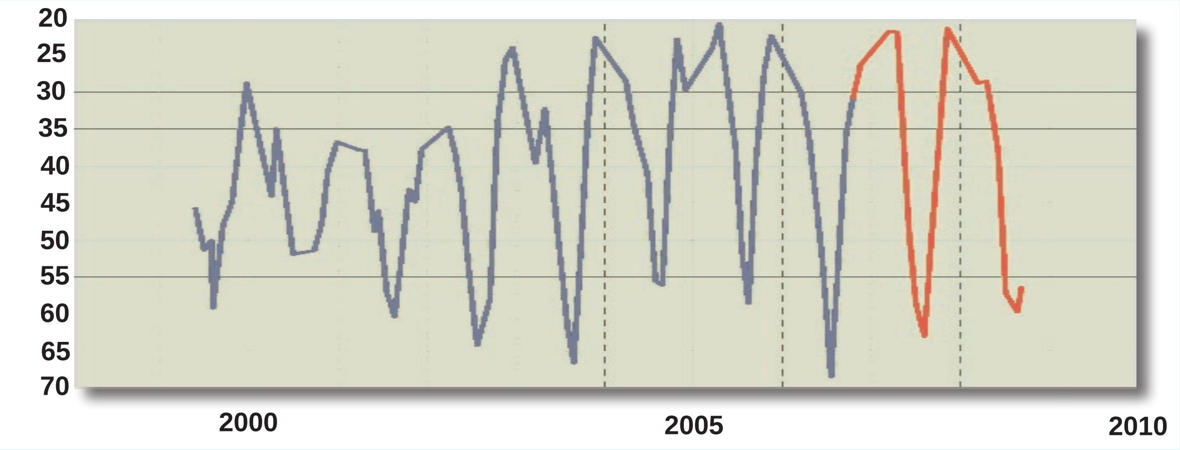


Figure 10B

Chisago County - Mt. Simon #13006

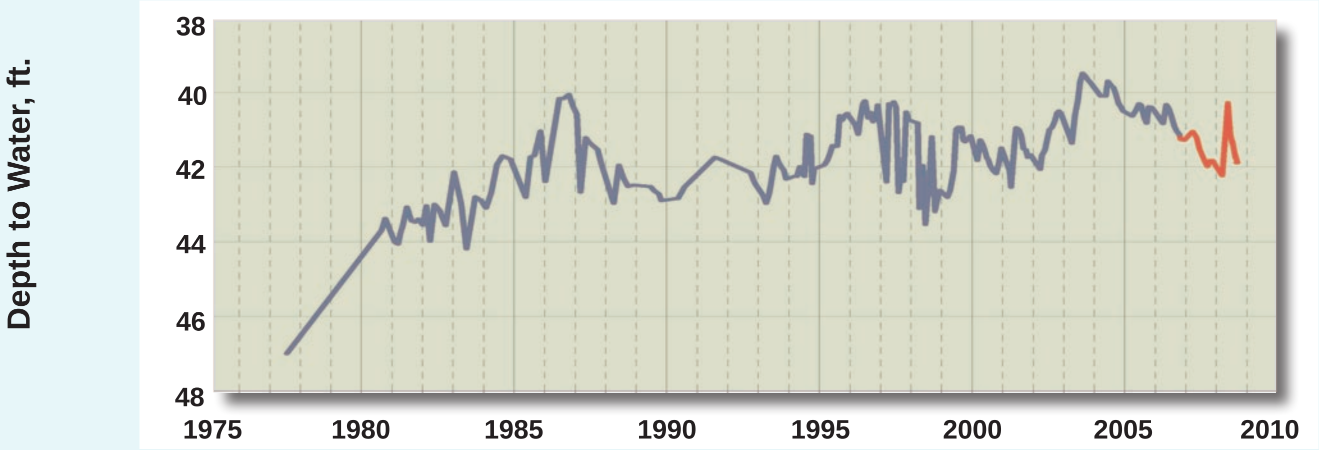


Figure 10C

Hennepin County - Mt. Simon #27004/27048

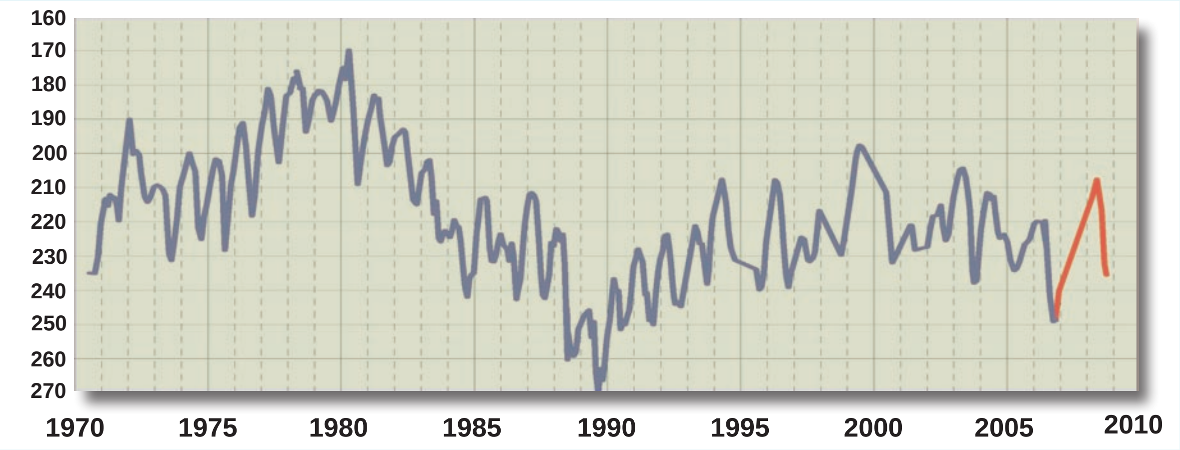


Figure 10D

Hennepin County - Mt. Simon #27043

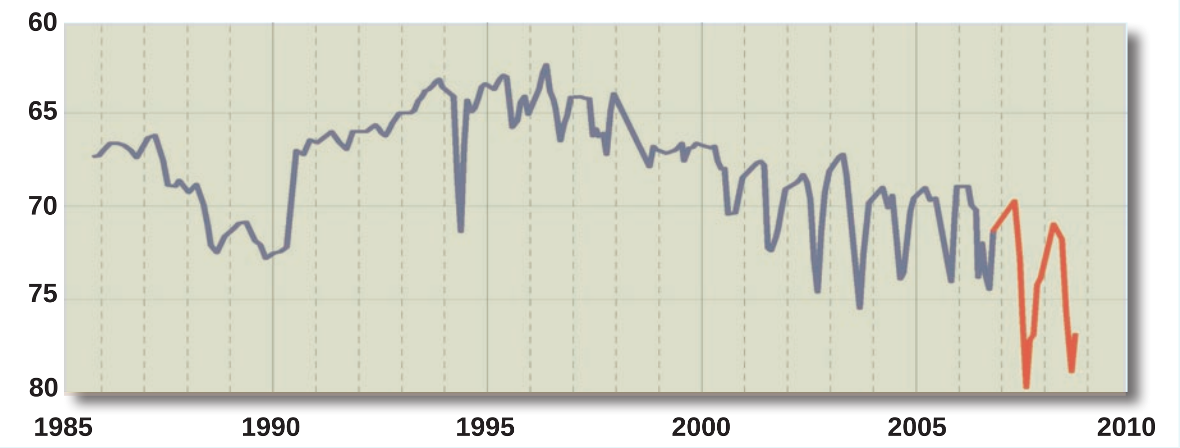


Figure 10E

Isanti County (Cambridge) - Mt.Simon #30009

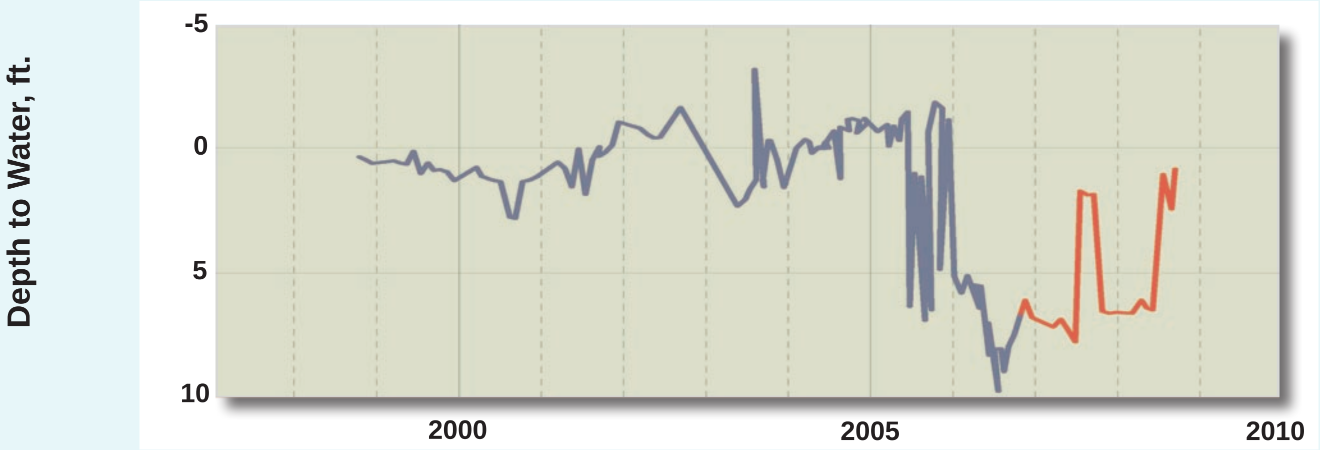


Figure 10F

Ramsey County - Mt.Simon #62046

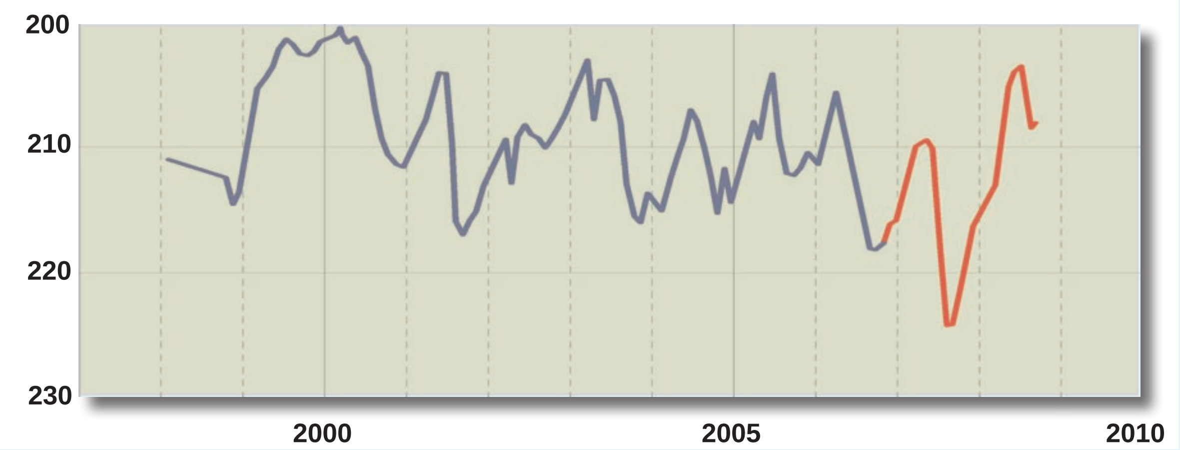


Figure 10G

Scott County (Savage) - Mt.Simon #70002/70030

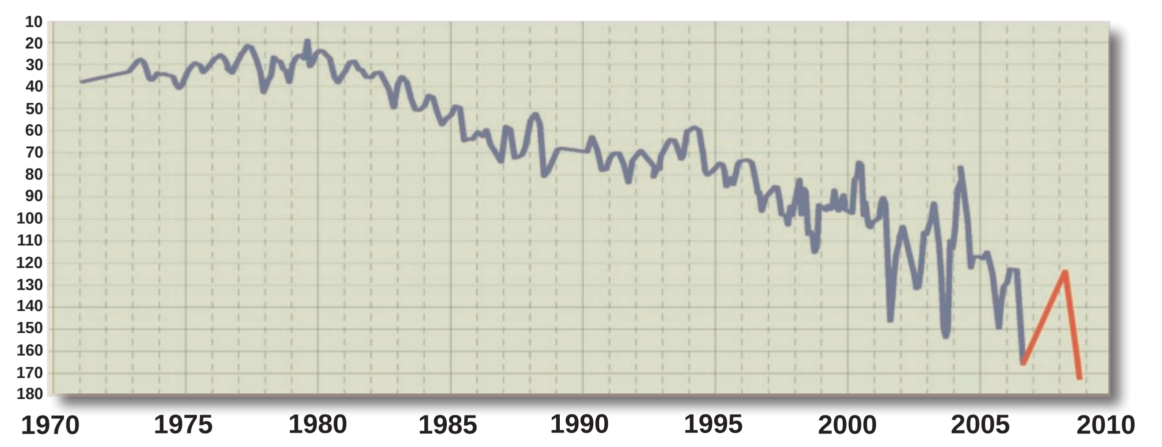


Figure 10H

Washington County - Mt.Simon #82046

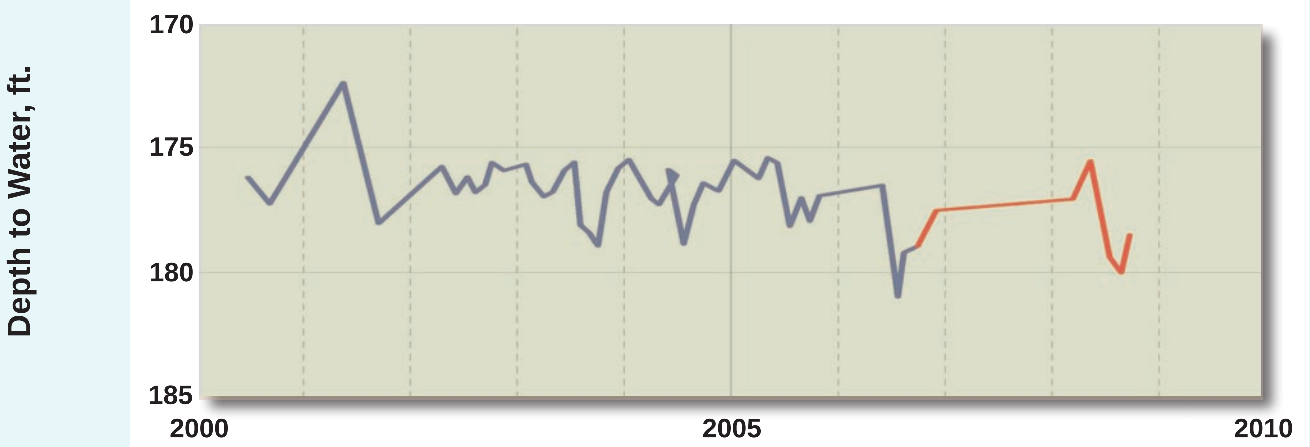
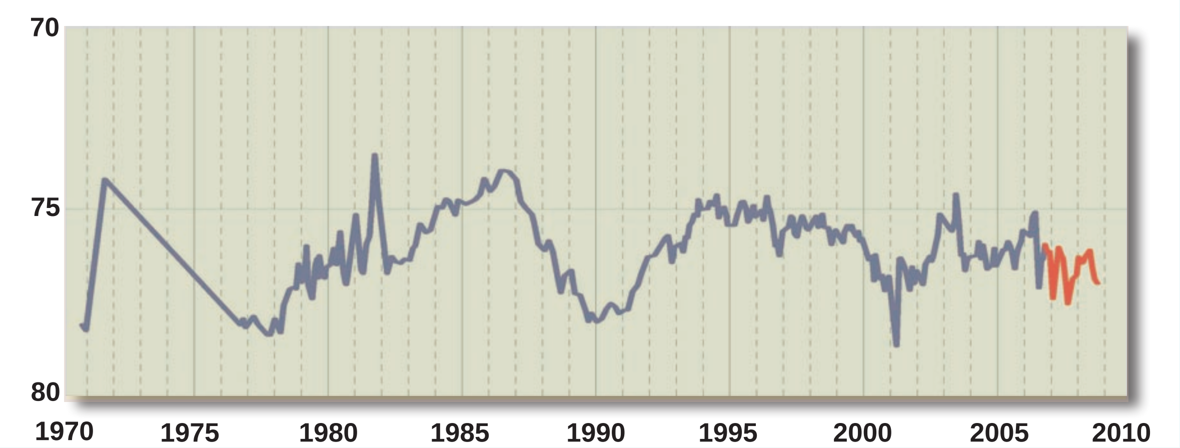


Figure 10i

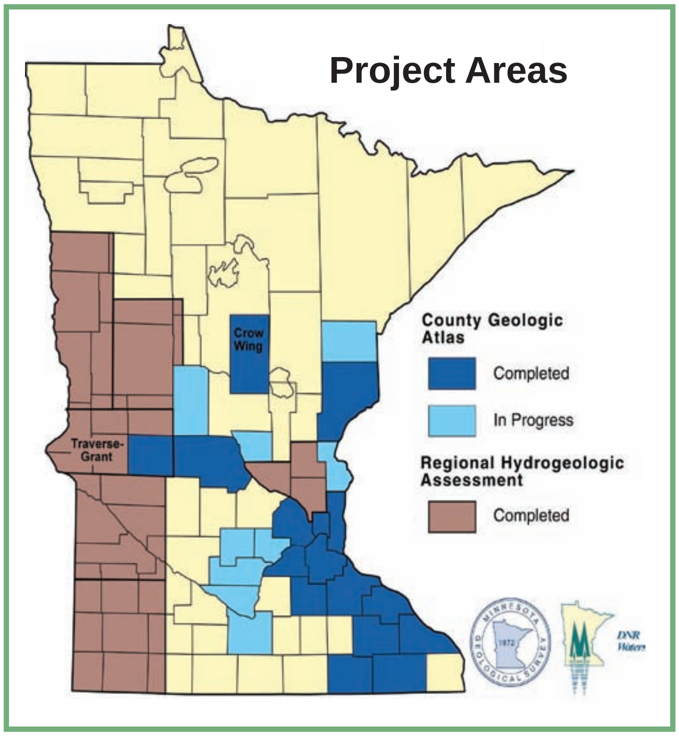
Wright County - Mt.Simon #86001



County Geologic Atlas and Regional Hydrogeologic Assessment Program

Ground Water Data

DNR Waters and the Minnesota Geological Survey (MGS) collaborate preparing the maps and reports of the County Geologic Atlases and Regional Hydrogeologic Assessments. The atlases and assessments provide data on Minnesota's geology and aquifers. The MGS provides geologic data collection, mapping, and interpretation of the rock and sediment beneath the earth's surface. DNR Waters uses the geologic framework for ground water studies of how water moves through those materials and interacts with water at the land's surface. DNR Waters staff measure water levels in wells and collect water samples for chemical and isotopic analysis. They also use ground water level monitoring data, climatology records, water use permits, and geophysical study reports. County-scale atlases and multi-county assessments are used in planning, environmental protection, and education. A better understanding of the physical environment ground water systems enables better environmental decision-making and resource management.



Recent Projects

The Crow Wing County Geologic Atlas, Part B, published in late 2007, covered an area in Minnesota known for its many high-quality lakes that are both intensively used for recreation and under pressure from development. The Part B report included examples of how water levels change over time in different lakes. These changes depend on geologic setting, watershed size, and amount of surface- and ground-water inflow and outflow. The report also looked at a location that illustrated the complex interaction of ground water and surface water.

The Traverse-Grant Regional Hydrogeologic Assessment, Part B, published in the fall of 2008, provided maps of five buried aquifers in glacial sediment that are vital for water supply. The extent of the aquifers had not previously been described well in that part of the state. The report shows that these buried aquifers are more localized and limited than the better-known thick, extensive bedrock aquifers in the southeast part of the state. In places, buried aquifers may be interconnected with others above or below it, so that the effect of pumping in one aquifer is observed in others.

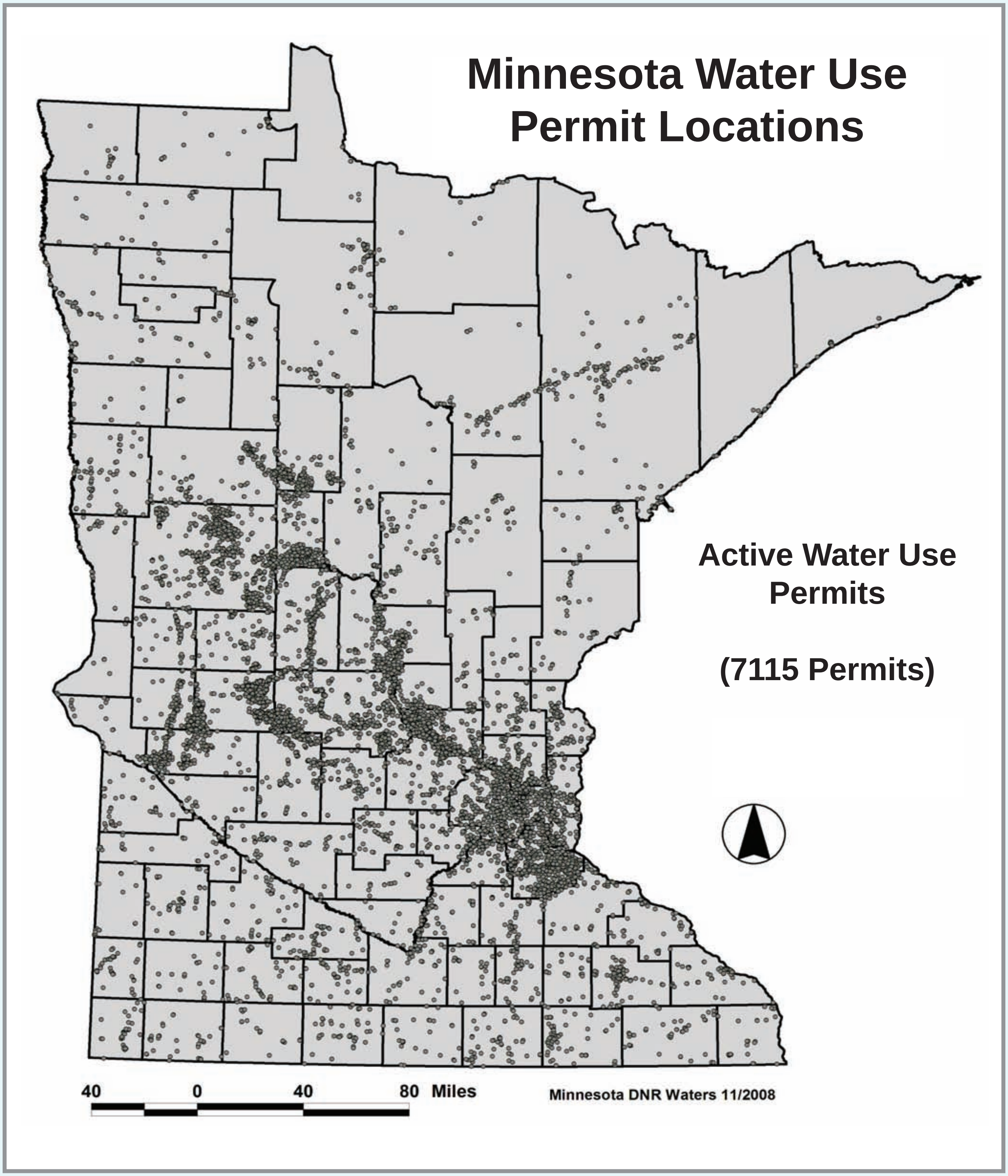
Data Available Online

Digital data for many atlases and assessments, including geographic information systems (GIS) and related resource data, can be downloaded over the Internet. Most map images and documents are available as portable document format (PDF) files. Digital data for many reports can be downloaded for use in GIS programs such as ArcView, ArcGIS, and EPPL7. Map viewers (at no or low cost) such as ArcExplorer can also be used to visualize the downloaded data.

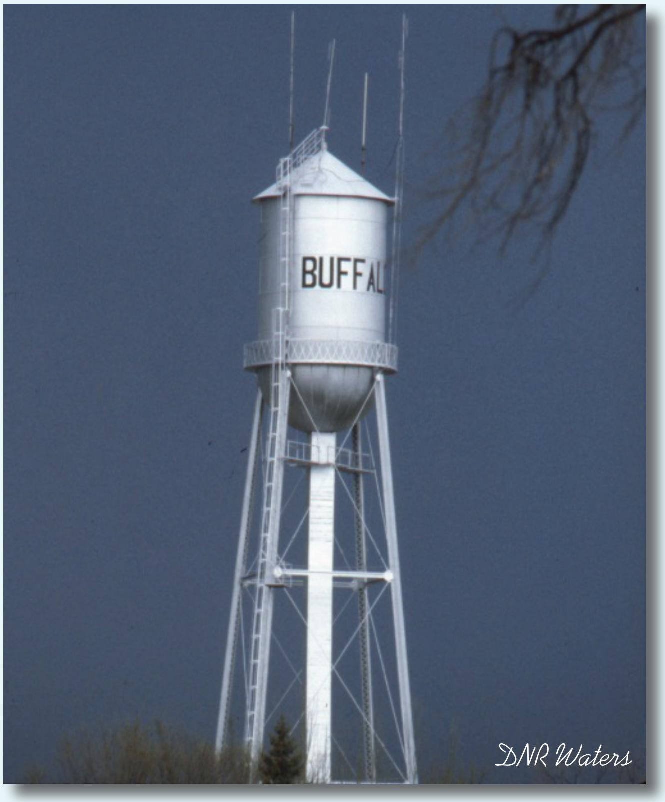
Other county atlas and assessment report data, including MGS report data, can be accessed through the DNR Waters website (status map).

For more information on MGS atlas and assessment report data see the list of current publications on the MGS website.

Chapter 4 Water Use


Minnesota Water Use Permit Locations
Active Water Use Permits
(7115 Permits)
40
0
40
80 Miles
Minnesota DNR Waters 11/2008

Introduction


DNR Waters

Introduction

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

All permittees must use a flow meter or other approved method of measurement to determine the volume of water withdrawn and must submit an annual report of water use. Reported water use data are used for many purposes, such as documenting water conflicts, understanding the hydrology of aquifers from which water is withdrawn, and evaluating existing water supplies by monitoring use and the impact of that use. The data are reported on a calendar year basis. This chapter summarizes the reported water use data for calendar years (CY) 2006 and 2007.

[insert major water use categories text from last time

MAJOR WATER USE CATEGORIES

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

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

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

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

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

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

Comparison of 2006 and 2007 Statewide Water Use

Water use in 2006 and 2007 were 1420.3 billion gallons (BG) and 1430.5 BG respectively. These values closely matched the highest reported water use of 2005. 2007 water use was 1% more than the 2006 total. Figure 1 is a comparison of the two years showing use by major category and the volume and percent change between the years. The largest increase in the two-year period was for irrigation, increasing by 15 BG or 13%. The largest decrease in use was for the category power generation, decreasing by 14 BG or 2%.

Figure 2 graphically shows the changes in use patterns for four main use categories (excluding power generation) from 1985 to 2007. Water use in 2007 for public supply increased to levels closely matching the high of 2003, a high-use year. Irrigation water use increased dramatically probably due to very dry conditions in 2006 and 2007 and increased acres irrigated. Industrial processing water use is generally influenced by overall economic vitality and can be heavily influenced by fluctuations in large mine processing and mine pit dewatering operations on the Minnesota Iron Range.

here]

Comparison of 2006 and 2007 Statewide Water Use

Water use in 2007 was 1430.5 billion gallons (BG) and matches closely with the highest reported water use of 2005. Reported use in 2006 was 1% less than the 2007 total. Figure 1 is a comparison of the two years showing use by major category and the volume and percent change between the years. The largest increase in the two-year period was for irrigation, increasing by 15 BG or 13%. The largest decrease in use was for the

Figure 1

Water Use Comparison by Major Use Category: 2006 & 2007

(Billions of Gallons)

	2006		**2007**		**Change From 2006 to 2007**	
Use Category	**BG**	**% of Total**	**BG**	**% of Total**	**BG Change**	**% Change**
Power Generation	852.9	60%	838.7	58%	-14.2	-2%
Public Supply	220.6	15%	226.9	16%	6.3	3%
Industrial Processing	163.8	12%	167.5	12%	3.7	2%
Irrigation	117.2	8%	132.3	9%	15.1	13%
Other	65.7	5%	65.2	5%	-0.5	-1%
Totals	1,420.3	**100%**	1,430.5	**100%**	**+10.3**	**+.7%**

column totals may not sum due to independent rounding

Figure 2

Minnesota Water Use
(excluding Power Generation) in Billions of Gallons

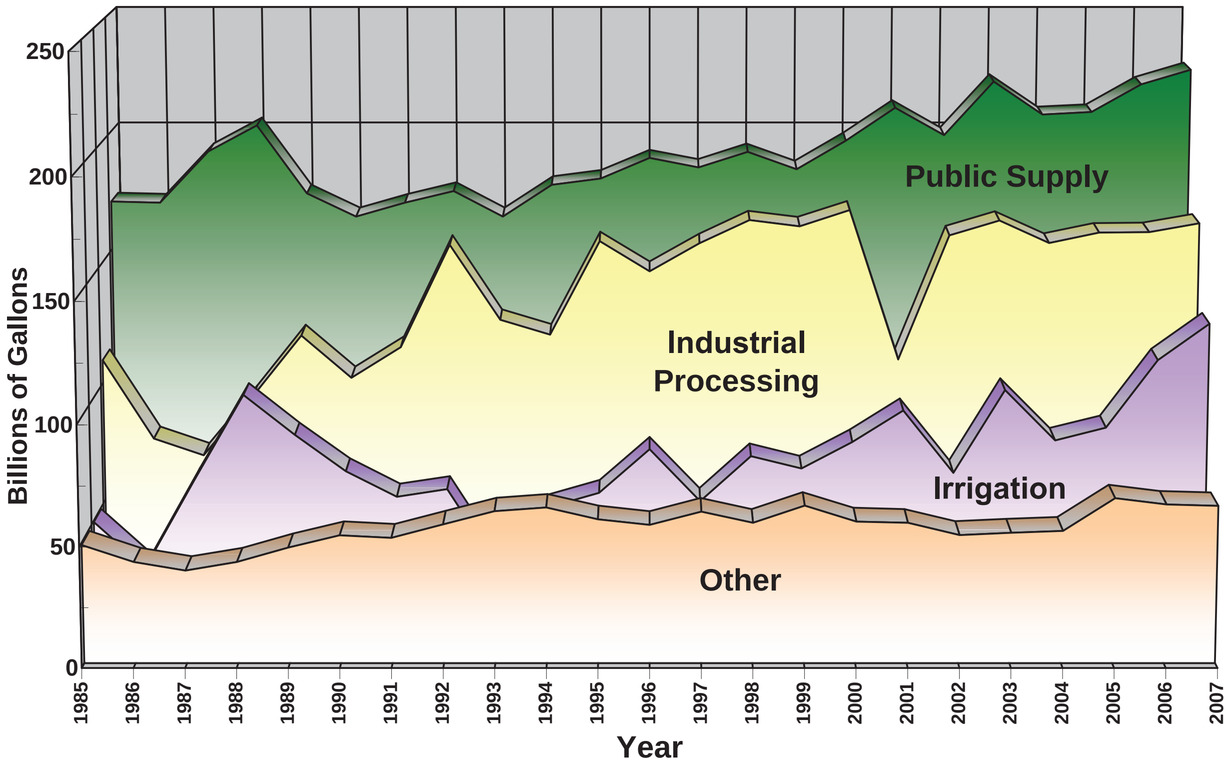
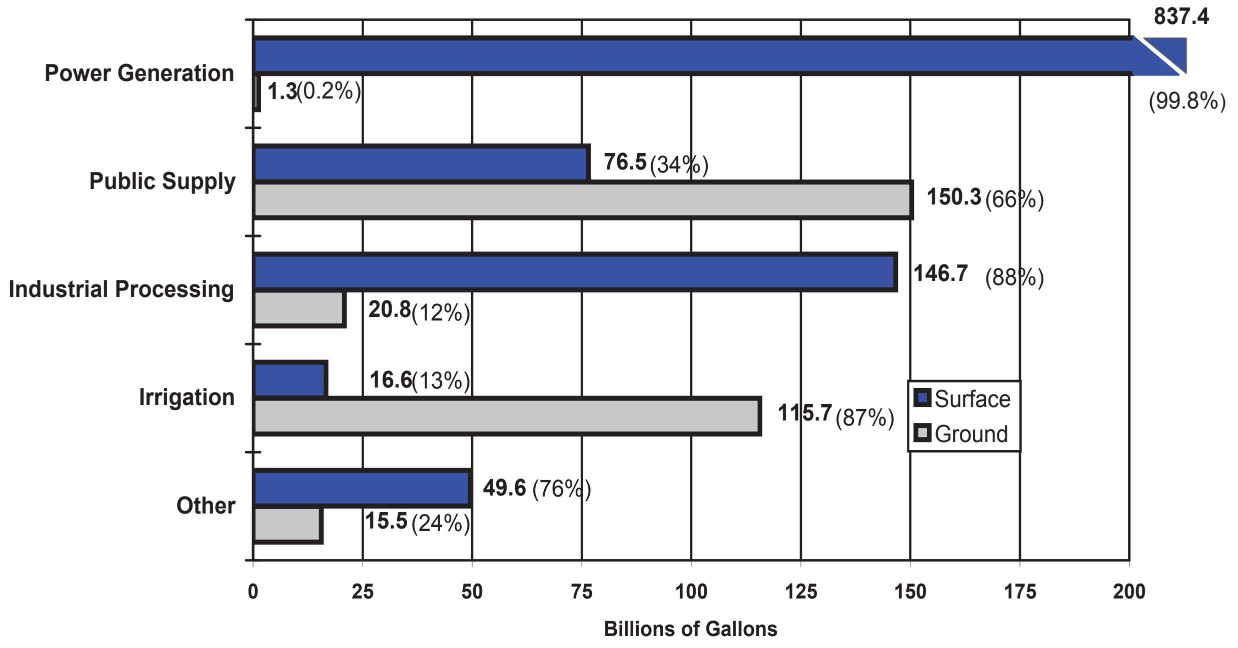


Figure 3

Comparison of Surface and Ground Water Use by Category - 2007
Billions of Gallons (% of category)



Power Generation

Figure 4 shows that power generation was the primary use in 8 of the 10 counties with the highest total use in 2007. Power generation accounted for 59% of all use reported in Minnesota for the year. Power generation in Goodhue and Wright Counties alone accounted for 24% of all reported use in 2007, largely due to power plant cooling. Surface water sources supply almost all of the water used for power generation. Most of the water is used for cooling purposes and is returned to the surface water source.


Blanchard Dam on Mississippi

Figure 4

Appropriations by the Counties with the Greatest Use in CY 2007

Billions of Gallons

	County	Ground Water	Surface Water	Total	Primary Use
1)	Goodhue	2.3	228.7	231.0	Nuclear Power Cooling
2)	Dakota	32.3	107.8	140.1	Steam Power Cooling
3)	Hennepin	40.5	87.1	127.6	Steam Power Cooling
4)	Wright	4.7	109.2	113.9	Nuclear Power Cooling
5)	St. Louis	2.0	107.4	109.4	Steam Power Cooling
6)	Washington	14.0	82.6	96.6	Steam Power Cooling
7)	Itasca	1.0	66.7	67.7	Steam Power Cooling
8)	Cook	0.0	65.6	65.6	Mine Processing
9)	Ramsey	12.4	49.1	61.5	Steam Power Cooling
10)	Anoka	14.0	36.6	50.6	Municipal Waterworks
	Billions of gallons	*41% of all* GW Use	*83% of all* SW Use	*74% of* Total Use	


Molly Shodeen


Julie Ekman

Public Water Supply

Public supply water use gradually increased from 1990 to 1999 due to population increases, higher demand for outdoor uses such as lawn watering and demands by industrial customers. After some fluctuations from 2001 to 2004, use in this category showed an increase in 2006 and 2007 back to 2003 peak levels. Sixty-six percent of public water supply use came from ground water in 2007, compared to 37% nationally (USGS, *Estimated Use of Water in the United States in 2000*).

Local water conservation programs that implement measures to improve water use efficiencies and promote the wise use of water can help communities reduce the need for expensive new municipal wells and water/wastewater treatment plants. Public water suppliers that serve more than 1,000 people are required to develop water supply plans and also implement demand management measures before requesting approvals for new supply wells. These efforts can help water customers and communities save money while helping to protect Minnesota's valuable water resources for future domestic and economic uses.

The water supply planning process has resulted in a general commitment on the part of Minnesota communities to increase the monitoring of the impacts of their water supply systems on the aquifers from which they draw water. Numerous communities have made commitments to decrease their water usage by reducing their unaccounted water volumes, reducing the water used for lawn watering or increasing their water conservation education efforts.

Irrigation

Annual variations in the amount and distribution of rainfall can greatly affect the demand for irrigation water. New applications for major crop irrigation permits increased in 2006 and 2007. This apparent increase in irrigated acres, combined with low precipitation levels during the growing season, resulted in irrigation at peak levels exceeding all previous years.

Irrigation accounts for a relatively small amount (9%) of total water use in Minnesota. However, this use is significant because it is almost entirely consumptive and the majority is from ground water sources (87% in 2007). The timing of irrigation water use can be significant when evaluating regional water supplies and the potential for well interferences. Almost all irrigation water use occurs in the five-month period from May to September of each year.

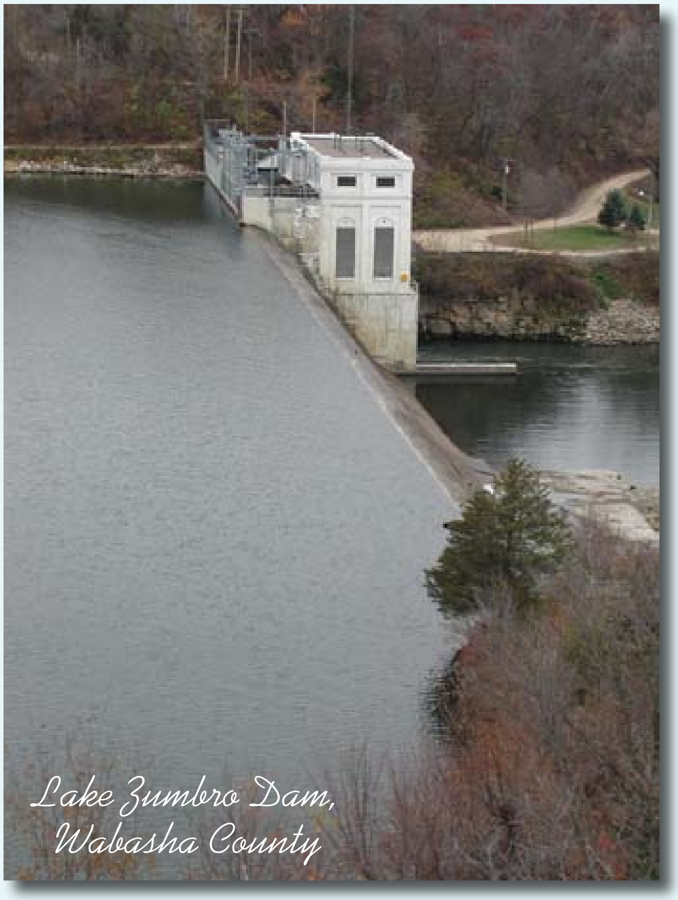
Dale Homuth

Industrial Processing

Industrial processing use maintained at a fairly stable level from 2002 to 2007, averaging 164 BG each year over the last 4 year period. Mine processing and pulp and paper processing accounted for the majority or water use reported for industrial processing.

Other Uses

Other uses include air conditioning, water level maintenance, fisheries, temporary construction dewatering, pollution confinement, snow making and other specialty uses that represent about 5% of Minnesota's total water use.


Lake Zumbro Dam,
Wabasha County

Summary

Total water use in 2007 stayed at nearly the same record high level of 1430 billion gallons as in 2005. Power generation continues to account for the majority of use totaling 838.7 BG (or 59%) in 2007. Surface water accounts for 79% of all appropriations.


Making Snow


Molly Shodeen

An intensively irrigated portion of Sherburne County.

Radial patterns are from center pivot irrigation systems; in these cases, the water is supplied by wells.

Reported Water Use by County
2006 - 2007 (Millions of Gallons)

Reported Water Use

	2006			2007				% of 2007 Total
County	Ground	Surface	Total	Ground	Surface	Total	Primary Use	
1 Aitkin	126.8	1,339.6	1,466.5	126.8	1,916.8	2,043.6	Wild Rice Irrigation	92
2 Anoka	13,276.0	34,977.3	48,253.3	13,979.6	36,642.1	50,621.7	Municipal Waterworks	94
3 Becker	3,888.4	67.9	3,956.3	3,395.9	66.5	3,462.4	Major Crop Irrigation	69
4 Beltrami	714.9	1,701.5	2,416.4	746.9	1,365.2	2,112.1	Wild Rice Irrigation	64
5 Benton	4,820.1	3,745.0	8,565.1	5,798.1	3,779.3	9,577.4	Major Crop Irrigation	49
6 Big Stone	619.7	101.7	721.4	576.3	111.9	688.2	Major Crop Irrigation	50
7 Blue Earth	4,179.7	8,384.4	12,564.1	4,140.6	9,062.5	13,203.1	Steam Power Cooling	68
8 Brown	953.1	63.3	1,016.4	905.0	77.1	982.1	Major Crop Irrigation	46
9 Carlton	652.5	2,049.1	2,701.6	621.5	2,407.9	3,029.4	Pulp/Paper Processing	68
10 Carver	3,934.2	45.4	3,979.6	4,034.6	47.7	4,082.3	Municipal Waterworks	89
11 Cass	1,528.8	36.5	1,565.3	1,480.2	38.7	1,518.9	Major Crop Irrigation	42
12 Chippewa	622.2	34.8	657.0	629.9	147.1	777.0	Municipal Waterworks	67
13 Chisago	1,545.3	205.3	1,750.6	1,422.6	215.5	1,638.1	Municipal Waterworks	52
14 Clay	1,064.5	1,730.4	2,794.9	1,211.3	1,644.9	2,856.2	Municipal Waterworks	71
15 Clearwater	124.9	1,910.0	2,034.9	109.7	3,880.4	3,990.1	Wild Rice Irrigation	97
16 Cook	9.8	62,864.5	62,874.3	9.8	65,636.1	65,645.9	Mine Processing	99.7
17 Cottonwood	1,306.1	312.8	1,618.9	1,271.4	197.5	1,468.9	Municipal Waterworks	39
18 Crow Wing	2,437.5	841.0	3,278.5	2,172.8	774.2	2,947.0	Municipal Waterworks	42
19 Dakota	32,299.9	115,342.5	147,642.4	32,263.0	107,805.7	140,068.7	Steam Power Cooling	74
20 Dodge	573.2	15.3	588.5	570.6	46.3	616.9	Municipal Waterworks	58
21 Douglas	1,997.1	119.5	2,116.6	2,384.4	115.9	2,500.3	Major Crop Irrigation	49
22 Faribault	707.0	0.6	707.6	698.4	0.0	698.4	Municipal Waterworks	59
23 Fillmore	657.3	3,972.6	4,629.9	646.3	4,113.5	4,759.8	Hatcheries & Fisheries	86
24 Freeborn	1,562.5	27.3	1,589.8	1,578.7	24.6	1,603.3	Municipal Waterworks	75
25 Goodhue	2,207.4	216,821.9	219,029.3	2,268.6	228,671.9	230,940.5	Nuclear Power Cooling	92
26 Grant	929.5	0.0	929.5	980.1	0.0	980.1	Major Crop Irrigation	82
27 Hennepin	38,734.4	78,633.5	117,367.9	40,450.2	87,118.3	127,568.5	Steam Power Cooling	68
28 Houston	527.7	8.9	536.6	657.8	16.8	674.6	Municipal Waterworks	76
29 Hubbard	5,979.0	30.2	6,009.2	5,799.3	24.2	5,823.5	Major Crop Irrigation	83
30 Isanti	1,083.0	49.8	1,132.8	1,058.3	5.7	1,064.0	Municipal Waterworks	57
31 Itasca	967.2	71,101.2	72,068.4	961.1	66,681.1	67,642.2	Steam Power Cooling	83
32 Jackson	361.6	157.6	519.2	419.0	79.1	498.1	Municipal Waterworks	45
33 Kanabec	229.0	11.1	240.1	257.2	12.0	269.2	Municipal Waterworks	56
34 Kandiyohi	3,936.1	512.3	4,448.4	4,391.8	504.0	4,895.8	Major Crop Irrigation	42
35 Kittson	352.2	161.9	514.1	325.9	132.5	458.4	Major Crop Irrigation	51
36 Koochiching	39.1	17,238.1	17,277.2	38.5	16,573.2	16,611.7	Pulp/Paper Processing	96
37 Lac Qui Parle	1,417.9	49.4	1,467.3	1,397.3	64.9	1,462.2	Major Crop Irrigation	41
38 Lake	0.3	46,999.4	46,999.7	40.9	48,377.2	48,418.1	Mine Processing	99
39 Lake of the Woods	67.1	283.1	350.2	60.3	324.4	384.7	Wild Rice Irrigation	83
40 Le Sueur	1,470.5	5,594.1	7,064.6	1,471.6	5,498.3	6,969.9	Quarry/Mine Dewatering	79
41 Lincoln	534.9	15.7	550.6	598.7	26.3	625.0	Rural Waterworks	67
42 Lyon	1,616.1	163.5	1,779.6	1,834.8	158.0	1,992.8	Municipal Waterworks	65
43 McLeod	2,168.0	334.7	2,502.7	2,061.3	259.2	2,320.5	Municipal Waterworks	52
44 Mahnomen	92.0	6.4	98.4	96.3	3.9	100.2	Municipal Waterworks	87

Reported Water Use by County
2006 - 2007 (Millions of Gallons)

Reported Water Use

County		2006			2007				% of 2007 Total
		Ground	Surface	Total	Ground	Surface	Total	Primary Use	
45	Marshall	220.4	36.3	256.7	222.1	41.6	263.7	Municipal Waterworks	36
46	Martin	293.6	4,420.7	4,714.3	461.3	4,976.6	5,437.9	Steam Power Cooling	80
47	Meeker	1,928.9	16.2	1,945.1	2,152.6	29.6	2,182.2	Major Crop Irrigation	69
48	Mille Lacs	685.2	34.1	719.3	685.3	56.1	741.4	Municipal Waterworks	56
49	Morrison	5,501.2	221.9	5,723.1	6,349.0	172.7	6,521.7	Major Crop Irrigation	80
50	Mower	2,685.8	170.7	2,856.5	2,853.6	219.5	3,073.1	Municipal Waterworks	44
51	Murray	195.9	111.7	307.6	208.2	92.9	301.1	Municipal Waterworks	67
52	Nicollet	1,944.6	112.7	2,057.3	2,039.4	55.5	2,094.9	Municipal Waterworks	86
53	Nobles	1,192.3	78.4	1,270.7	1,194.4	69.4	1,263.8	Municipal Waterworks	94
54	Norman	144.4	0.0	144.4	146.6	0.0	146.6	Municipal Waterworks	85
55	Olmsted	6,508.2	14,245.3	20,753.5	6,486.8	13,773.4	20,260.2	Steam Power Cooling	47
56	Ottertail	17,554.4	26,557.0	44,111.4	19,709.0	28,899.8	48,608.8	Steam Power Cooling	57
57	Pennington	38.8	665.1	703.9	29.4	815.3	844.7	Municipal Waterworks	54
58	Pine	535.4	46.7	582.1	513.6	43.9	557.5	Municipal Waterworks	55
59	Pipestone	1,119.5	84.7	1,204.2	1,231.0	61.8	1,292.8	Rural Waterworks	45
60	Polk	573.5	4,659.0	5,232.5	541.8	5,908.7	6,450.5	Municipal Waterworks	53
61	Pope	11,221.3	31.0	11,252.3	11,742.1	35.9	11,778.0	Major Crop Irrigation	96
62	Ramsey	12,239.0	62,147.7	74,386.7	12,417.4	49,139.0	61,556.4	Steam Power Cooling	49
63	Red Lake	280.6	157.2	437.8	297.7	437.4	735.1	Wild Rice Irrigation	56
64	Redwood	434.5	97.8	532.3	420.9	61.8	482.7	Municipal Waterworks	77
65	Renville	919.4	100.3	1,019.7	831.3	113.0	944.3	Municipal Waterworks	45
66	Rice	2,807.5	495.7	3,303.2	2,699.7	300.4	3,000.1	Municipal Waterworks	76
67	Rock	642.1	57.2	699.3	668.0	55.4	723.4	Municipal Waterworks	51
68	Roseau	312.6	7.5	320.1	299.2	8.1	307.3	Municipal Waterworks	88
69	St. Louis	1,969.5	102,897.7	104,867.2	1,995.1	107,417.8	109,412.9	Steam Power Cooling	61
70	Scott	6,189.6	165.8	6,355.4	6,779.5	130.1	6,909.6	Municipal Waterworks	70
71	Sherburne	12,606.0	20,571.0	33,177.0	13,502.3	20,903.8	34,406.1	Steam Power Cooling	37
72	Sibley	671.4	42.8	714.2	822.7	21.7	844.4	Municipal Waterworks	68
73	Stearns	12,676.5	3,447.6	16,124.1	13,419.5	3,473.5	16,893.0	Major Crop Irrigation	57
74	Steele	1,894.0	1,064.7	2,958.7	1,861.1	580.2	2,441.3	Municipal Waterworks	72
75	Stevens	3,265.9	68.8	3,334.7	3,320.4	56.7	3,377.1	Major Crop Irrigation	75
76	Swift	5,363.5	43.9	5,407.4	6,315.1	18.2	6,333.3	Major Crop Irrigation	90
77	Todd	3,694.6	246.4	3,941.0	4,221.3	257.2	4,478.5	Major Crop Irrigation	82
78	Traverse	86.3	2.1	88.4	78.6	2.2	80.8	Municipal Waterworks	97
79	Wabasha	1,173.3	20.7	1,194.0	1,288.0	15.9	1,303.9	Municipal Waterworks	69
80	Wadena	4,109.8	679.0	4,788.8	4,952.7	851.7	5,804.4	Major Crop Irrigation	93
81	Waseca	677.0	29.5	706.5	676.5	28.5	705.0	Municipal Waterworks	89
82	Washington	13,054.4	84,037.2	97,091.6	13,961.7	82,592.9	96,554.6	Steam Power Cooling	83
83	Watonwan	1,024.3	15.5	1,039.8	1,123.1	22.4	1,145.5	Municipal Waterworks	59
84	Wilkin	369.5	145.3	514.8	346.3	99.7	446.0	Municipal Waterworks	67
85	Winona	2,447.3	975.0	3,422.3	3,527.3	1,048.2	4,575.5	Municipal Waterworks	32
86	Wright	4,585.1	124,417.8	129,002.9	4,719.7	109,162.2	113,881.9	Nuclear Power Cooling	96
87	Yellow Medicine	532.2	88.6	620.8	642.7	103.4	746.1	Rural Waterworks	50
	Total			**1,420,259**			**1,430,500**		

Minnesota Reported Water Use

Category	2006	2007
Power Generation	(Millions of Gallons)	
Nuclear Power		
surface	327,430.4	321,771.3
ground	61.6	49.4
Steam Power Cooling		
surface	438,740.3	430,722.8
ground	588.5	406.8
Other Power		
surface	85,266.4	84,862.2
ground	845.9	846.5
Subtotal	**852,933.1**	**838,659.0**
Percent of Total	**60%**	**59%**
surface	851,437.1	837,356.3
ground	1,496.0	1,302.7
Public Supply		
Municipal Water Works		
surface	73,636.7	76,518.6
ground	143,034.9	146,230.0
Private Water Works		
surface	9.7	9.7
ground	709.5	744.4
Comercial & Institutional		
surface	0.0	0.0
ground	1,162.7	1,146.8
Cooperative Water Works		
surface	0.0	0.0
ground	2.2	2.1
Fire Protection		
surface	1.6	0.0
ground	12.3	18.3
State Parks, Waysides, Rest Areas		
surface	0.0	0.0
ground	49.2	51.2
Rural Water Districts		
surface	0.0	0.0
ground	2,003.0	2,138.7
Subtotal	**220,621.8**	**226,859.8**
Percent of Total	**16%**	**16%**
surface	73,648.0	76,528.3
ground	146,973.8	150,331.5

Minnesota Reported Water Use

Category	2006	2007
Irrigation	(Millions of Gallons)	
Golf Course		
surface	2,017.0	1,934.0
ground	6,954.0	7,727.7
Cemetary		
surface	3.9	4.5
ground	102.1	120.5
Landscaping		
surface	114.1	82.3
ground	980.1	1,163.2
Sod		
surface	73.3	124.4
ground	334.4	369.4
Nursery		
surface	172.6	177.3
ground	727.8	722.1
Orchard		
surface	12.0	11.9
ground	18.1	11.7
Non Crop		
surface	0.0	0.0
ground	27.7	16.5
Temporary		
surface	0.0	0.0
ground	25.7	0.0
Major Crop		
surface	3,131.0	3,145.7
ground	95,443.6	105,576.9
Wild Rice		
surface	7,022.7	11,156.6
ground	3.5	3.0
Subtotal	**117,163.6**	**132,347.7**
Percent of Total	**8%**	**9%**
surface	12,546.6	16,636.7
ground	104,617.0	115,711.0

Minnesota Reported Water Use

Category	2006	2007
Industrial Processing	(Millions of Gallons)	
Agricultural		
surface	8.2	3.5
ground	9,015.8	9,301.6
Pulp and Paper		
surface	25,994.9	25,346.7
ground	912.9	872.3
Mine		
surface	113,407.3	118,278.2
ground	113.0	95.4
Sand and Gravel Washing		
surface	3,268.7	2,540.3
ground	1,383.4	1,178.0
Industrial Process Cooling Once-through		
surface	211.9	203.3
ground	2,085.8	2,006.8
Petroleum or Chemical		
surface	118.0	289.9
ground	4,502.2	4,520.6
Metal		
surface	0.0	0.0
ground	1,327.2	1,431.7
Non-Metal		
surface	0.0	0.0
ground	1,064.1	990.6
Other		
surface	0.0	0.0
ground	399.8	408.7
Subtotal	**163,813.2**	**167,467.6**
Percent of Total	**12%**	**12%**
surface	143,009.0	146,661.9
ground	20,804.2	20,805.7
Other		
Air Conditioning		
Commercial & Institutional Building AC		
surface	258.8	267.9
ground	63.3	69.8

Minnesota Reported Water Use

Category	2006	2007
Heat Pumps & Coolant Pumps	(Millions of Gallons)	
surface	1.7	2.0
ground	0.0	0.0
District Heating		
surface	0.0	0.0
ground	107.5	112.4
Once Through Heating or AC		
surface	0.0	0.0
ground	1,680.2	1,531.0
Temporary		
Temporary Construction Non-Dewatering		
surface	0.4	0.0
ground	17.5	0.2
Temporary Construction Dewatering		
surface	311.1	211.7
ground	3,592.9	4,012.8
Temporary Pipeline and Tank Testing		
surface	22.5	0.1
ground	0.8	0.0
Other Temporary		
surface	87.2	42.3
ground	36.0	2.7
Water Level Maintenance		
Basin (Lake) Level Maintenance		
surface	2,340.5	874.3
ground	241.8	255.4
Mine Dewatering		
surface	22,012.8	24,840.2
ground	5.2	6.0
Quarry Dewatering		
surface	18,519.2	15,695.8
ground	0.0	0.0
Sand/Gravel Pit Dewatering		
surface	1,058.3	1,143.5
ground	2.9	0.7
Tile Drainage & Pumped Sumps		
surface	33.9	31.0
ground	20.6	19.4

Minnesota Reported Water Use

Category	2006	2007
Other Water Level Maintenance	(Millions of Gallons)	
surface	26.1	29.2
ground	1,561.3	1,902.0
Special Categories		
Pollution Confinement		
surface	0.0	0.0
ground	4,665.4	4,664.2
Hatcheries & Fisheries		
surface	5,750.7	6,050.8
ground	582.0	607.3
Snow Making		
surface	178.5	195.8
ground	215.0	249.2
Livestock Watering		
surface	0.0	2.4
ground	899.3	945.3
Other Special Categories		
surface	332.9	232.4
ground	1,101.6	1,167.5
Subtotal	**65,727.9**	**65,165.3**
Percent of Total	**5%**	**5%**
surface	50,934.6	49,619.4
ground	14,793.3	15,545.9
Grand Total (Millions of Gallons)	**1,420,259**	**1,430,500**
surface	**1,131,575**	**1,126,803**
ground	**288,684**	**303,697**

Water Use Efficiency at Ethanol Production Facilities

Water use efficiency is important in all areas of industry. There has been much interest in water use for expanding industries including ethanol production. The water use and ethanol production data come from several sources. About half of Minnesota's ethanol plants have a water use permit which requires direct reporting of water used each year. The other plants use water from municipal water suppliers. For the latter, a survey is conducted of their supply source to determine annual volumes. The ethanol production number is generally supplied by the Minnesota Department of Agriculture from the Ethanol Producers Payment program. Where that information is not available, production values from the Minnesota Pollution Control Agency (Air Quality Emission Inventory) reports are used.

The ratio of gallons of water used to gallons of ethanol produced from 1998 to 2007 is shown in the Table below. Generally the efficiency of operations has increased over time from 5.8 gallons of water used per gallon of ethanol produced in 1998 to 3.8 in 2007. Overall ethanol production used 2.4 billion gallons of water in 2007. This compares to 9.3 billion gallons reported for other agricultural processing purposes.

Gallons of water used
per gallon of ethanol produced

Ethanol Producers	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**
Albert Lea (Exol/Agra Resources)	6.3	6.3	6.0	6.1	5.6	5.5	5.2	4.9	4.8	4.4
Atwater(Bushmill's Ethanol)									3.2	3.4
Benson (Chippewa Valley Ethanol)	3.3	3.5	4.8	3.5	3.5	3.1	3.2	3.6	3.4	3.7
Bingham Lake (Ethanol2000)	4.0	4.2	4.7	4.6	4.3	4.7	4.2	4.4	4.6	4.3
Buffalo Lake (Minnesota Energy)	10.6	6.2	7.1	6.9	7.0	5.8	4.6	4.5	4.5	4.2
Claremont (Al-Corn Clean Fuel)	4.6	4.3	4.1	4.2	3.9	5.4	4.5	4.3	4.1	3.7
Granite Falls (Granite Falls Energy)								5.3	4.0	2.8
Lake Crystal (POET Biorefining)								2.8	2.8	2.9
Little Falls (Central MN Ethanol)		5.9	4.8	4.2	4.1	3.8	3.5	4.2	4.3	5.0
Luverne (AgriEnergy)	4.9	5.8	5.2	4.8	4.7	4.6	4.5	4.5	4.5	4.7
Marshall (ADM) **	7.7	7.6								
Melrose (Dairy Proteins) *	0.6	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.4
Morris (DENCO LLC)	9.3	10.0	12.3	8.2	6.0	6.1	6.0	6.1	5.9	6.4
Preston (POET Biorefining)	5.6	5.2	4.7	4.6	4.4	4.1	3.8	4.0	4.0	3.7
St. Paul (MN Brewing)		18.7	7.9	21.9	32.6	12.2				
Winnebago (Corn Plus)	4.1	3.5	3.5	3.5	4.5	4.1	3.9	3.9	3.4	4.1
Winthrop (Heartland Corn Products)	4.8	5.1	4.3	5.0	4.1	3.7	4.5	4.2	3.4	2.7

MN DNR Waters, 2009

Average of dry mill facilities	5.8	5.5	5.6	5.1	4.8	4.6	4.3	4.1	3.9	3.8

* estimates based on approximate water use - process: waste cheese whey

** estimates based on percent ethanol production compared to other corn products from the same facility
Ethanol production continues for all years, but water use estimates unknown - process: wet mill corn

Website Links Referenced in Document

Chapter 1 Climatology links

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Cool and Dry October 2006 in the Twin Cities:
http://climate.umn.edu/doc/journal/coolmsp0610.htm

Heavy Snow over Southeast Minnesota:
November 10, 2006
http://climate.umn.edu/doc/journal/snow061110.htm

November 30 Lake Effect Snow
http://www.crh.noaa.gov/mpx/?n=nov30lakeeffect

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Snow Drought in Minnesota 2006-07
http://climate.umn.edu/doc/journal/snowdrought0607.htm

Extended Period of Below Zero in the Twin Cities
http://climate.umn.edu/doc/journal/zero0702.htm

Snowfall of February 23-26, 2007
http://climate.umn.edu/doc/journal/snow070223_26.htm

Snowstorm and Blizzard: February 28 to March 2, 2007
http://climate.umn.edu/doc/journal/snow070228_070302.htm

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Record Warmth: March 26, 2007
http://climate.umn.edu/doc/journal/warm070326.htm

Cold First Week of April 2007
http://climate.umn.edu/doc/journal/coldapril2007.htm

Smoky Skies: May 11, 2007
http://climate.umn.edu/doc/journal/smoke070511.htm

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Tornadoes and Heavy Rains in Northwest Minnesota:
June 13-14, 2007
http://climate.umn.edu/doc/journal/tornado070614.htm

Monthly Summary for July 2007
http://climate.umn.edu/cawap/monsum/0707.txt

Dry and Warm July 2007
http://climate.umn.edu/doc/journal/warm0707.htm

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Historic Flood of August 18-20, 2007
http://climate.umn.edu/doc/journal/flash_floods/ff070820.htm

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Heavy Rains Drench Iron Range: September 6, 2007
http://climate.umn.edu/doc/journal/flash_floods/ff070906.htm

Heavy Rains: September 20-21, 2007
http://climate.umn.edu/doc/journal/rain070920.htm

Chilly September 15, 2007
http://climate.umn.edu/doc/journal/cold070915.htm

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Drought Situation Report: September 27, 2007
http://climate.umn.edu/doc/journal/drought_situation_report_2007_070927.htm

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Top Ten Wettest October in the Twin Cities
http://climate.umn.edu/doc/journal/wet_aug_oct_msp.htm

Dry November 2007
http://climate.umn.edu/doc/journal/drynov2007.htm

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Heavy Snow: December 1, 2007
http://climate.umn.edu/doc/Journal/snow071201.htm

More Snow: December 4, 2007
http://climate.umn.edu/doc/journal/snow071204.htm

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"January Thaw" of January 5-7, 2008
http://climate.umn.edu/doc/journal/January_thaw08.htm

Rapid Temperature Change: January 29, 2008
http://climate.umn.edu/doc/journal/temperature_change080129.htm

Website Links Referenced in Document

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Snowstorm of March 31-April 1, 2008
http://climate.umn.edu/doc/journal/snow080331_0401.htm

Very Heavy Snow: April 5-7, 2008
http://climate.umn.edu/doc/journal/snow080405_07.htm

Blizzard: April 10-11, 2008
http://climate.umn.edu/doc/journal/blizzard080410_11.htm

Snowstorm and Blizzard: April 25-26, 2008
http://climate.umn.edu/doc/journal/blizzard080425_26.htm

Lake Ice Out 2008
http://climate.umn.edu/doc/ice_out/ice_out_status_08.htm

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Southeast Minnesota Flooding: June 7-9, 2008
http://climate.umn.edu/doc/journal/flash_floods/ff080607_09.htm

More Southeast Minnesota Flooding: June 11-12, 2008
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Beneficial Rains: August 27-28, 2008
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Dry 2008 Growing Season
http://climate.umn.edu/doc/journal/dry_mid-summer_2008_081007.htm

Chapter 2 Surface Water links

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Watershed Delineation Project
http://www.dnr.state.mn.us/watersheds/lakeshed_project.html

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Snow Drought
http://climate.umn.edu/doc/journal/snowdrought0607.htm

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DNR Lake Finder web site
http://www.dnr.state.mn.us/lakefind/

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White Bear Lake lake-groundwater interaction
http://files.dnr.state.mn.us/publications/waters/wbl_98.pdf

Lake Level Fluctuation Tables
http://files.dnr.state.mn.us/waters/surfacewater_section/lake_level_fluctuations0708.xls

Chapter 3 Ground Water links

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Obwell Data
http://climate.umn.edu/ground_water_level

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County Geologic Atlas and Regional Hydrogeologic Assessment Status Map
http://www.dnr.state.mn.us/waters/groundwater_section/mapping/status.html

MGS Current Publications

http://www.geo.umn.edu/mgs/county_atlas/countyatlas.htm

DNR Information Center

Twin Cities: (651) 296-6157
Minnesota Toll Free: 1-888-646-6367 (or 888-MINNDNR)
Telecommunication Device for the Deaf: (TDD): (651) 296-5484
TDD Toll Free: 1-800-657-3929

DNR Waters
500 Lafayette Road
St. Paul, MN 55155-4032
(651) 259-5700

Web Address: mndnr.gov/waters