WATER AVAILABILITY ASSESSMENT REPORT

Appendix to the EQB Water Policy Report: Beyond the Status Quo

Minnesota Department of Natural Resources
Ecological and Water Resources Division

September 15, 2015

Water Availability Assessment Report

Appendix to the EQB Water Policy Report: Beyond the Status Quo

Copies of this report may be obtained at:

Minnesota Department of Natural Resources
500 Lafayette Road
St. Paul, MN 55155-4025

(651) 296-6157
1-888-MINNDNR
(888) 646-6367

www.dnr.state.mn.us

Email: info.dnr@state.mn.us

Estimated cost of preparing this report
(as required by Minn. Stat. 3.197): $6,480

TABLE OF CONTENTS

FIGURES

TABLES

Introduction

Water sustains Minnesota's economy and environment, and is still perceived as widely abundant across the state. However, there is an increasing awareness that water is not unlimited. In many instances, poor water quality limits water access. Conflicts between businesses, municipal supplies, water-based recreation and agricultural uses are increasing, and valued ecosystems are threatened, especially during periods of drought.

In order to address the long-term sustainability and availability of our water and natural resources, the Department of Natural Resources (DNR) must engage in long-term thinking and planning efforts. Minnesota Statutes, 103G.265 requires the DNR to provide for an assurance of water supply: "The commissioner shall develop and manage water resources to assure an adequate supply to meet long-range seasonal requirements for domestic, municipal, industrial, agricultural, fish and wildlife, recreational, power, navigation, and quality control purposes from waters of the state." Under MS 103G.287, issuance of permits to appropriate groundwater must meet a sustainability standard: the use must be "sustainable to meet the needs of future generations and… will not harm ecosystems, degrade water, or reduce water levels beyond the reach of public water supply and private domestic wells."

The availability of water to meet the state's needs is determined by three basic factors; climate and global weather patterns, human use of water, and human changes to water quality. In Minnesota, we have limited ability to affect the first factor, but great ability to change our use of water, and the land uses and practices that can affect water quality.

This report provides a review of the current state of our water resources relative to the quantities and trends of our water supplies. It builds upon the 2010 Water Availability Assessment Report produced by the DNR, updating much of the information in that report while adding new information about the DNR's ongoing water management efforts.

The legislative directive for this report is that, at five-year intervals, "The Department of Natural Resources shall provide an assessment and analysis of the quantity of surface and ground water in the state and the availability of water to meet the state's needs."[1] This report is an appendix to the Environmental Quality Board's 2015 Water Policy Report, "Beyond the Status Quo."

Water Management at the DNR: Accomplishments and Adaptation

The DNR plays an important role in supporting sustainable groundwater use through its permit programs, information collection and analysis activities, law enforcement responsibilities, education, and technical assistance opportunities. The DNR and other agencies in the executive branch have adopted a three-pronged approach to sustainable water resource management. This approach involves mapping, monitoring and managing water resources adaptively over time.

In the five years since the previous Water Availability Assessment Report, the DNR's approach to water management has continued to evolve. Increased financial support from the legislature for groundwater mapping and monitoring has accelerated mapping through the county geologic atlases and network of observation wells, improvements to the County Well Index program at the Minnesota Department of Health, and other hydrogeological studies.

The following are among the DNR's new and ongoing water management initiatives.

Mapping and Research

The DNR is developing better maps to identify areas where groundwater may not be able to sustain large volume users or high densities of users. Since 1995 the DNR, in collaboration with the Minnesota Geological Survey (MGS) has produced county geologic atlases. The MGS produces Part A, Geology, while the DNR produces Part B, Hydrogeology. Atlases are complete for most metro-area, southeast and central counties, and in process for over 15 other counties, mainly in central Minnesota. These maps, which are available to the public, show our current understanding of the aquifer systems, along with sensitivity maps that show the interaction of groundwater and surface water. This information will ultimately be combined into a single statewide GIS layer that includes near-surface pollution sensitivity, pollution sensitivity for the top of bedrock surface (selected counties in central and southeastern Minnesota only), water table elevation, and water table depth. These compilations should increase the usefulness of these maps for projects and users that span county boundaries for regional or watershed-based evaluations.

Monitoring

The DNR maintains a groundwater level monitoring network across the state, with approximately 1,000 observation wells. Data collected from the network is used to assess groundwater resources, determine long-term trends in water levels, interpret impacts of pumping and climate, plan for water conservation, and evaluate water conflicts. Traditionally, the DNR has measured water levels monthly, in cooperation with soil and water conservation districts or other local units of government. This system is being converted to "continuous" water level monitoring, using in-well recording devices which record readings every 15 minutes.

Water level monitoring is also conducted at approximately 400 locations associated with groundwater appropriation permits. Information from these wells helps determine if pumping of groundwater is causing adverse impacts to surface water features or other water users.

Groundwater Strategic Plan

During the 2013 legislative session, risks to the state's water future were highlighted and discussed. The legislature responded by appropriating 7 million dollars in new general fund to support enhanced water management programs, and an additional 3 million dollars for statewide mapping and establishment of groundwater management areas.

Concurrent with these discussions, the Division of Ecological and Water Resources initiated a strategic planning project to chart a course for addressing issues of water allocation, water use conflict, and contamination. The Draft Groundwater Strategic Plan was published in September 2013. The

DNR's Groundwater Management Objectives

- All aquifers are within sustainability thresholds for water levels
- All appropriators of groundwater have the required permits
- All permitted groundwater users employ water conservation practices
- All aquifers are without water use conflicts and well interferences
- Permitted groundwater appropriations do not adversely impact trout streams, calcareous fens, other groundwater-dependent surface water features, or other groundwater-dependent biological communities
- Permitted groundwater appropriations do not adversely impact water quality

Groundwater Management Strategies

- Heighten the priority given to groundwater management
- Improve information available for groundwater management decisions
- Improve the management of groundwater appropriation permits
- Improve compliance with groundwater appropriation regulations
- Improve communication for users, stakeholders, partners, and the general public about the importance of groundwater resources and the challenges facing groundwater management
- Effectively address groundwater management challenges in areas of high groundwater use and/or limited groundwater supply
- Promote the wise use of groundwater and the implementation of water conservation practices

draft plan outlines six management objectives for the 2013-2018 period, and seven primary management strategies (see sidebars). The plan will be finalized in 2016 following completion of the three Groundwater Management Area plans discussed below.

Groundwater Management Area Planning

The Minnesota legislature created groundwater management areas as a tool for the DNR to address difficult groundwater-related resource challenges.[2] Certain areas of Minnesota are vulnerable to groundwater shortages or contamination, based on high levels of pumping, highly permeable soils, or population growth combined with over-reliance on a single water source. About twenty such areas of intensive use were identified around the state, and three pilot Groundwater Management Areas (GWMAs) were initiated for more intensive planning efforts: the North & East Metro, Bonanza Valley, and Straight River GWMAs. Within each pilot area, a planning effort brought water users and other stakeholders together to identify their common interests in the groundwater resource. The plans for each area set goals for sustainable water use and include a set of actions the DNR will take over the next five years. Once the plans are approved, the DNR will manage all appropriations within each area to meet these sustainability goals.

MNDNR Permitting and Reporting System (MPARS)

Over the last four years, the DNR developed the well-received MNDNR Permitting and Reporting System (MPARS). This system allows the public to apply for three DNR permit types (water appropriation, public waters work, and dam safety) online, as well as request changes to existing permits, pay permit related fees, report their water use, and communicate with appropriate DNR staff. The system is used by over 8,000 customers, DNR water regulations staff, and interagency partners statewide. Work is currently underway to expand the system to include additional DNR permit types. MPARS is saving the department an estimated $255,000 annually. It automates much of the repetitive work that comes with water regulatory programs, freeing DNR employees to devote more time to core conservation work, and is a significant step toward our goal of water sustainability.

Well Construction Preliminary Assessments

Prior to 2013, well construction (regulated by the Department of Health) and water appropriation permitting (regulated by the Department of Natural Resources) were disconnected. Water appropriation permits could not be applied for until <u>after</u> a well was drilled, resulting in situations where the expected volume of water could not be permitted due to hydrologic conditions or potential ecosystem impacts. Legislation enacted in 2013 requires preliminary well construction approval for proposed wells that would need a groundwater appropriation permit.[3] Through this process the DNR reviews existing information about resources and conditions near the proposed well site, including specific natural resources such as trout streams and wetlands, wellhead protection and other source water protection areas, known groundwater contamination areas, and other potential factors that could limit water availability. If the DNR identifies water resource concerns, the potential well owner is advised that if they apply for an appropriation permit they can expect additional monitoring, aquifer tests, or limitations on the amount of water allowed. They can then make an informed decision about whether or not to drill the well.

Report to Legislature, 2014

In 2013 the Legislature directed the DNR to develop recommendations on additional tools needed to fully implement the groundwater sustainability requirements in Minnesota Statutes, section 103G.287, subdivisions 3 (protection of groundwater supplies) and 5 (sustainability standard). The report recommended several statutory changes, a number of which were enacted during the 2014 and 2015 legislative sessions:

- Giving the DNR authority to use administrative penalty orders as an option to address appropriation of water without a permit;
- Directing the DNR to waive fees for installations and projects that use stormwater runoff or divert water to treat a water quality issue;
- Prohibiting issuance of appropriation permits for new small open loop geothermal groundwater systems (those using between 1 million and 5 million gallons per year).

Water Supply Planning and Conservation

One of the ways that the DNR is seeking to elevate the importance of water conservation is through local Water Supply Plans. Every ten years, all public water suppliers in Minnesota that serve more than 1,000 people must have a water supply plan approved by the DNR. This requirement, in place since the 1990s, is designed to encourage communities to deal proactively with providing sustainable drinking water for citizens, businesses, and industry.[4] The third generation of Water Supply Plans will be due between 2016 and 2018; the DNR will notify the 360+ public water suppliers as to when their specific city water plan is due. All communities in the seven-county metropolitan area, even those of fewer than 1,000 people, must also fill out an additional section relating to the Metropolitan Council's Master Water Supply Plan.

To encourage regional cooperation, the DNR will host a series of meetings throughout the state to bring water suppliers together. These meetings will outline the importance of completing water supply plans, highlight water conservation projects, and address local water supply issues.

In the plans, communities are asked to describe their existing and planned water supply, and to develop an emergency plan and a conservation plan. The plan updates will emphasize demand reduction and developing rate structures that encourage conservation. Communities will identify and meet with their large volume water users to discuss possible water conservation actions. Water suppliers will also summarize maintenance issues/problems with their water systems and identify ways to resolve inefficient water use.

The updated Water Supply Plans will also place a stronger emphasis on monitoring and tracking water use. Suppliers are asked to review their conservation progress from the previous ten year water supply plan and identify gaps and areas for improvement. There is a stronger emphasis on using smart meters and technology to monitor water use.

The new water supply plan template requires every water supplier to identify strategies they will use to achieve eight conservation objectives. Cities have many options as to how to achieve these objectives, which include:

1) **Reduce unaccounted (non-revenue) water loss to less than 10%**
2) **Achieve less than 75 residential gallons per capita daily demand (GPCD)**
3) **Achieve at least a 1.5% per year reduction in industrial, commercial, and agricultural GPCD over the next 10 years, or a 15% reduction in ten years**
4) **Achieve a decreasing trend in total per capita demand**
5) **Reduce summer water use: reduce peak day demand so that the ratio of the average maximum day to the average day is less than 2.6**

6) IMPLEMENT A CONSERVATION WATER RATE (PRICING) STRUCTURE AND/OR A UNIFORM RATE STRUCTURE WITH A WATER CONSERVATION PROGRAM
7) ADDITIONAL STRATEGIES TO REDUCE WATER USE AND SUPPORT WELLHEAD PROTECTION PLANNING
8) INDICATORS FOR MEASURING PROGRESS OVER THE NEXT TEN YEARS

Throughout the plan template, there is an emphasis on water conservation education and outreach. The DNR, PCA and other agencies and organizations are partnering to provide additional water conservation and efficient use messaging that can be used by local water suppliers. The DNR also provides training on groundwater hydrogeology to soil and water conservation district staff, and other professionals to assist with management of groundwater use throughout the state. The DNR is also working with the Department of Health to conserve our source waters by integrating water conservation into wellhead protection plans.

Although current plumbing codes require variances for water reuse projects, this is likely to change in the next ten years. Communities are encouraged to think creatively about how water can be reused safely in the future through the capture of rainwater, stormwater, or through wastewater reclamation. For example, using recycled water for irrigation reduces demand on aquifers.

DATA MANAGEMENT

The DNR relies on high quality water data to make decisions about how groundwater usage might affect long-term sustainability of groundwater systems and whether the usage might negatively impact ecological systems such as streams, lakes, or wetlands.

To maximize the value and use of all data available, DNR is working with other state agencies to share data and data systems. Two recent examples of interagency cooperation are the Aquifer Test Database and the EQuIS data system.

AQUIFER TEST DATABASE

Aquifer tests are conducted to determine key aquifer characteristics that are used to calculate the effects of groundwater pumping. At the DNR, aquifer tests provide a basis for understanding the radius of influence of pumping or how pumping might affect surface water features. The Minnesota Department of Health (MDH) uses aquifer tests to establish municipal wellhead protection areas.

There is currently no system available to store or share aquifer test data or information on an interagency or enterprise system. The DNR is teaming with MDH, MNIT, MPCA, MDA, and the Metropolitan Council to establish a multi-agency Aquifer Test Database that will provide a permanent "safe home" for the data. The system will provide a web-based portal to enter new data and access the database.

EQUIS

EQuIS is a multi-agency (enterprise) discrete-series database that serves as a repository for groundwater and surface water chemistry and non-continuous groundwater elevation data. EQuIS provides a "safe home" for storage of these data and also provides some mapping and report production capabilities. The system also provides opportunities for sharing of data and information between agencies. In FY2015, the DNR gained licensure of EQuIS for storage of groundwater chemistry collected by the DNR for the County Geologic Atlas Program. The system is also used by water programs at the MPCA and MDA. Further expansion of the use of EQuIS by other agencies and programs is expected in the future.

MINNESOTA'S WATER BUDGET AND HUMAN IMPACTS, 2005 - 2014

The following charts, maps, diagrams and narratives provide information to evaluate the trends of our climate, surface waters, groundwater systems and water use over the last ten years and in relation to long-term historic trends.

Water budget elements are the components of the hydrologic cycle. A water budget is an estimation of the water resources available to "spend" or "save" and must take into account all available ground and surface water. This includes groundwater (flow, storage), climate (precipitation and evaporation), and surface water (runoff, streamflow, and storage). Precipitation either soaks into the ground or runs off into lakes, rivers, and wetlands. Much of the water that soaks into the ground is stored in soil to be taken up by plants. Evaporation from plants and from the land and water surfaces returns moisture to the atmosphere, which perpetuates the cycle. Each of these components is influenced to some degree by human actions at or near the land surface. Components such as flow, storage, and groundwater use can be controlled by human actions; however, natural variability of other components such as drought, flood, and geographic distribution of aquifers cannot be controlled, and these can cause concern for a variety of human endeavors.

CLIMATE

Climate is a fundamental driver of Minnesota's water supply. Human activity aside, surface and groundwater quantity is governed by the balance between inputs from precipitation, and losses due to runoff and evapotranspiration. Because Minnesota is at the headwaters of four continental watersheds, relatively little water flows into the state from beyond its borders. Therefore, surface and groundwater quantity in Minnesota is primarily driven by the region's climate, dictated by the balance between input from precipitation and losses due to evapotranspiration. Knowledge of Minnesota's climate patterns provides important insight into water availability issues.

Due to its position near the center of the North American continent, Minnesota is subject to a variety of air masses that determine its climate. Cold, dry continental polar air dominates the winter season, occasionally replaced by somewhat milder maritime polar air. During the summer, hot and dry continental tropical air masses from the desert southwest share predominance with warm and moist maritime tropical air that originates over the Gulf of Mexico. The spring and fall seasons are transition periods composed of alternate intrusions of air from various sources. The diverse nature of the air masses impacting Minnesota's climate leads to a high degree of variability across distance and time.

As used in this report, the term "normal" refers to a historical benchmark used by climatologists and reflects a 30-year average that is updated once per decade. It is different from a simple average, which can be calculated over nearly any interval.

Climate variability across distance (spatial variability)

The primary source of moisture for precipitation in Minnesota is the tropical maritime air that moves into the state from the south and southeast. The spatial variation of normal annual precipitation across Minnesota is determined by proximity to these moist air masses moving northward out of the Gulf of Mexico. Therefore, southeastern Minnesota typically receives more precipitation than northwestern Minnesota (Figure 1).

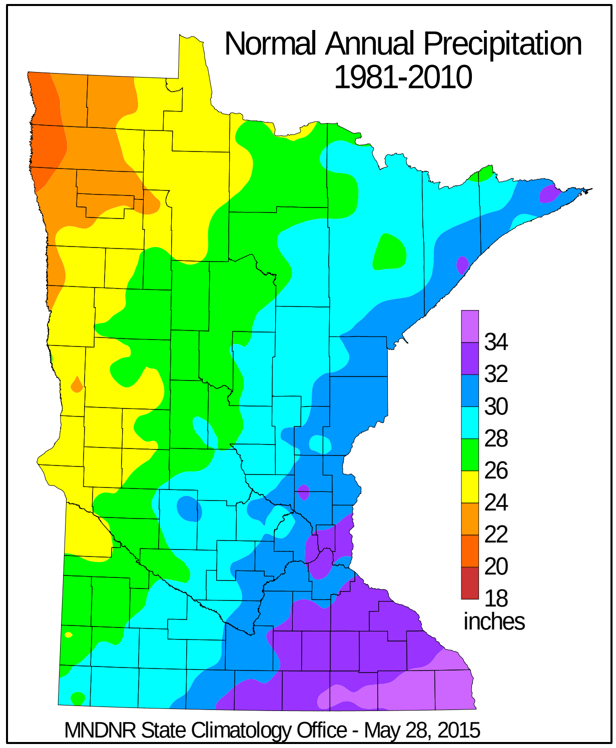


FIGURE 1. NORMAL ANNUAL PRECIPITATION, 1981 – 2010

The presence of moist vs. dry air masses also helps to determine the atmosphere's ability to take up water vapor evaporating from soil and open-water surfaces, and evaporating from leaf surfaces (transpiration). The combination of evaporation plus transpiration is called "evapotranspiration." Western Minnesota is more frequently under the influence of drier, warmer air masses, and therefore has higher evapotranspiration rates than the eastern half of the state.

Minnesota is located on the boundary between the semi-humid climate regime of the eastern U.S., and the semi-arid regime to the west. Semi-humid climates exist in areas where average annual precipitation somewhat exceeds average annual potential evapotranspiration, leading to a net surplus of water. In semi-arid areas, potential evapotranspiration somewhat outpaces precipitation on average, creating a water deficit landscape. In Minnesota today, the boundary between these climate regimes cuts the state roughly into east-west halves (Figure 2).

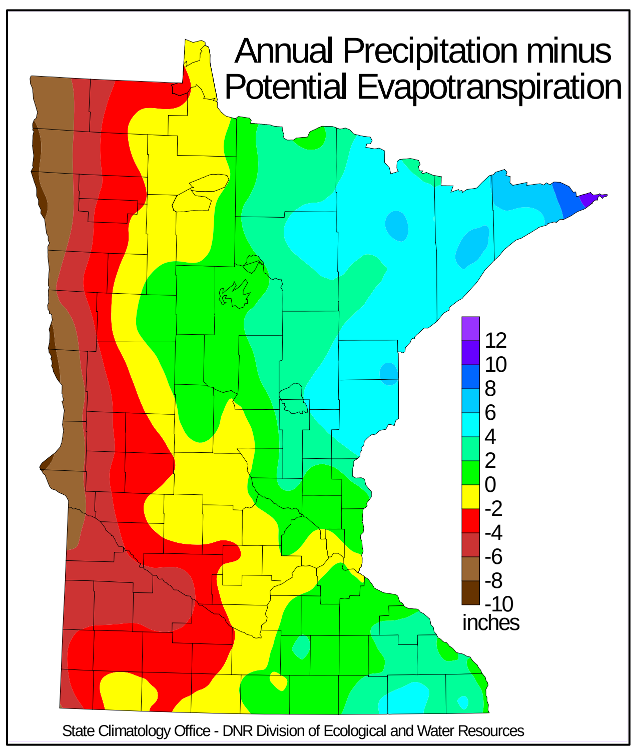


FIGURE 2. ANNUAL PRECIPITATION MINUS POTENTIAL EVAPOTRANSPIRATION, 1961 – 1990

Given the nature of summertime thunderstorms in Minnesota, large variations in rainfall amounts are often observed across short distances. It is common for an individual thunderstorm cell, or a cluster of thunderstorm cells, to drop heavy streaks of rain in one area, leaving nearby locations with substantially lower precipitation totals (Figure 3). Seasonal precipitation totals at a location reflect the number and intensity of rainfall streaks impacting that spot on the landscape. These randomly overlapping streaks can lead to large differences in weekly, monthly, and seasonal precipitation totals within a state, region, or county.

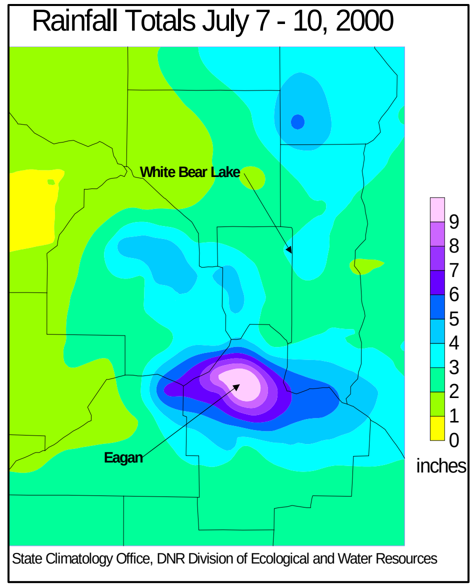


FIGURE 3. EXAMPLE OF SPATIAL VARIABILITY OF RAINFALL AMOUNTS

SEASONAL AND INTER-ANNUAL VARIABILITY

Seasonal variability occurs as different air masses dominate the weather at different times of the year. Nearly two thirds of Minnesota's annual precipitation falls during the growing season months of May through September, a period during which Gulf of Mexico moisture is often available. Dry spells occur when this moisture source is obstructed or when atmospheric patterns divert storm systems around Minnesota. When hot, dry air prevails, increased evapotranspiration combines with deficient rainfall to create drought conditions. When Gulf moisture is abundant and numerous storms move through Minnesota, unusually heavy precipitation falls. Repeated rain events can overwhelm surface water systems, raising lake levels and forcing streams out of their banks. Singular, intense rain events can lead to flash floods.

Only eight percent of average annual precipitation falls in the winter months (December through February), when the dry polar air masses prevail. Most of Minnesota's largest wintertime precipitation events arise, however, when moisture from the Gulf of Mexico displaces the typically dry air mass in place. Heavy snowfalls resulting from these situations can increase the snow pack and extend its presence later into spring. Large-scale spring flooding can occur as a result of a combination of a deep late winter snow pack, frozen soil that prohibits infiltration, rapid snow melt due to an intrusion of warm air, and heavy early spring precipitation.

Precipitation patterns in Minnesota often change abruptly within a given year or season. Weeks of wet weather can be followed by an extended spell of dry conditions. These periods of anomalously wet or dry weather have significant impact on the landscape. Caution must be used when utilizing annual precipitation totals as the sole measure of climate behavior because annual totals mask the influence of sub-annual precipitation variations on hydrologic systems. As an example, a multi-month episode of unusually dry weather in the East Metro area occurred from early-summer 2008 through late-summer 2009. During that 14-month interval, precipitation totals fell short of the historical average by more than 13 inches (Figure 4). The cumulative impact of these precipitation shortfalls led the *U.S. Drought Monitor* authors to place this area in their *Extreme Drought* category in the late summer of 2009 (Figure 5). Precipitation was average to above-average in early 2008, and again in late 2009. Therefore, calendar year

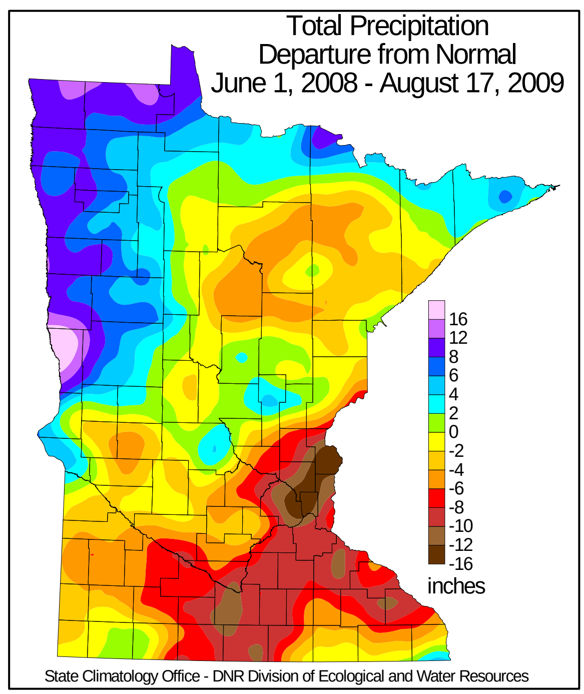


FIGURE 4: PRECIPITATION SHORTFALLS, JUNE 2008-AUGUST 2009

precipitation totals for 2008 and 2009 did not adequately represent the extent of the multi-month dry anomaly that occurred mid-year to mid-year.

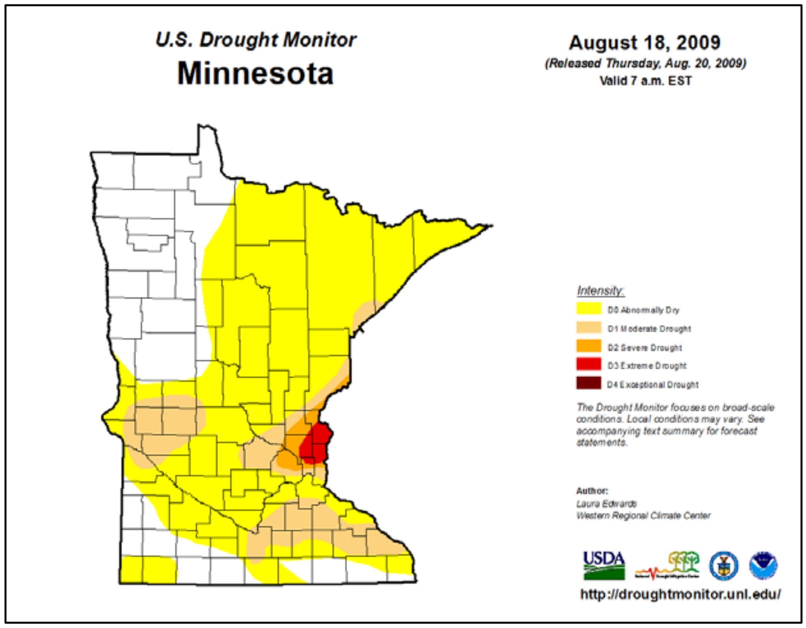


FIGURE 5: U.S. DROUGHT MONITOR—AUGUST 2009

In addition to typical seasonal variations, Minnesota's climate also exhibits substantial year-to-year or "inter-annual" variability. Wet years can follow dry years and vice versa. As an example, Minnesota's second driest year on record is 1976, which was followed by the wettest year on record in 1977. Minnesota also experiences wet and dry regimes, consisting of multiple-year runs of predominantly similar hydrological conditions. For example, a statewide drought occurred from 1987 to 1989.

Minnesota's seasonal and inter-annual climatic variations are also subject to the spatial variations described in the last section.

Given the multiple weather scenarios affecting Minnesota, wide ranges of climatic outcomes are typical. "Normal" and "average" are merely mathematical mid-points about which our climate fluctuates.

Climate Trends and Water Availability

The following key highlights represent a snapshot of the climate conditions in Minnesota, as of 2015:

1. Precipitation has increased, but with high spatial variability

Since 1895, annual precipitation in Minnesota has increased at a long-term rate of 0.25 inches per decade, though the trend has appeared to plateau during the past two decades (Figure 6). Within that plateau, however, annual precipitation has remained high relative to the full period of record. Moreover, the majority of Minnesota was wetter during the 1981-2010 normal period than during the previous period (1971-2000), indicating a continued trend towards more precipitation (Figure 7), with expected amounts of Inter-annual variation. The past ten years (2005-2014) produced two years that on the drier end of the historical distribution (2006, 2011) and one year that was the third wettest on record (2010).

The precipitation increase is found in all seasons except autumn, which has shown a slight decline in the past decade. Spring and summer are becoming wetter at a faster rate than winter.

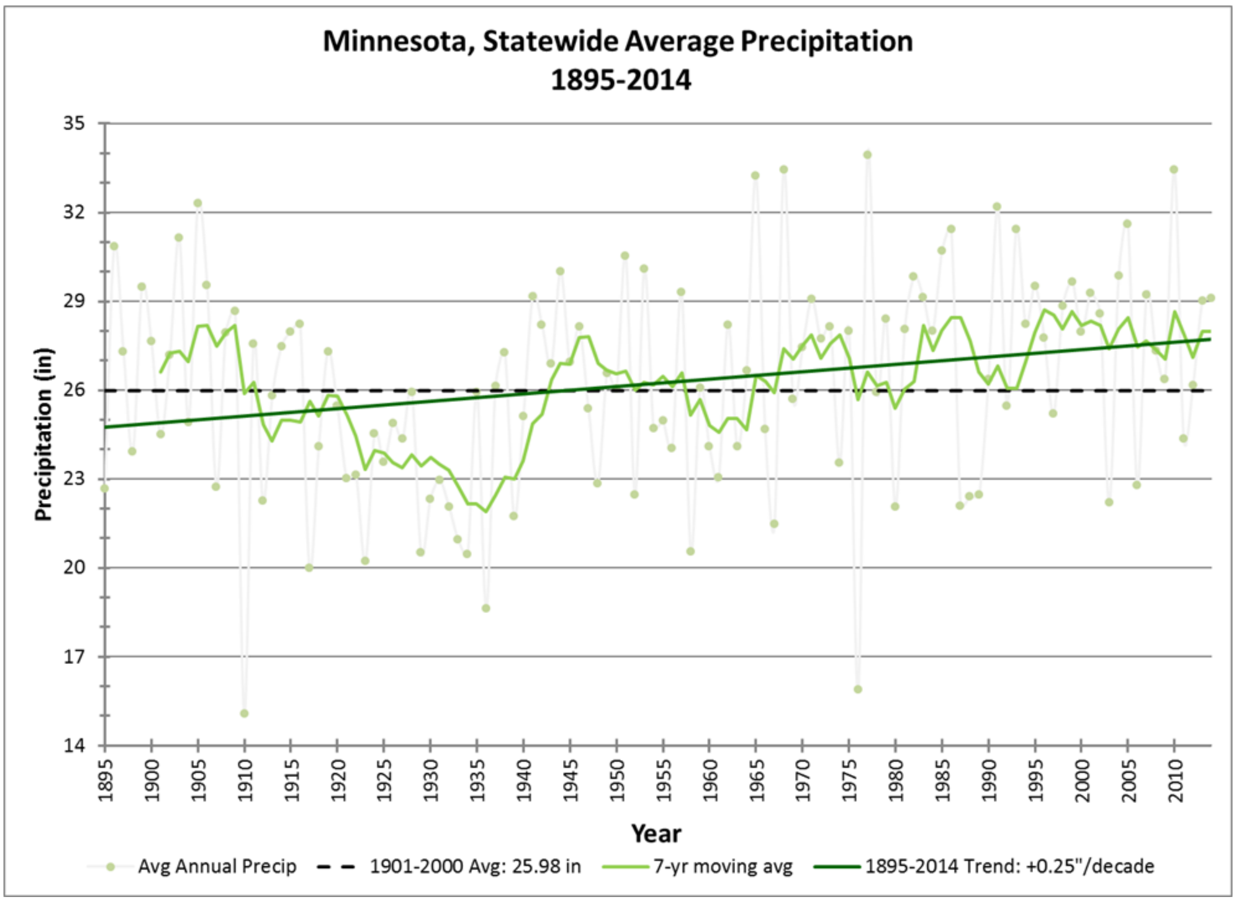


FIGURE 6: STATEWIDE AVERAGE ANNUAL PRECIPITATION, 1895-2014. THE DASHED LINE SHOWS THE LONG-TERM AVERAGE, FROM 1901-2000. THE 1895-2014 TREND IS BASED ON LINEAR STATISTICAL TECHNIQUES AND DOES NOT IMPLY AN EXACT DECADE-BY-DECADE TEMPERATURE CHANGE. SOURCE: NOAA CLIMATE AT A GLANCE HTTP://WWW.NCDC.NOAA.GOV/CAG/

Although the pattern of average annual precipitation from 2005 to 2014 appears to mimic the pattern of long-term "normal" precipitation (Figure 8; compare to Figure 1), spatial variations in rainfall received relative to normal have led to multi-year precipitation surpluses and deficits around the state. For instance, a high precipitation anomaly can be seen in west central and northwestern Minnesota (Figure 9). This anomaly dates back to 1991 and is responsible for high water level problems experienced in those areas, as well as the Devils Lake crisis in neighboring North Dakota. During the same period, relative dryness has taken hold in north central and northeastern Minnesota, also impacting water levels there.

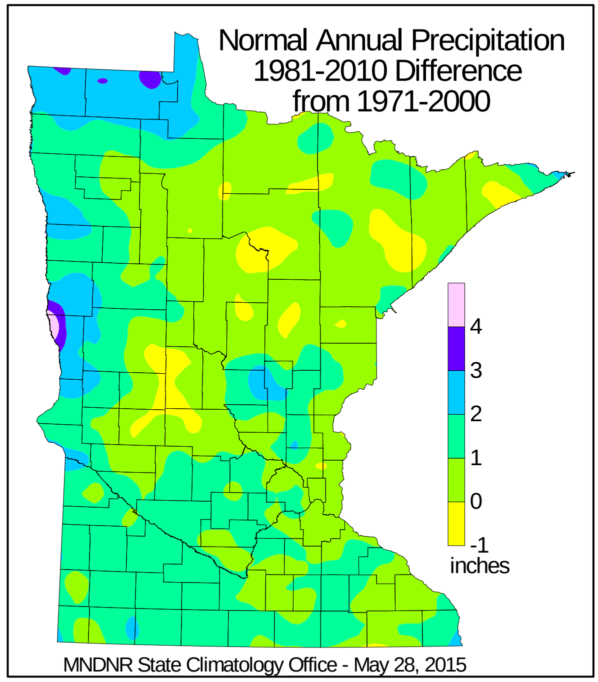


FIGURE 7: 1981-2010 NORMAL PRECIPITATION MINUS 1971 – 2000 NORMAL PRECIPITATION

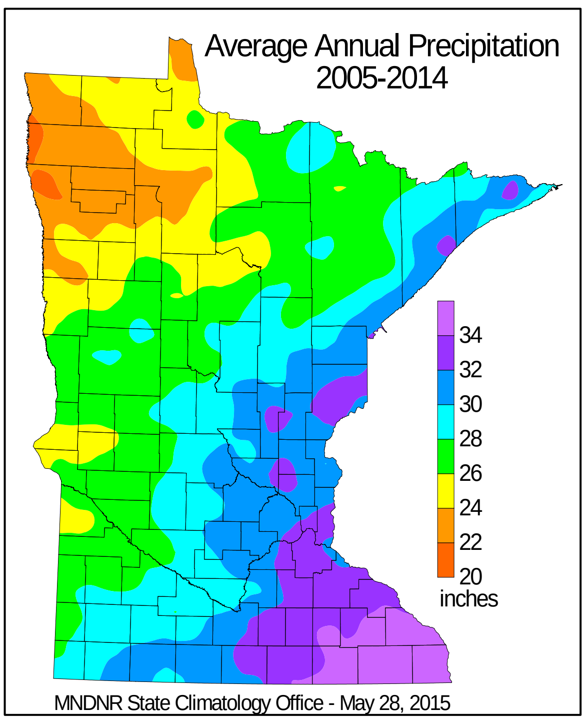


FIGURE 8: AVERAGE ANNUAL PRECIPITATION, 2005 – 2014

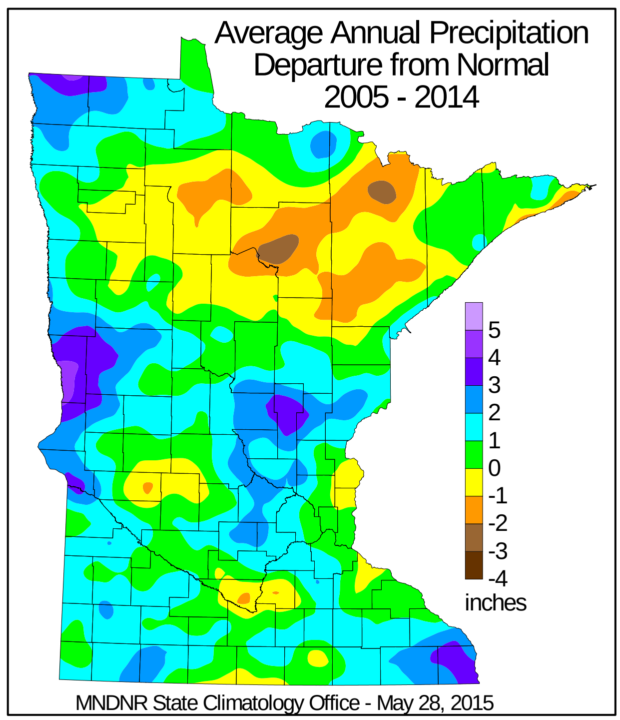


FIGURE 9. DEPARTURE OF AVERAGE ANNUAL PRECIPITATION, 2005-2014, FROM 1981-2010 NORMAL

2. No drought trends observed thus far, but late-summer drought expected in the future.

Drought has shown little or no trend in Minnesota with respect to frequency, intensity, and coverage. Since the 1930s, Minnesota has had more "wet" episodes than dry ones (Figure 10). This is consistent with recent research summarized by the National Climate Assessment, indicating no discernible trends in the frequency or intensity of drought in central North America, including Minnesota.[5]

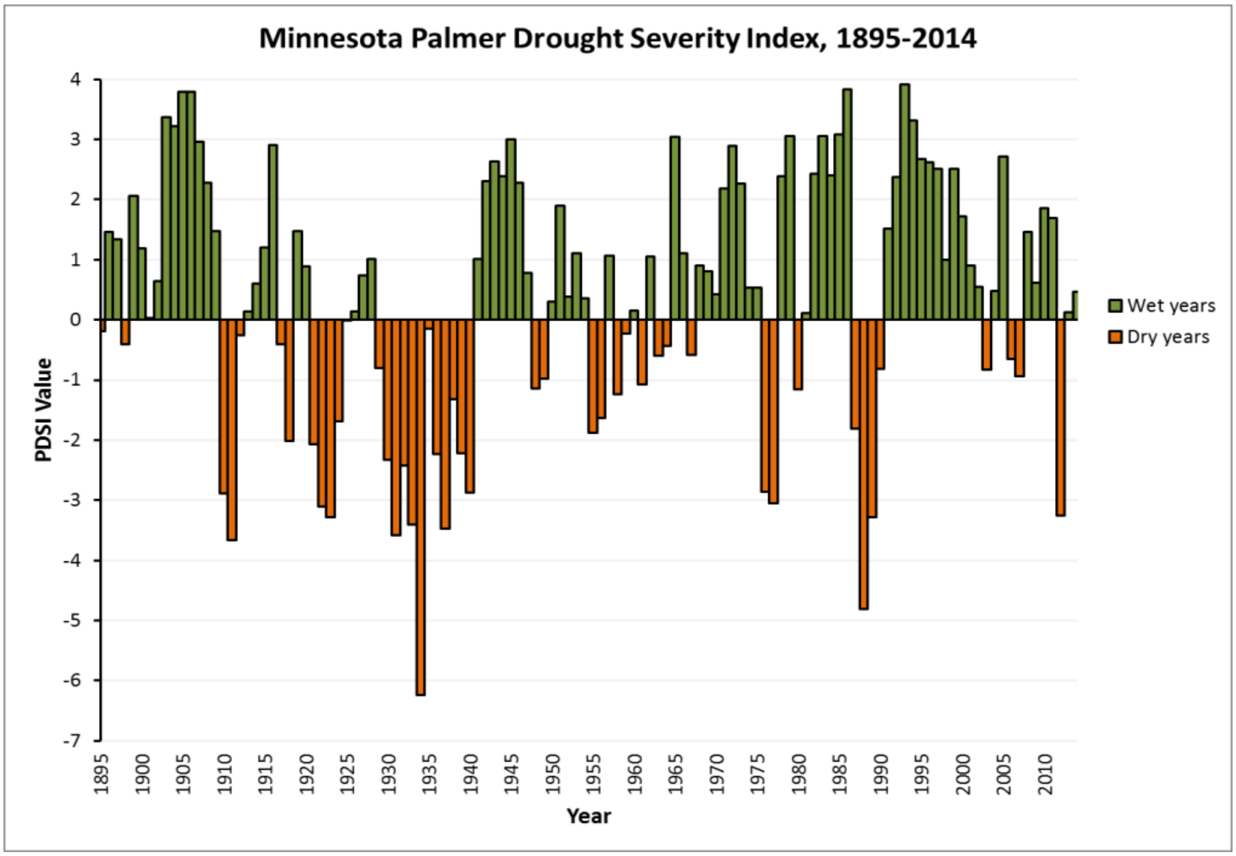


FIGURE 10: THE PDSI (PALMER DROUGHT SEVERITY INDEX) FOR MINNESOTA, 1895-2014, INDICATING ABNORMALLY LONG WET OR DRY PERIODS FROM A PURELY METEOROLOGICAL PERSPECTIVE (I.E., IT DOES NOT TAKE INTO ACCOUNT STREAMFLOW OR LAKE LEVELS). SOURCE: US DROUGHT MONITOR (USDM) HTTP://DROUGHTMONITOR.UNL.EDU MORE INFORMATION CAN BE FOUND AT THE NATIONAL DROUGHT MITIGATION CENTER HTTP://DROUGHT.UNL.EDU/PLANNING/MONITORING/COMPARISONOFINDICESINTRO/PDSI.ASPX

Despite the lack of major recent drought trends in Minnesota, projected warming is nonetheless expected to increase evapotranspiration rates, and thus will enhance the likelihood and impact of drought (see first two references in endnotes). Local research using future climate scenarios has, also suggested that seasonal wet periods will shift towards earlier parts of the growing season, and that as a result, drought will become more common during mid and late summer.[6, 7] (See Figure 8 for an example.)

3. Unprecedented rainfall events

Extreme rainfall events are already becoming larger and more common, and have been contributing to an increasing share of annual precipitation. Heavy rainfalls in excess of two inches have occurred about 7% more frequently per decade throughout Minnesota over the last 100 years, and the heaviest rainfall of the year has increased by about 6% per decade during that same period. Since 2002, the Minnesota State Climatology

Office has documented five of the state's 12 historical, "mega" rainfall events—storms that produce 6-inch totals covering at least 1,000 square miles or more. One such event in 2007, shattered the state's 24-hour rainfall record. The case study below illustrates another record-breaking event in 2014: Minnesota's wettest June, and wettest month of record.

The latest National Climate Assessment suggests that extreme rainfall events in Minnesota are expected to increase in both frequency and intensity in the years and decades ahead (see first two references).

Case Study: June 2014 Record Statewide Precipitation (Figures 11 and 12)

June 2014 was Minnesota's wettest June, and wettest month, of the modern record. The state-averaged monthly rainfall total for June 2014 in Minnesota was 8.03 inches. The total was well more than the previous record of 7.32 inches set in July 1897 and again in June 1914. The highest National Weather Service Cooperative Observer Program value found for June was 14.24 inches at Redwood Falls and Glencoe. The Minnesota state record is 15.63 inches at Delano in 2002.

The impacts of the heavy June rainfall were flooded farm fields and delayed field work, flooded basements, mudslides and flooded roads leading to transportation disruptions, and negative consequences for outdoor activities including construction and outdoor recreation. The spillway connected to a dam at Blue Mounds State Park washed out on June 15 and drained Lower Mound Lake.

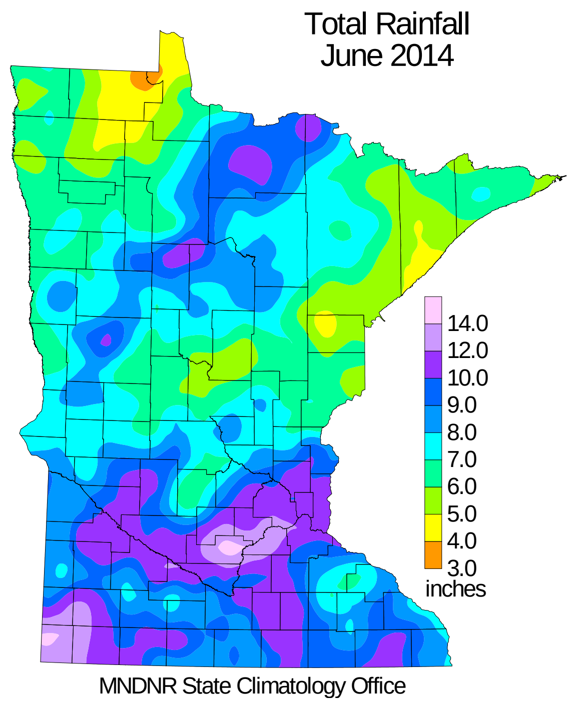


FIGURE 11. JUNE 2014 RAINFALL

In the Twin Cities metropolitan area, on June 30, Prior Lake broke its previous highest reported lake level record from July 1983 by more than six inches. The lake crested at 906.17 feet. Summer 2014 lake levels remained one to four feet above the historic record average until mid-August.

The state-averaged monthly rainfall record was established because of the broad geographic extent of heavy rainfall events. Individual station June monthly rainfall records were set from Luverne on the Iowa border, to International Falls on the Canadian border. June rainfall totals across large sections of the state ranked above the 95th percentile (one year in twenty) when compared with the historical record.

FIGURE 12. DAM AT BLUE MOUNDS STATE PARK, JUNE 2014

4. Warming is well underway in Minnesota.

Minnesota has warmed at a rate of approximately 0.22º F per decade since 1895, though the warming rate since 1970 is more than two times faster – averaging 0.5°F per decade (Figure 13). Minnesota has warmed faster than national and global averages, with the sharpest warming observed in the northern portions of the state.

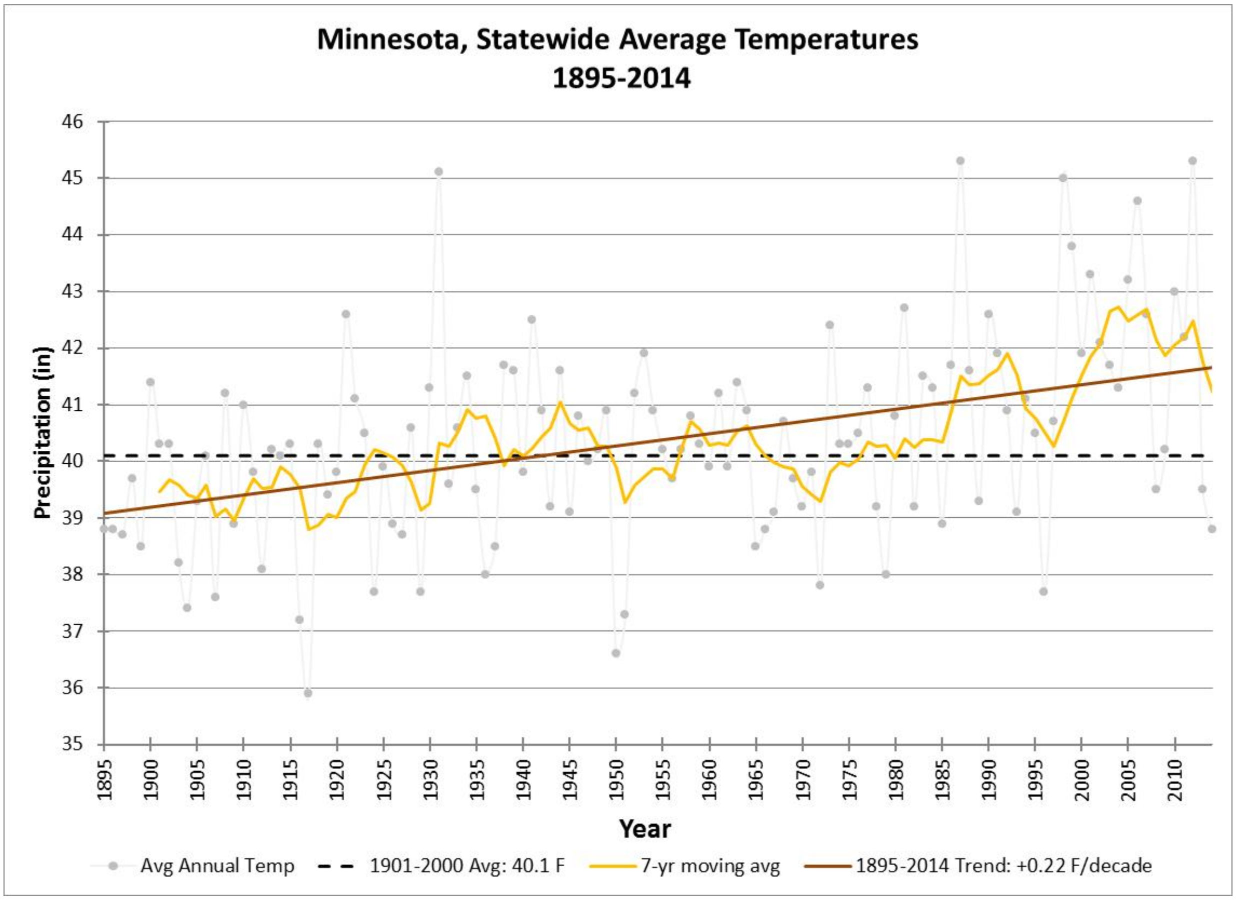


FIGURE 13: STATEWIDE AVERAGE TEMPERATURES, 1895-2014. THE DASHED LINE SHOWS THE LONG-TERM AVERAGE, FROM 1901-2000. THE 1895-2014 TREND IS BASED ON LINEAR STATISTICAL TECHNIQUES AND DOES NOT IMPLY AN EXACT DECADE-BY-DECADE TEMPERATURE CHANGE. SOURCE: NOAA CLIMATE AT A GLANCE HTTP://WWW.NCDC.NOAA.GOV/CAG/

5. Cold temperatures warming fastest in Minnesota.

Much of the temperature increase in Minnesota has been driven by a rapid warming of our coldest temperatures. Winter temperatures are warming considerably faster than summer temperatures, and daily minimum temperatures are warming faster than daily maximum temperatures (Table 1, Figure 14).

Winter warming has been most pronounced on the coldest days of the year. Thus, severe winters in particular have been less common in recent decades. Many communities throughout the state have seen a rapid decrease in the frequency of formerly common cold weather extremes. Simply put, we don't get as cold as we used to. Although it's by far most noticeable in winter, this "cold weather warming" is affecting the coolest temperatures in every season. The trend is most pronounced in Minnesota's northernmost counties.

TABLE 1: WINTER AND SUMMER STATEWIDE TEMPERATURE TRENDS SINCE 1895 AND 1970. NOTE THAT WARMING OF ALL WINTER TEMPERATURES SINCE 1895 HAS BEEN 2-5 TIMES FASTER THAN RATES OF SUMMER WARMING. SINCE 1970, WINTER WARMING RATES HAVE FURTHER ACCELERATED. RATES OF CHANGE ARE BASED ON LINEAR STATISTICAL TECHNIQUES AND DO NOT IMPLY AN EXACT DECADE-BY-DECADE TEMPERATURE CHANGE. SOURCE: NOAA CLIMATE AT A GLANCE HTTP://WWW.NCDC.NOAA.GOV/CAG/

Season	Temperature Value	Rate of change per decade since 1895	Rate of change per decade since 1970
Winter (Dec - Feb)	Seasonal Average	+ 0.36°F	+ 1.00°F
	Average Daily Min.	+0.45°F	+1.19°F
	Average Daily Max.	+0.27°F	+0.83°F
Summer (Jun - Aug)	Seasonal Average	+ 0.14°F	+ 0.10°F
	Average Daily Min.	+ 0.22°F	+ 0.33°F
	Average Daily Max.	+ 0.05°F	- 0.12°F

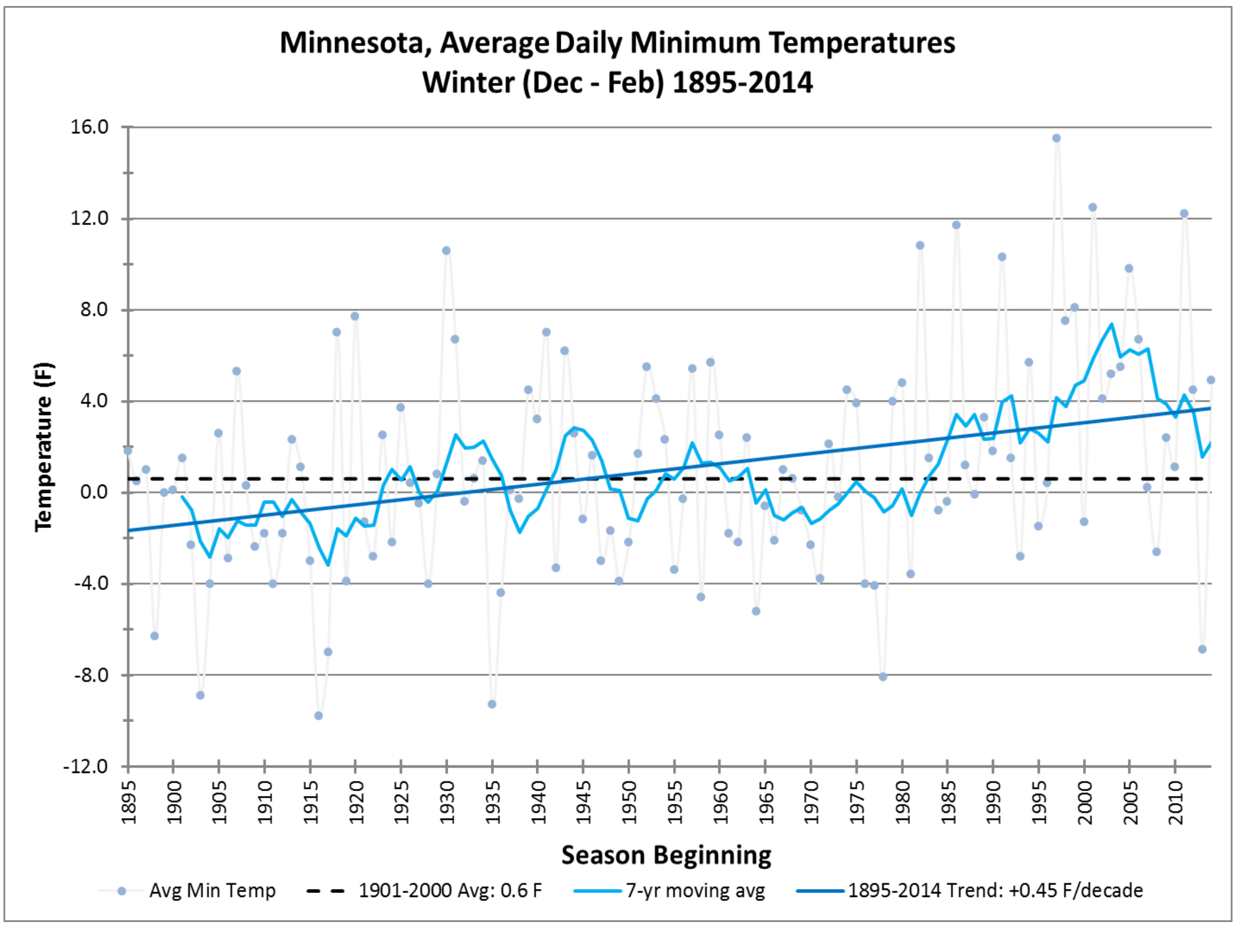


FIGURE 14: STATEWIDE AVERAGE DAILY MINIMUM WINTER TEMPERATURES, 1895-2014. THE DASHED LINE SHOWS THE LONG-TERM AVERAGE, FROM 1901-2000. THE 1895-2014 TREND IS BASED ON LINEAR STATISTICAL TECHNIQUES AND DOES NOT IMPLY AN EXACT DECADE-BY-DECADE TEMPERATURE CHANGE. SOURCE: NOAA CLIMATE AT A GLANCE HTTP://WWW.NCDC.NOAA.GOV/CAG/

6. Mixed signals for heat waves.

Minnesota's hottest summer days have not yet shown any significant warming trends, and extreme high temperature episodes have not yet intensified or become more frequent. Of all temperature categories, the June through August maximum temperatures have had the slowest long-term warming rate (0.05º F per decade; Figure 15). Since 1970, these temperatures have actually exhibited a slight downward trend.

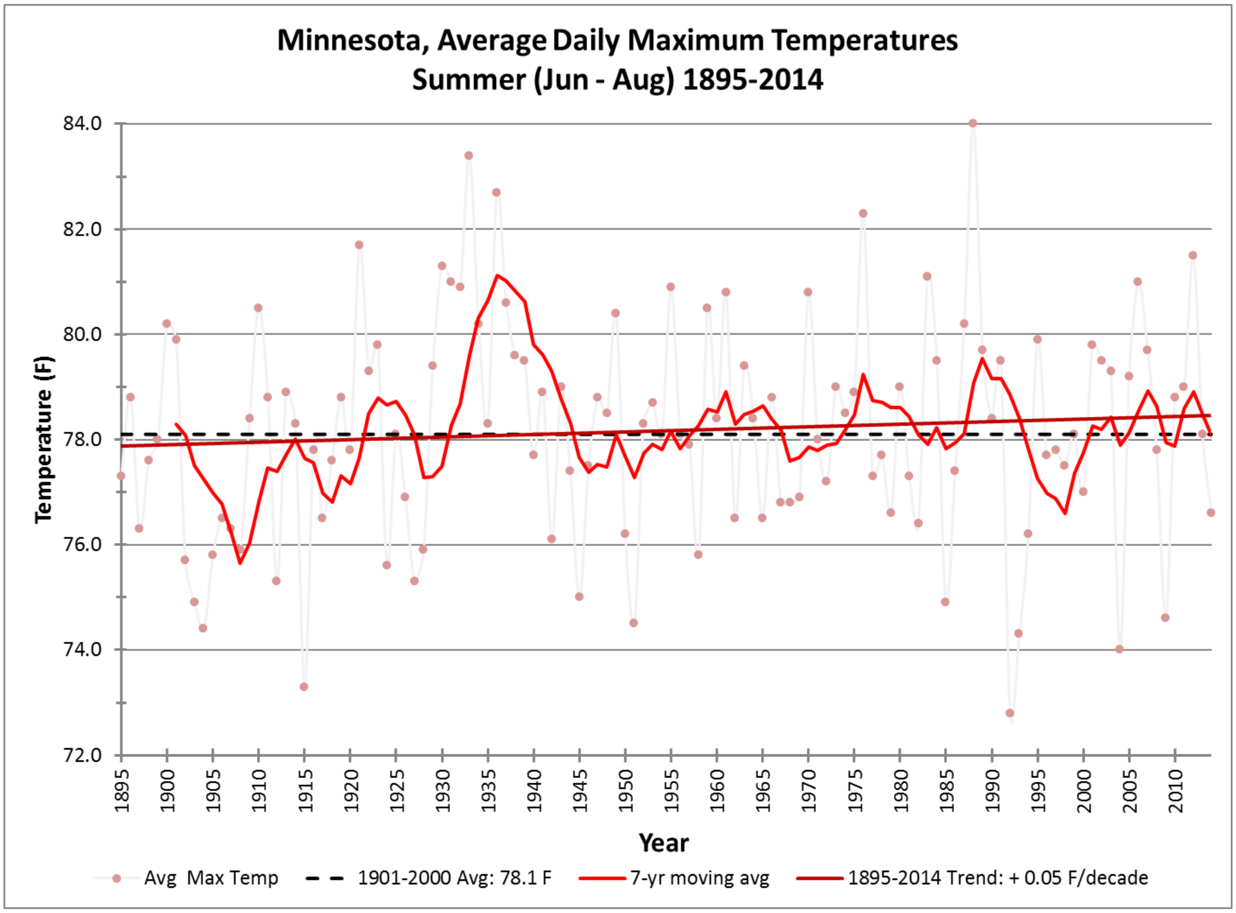


FIGURE 15: STATEWIDE AVERAGE DAILY MAXIMUM SUMMER TEMPERATURES, 1895-2014. THE DASHED LINE SHOWS THE LONG-TERM AVERAGE, FROM 1901-2000. THE 1895-2014 TREND IS BASED ON LINEAR STATISTICAL TECHNIQUES AND DOES NOT IMPLY AN EXACT DECADE-BY-DECADE TEMPERATURE CHANGE. SOURCE: NOAA CLIMATE AT A GLANCE HTTP://WWW.NCDC.NOAA.GOV/CAG/

Caution must be used when interpreting these findings. Despite no recent upward trends in summertime high temperatures, some data indicate that Minnesota has witnessed a noted increase in the number of hours with high dew point temperatures and the number of hours exceeding important heat index thresholds.

The latest scientific assessment of climate change for the Midwest indicates that in coming years and decades, the hottest temperatures should continue to warm at a slower pace than the coldest temperatures.[8] Nevertheless, Minnesota is expected to face a greater number of heat stress events, as atmospheric moisture continues to increase and as cool summer conditions become less common.

7. Other common weather hazards

Tornadoes, severe thunderstorms, ice storms, and blizzards have not been tracked as consistently over time as other weather variables, so it is unclear how they have been changing in Minnesota. It is clear that Minnesota will continue to experience all of these weather hazards, but research is inconclusive about changes in their intensity and frequency as the climate continues to warm (see first two references).

SURFACE WATER: STREAM FLOW

For the ten-year period of water year 2005 through water year 2014, watersheds across Minnesota rank in the normal and above normal flow category. This is similar to the previous ten-year period of water year 2000 through water year 2009, the major difference being a shift to a wetter period, with more watersheds in the above-normal versus normal flow rank. The percentage of watersheds in the above normal ranking increased from 54% to 72%.

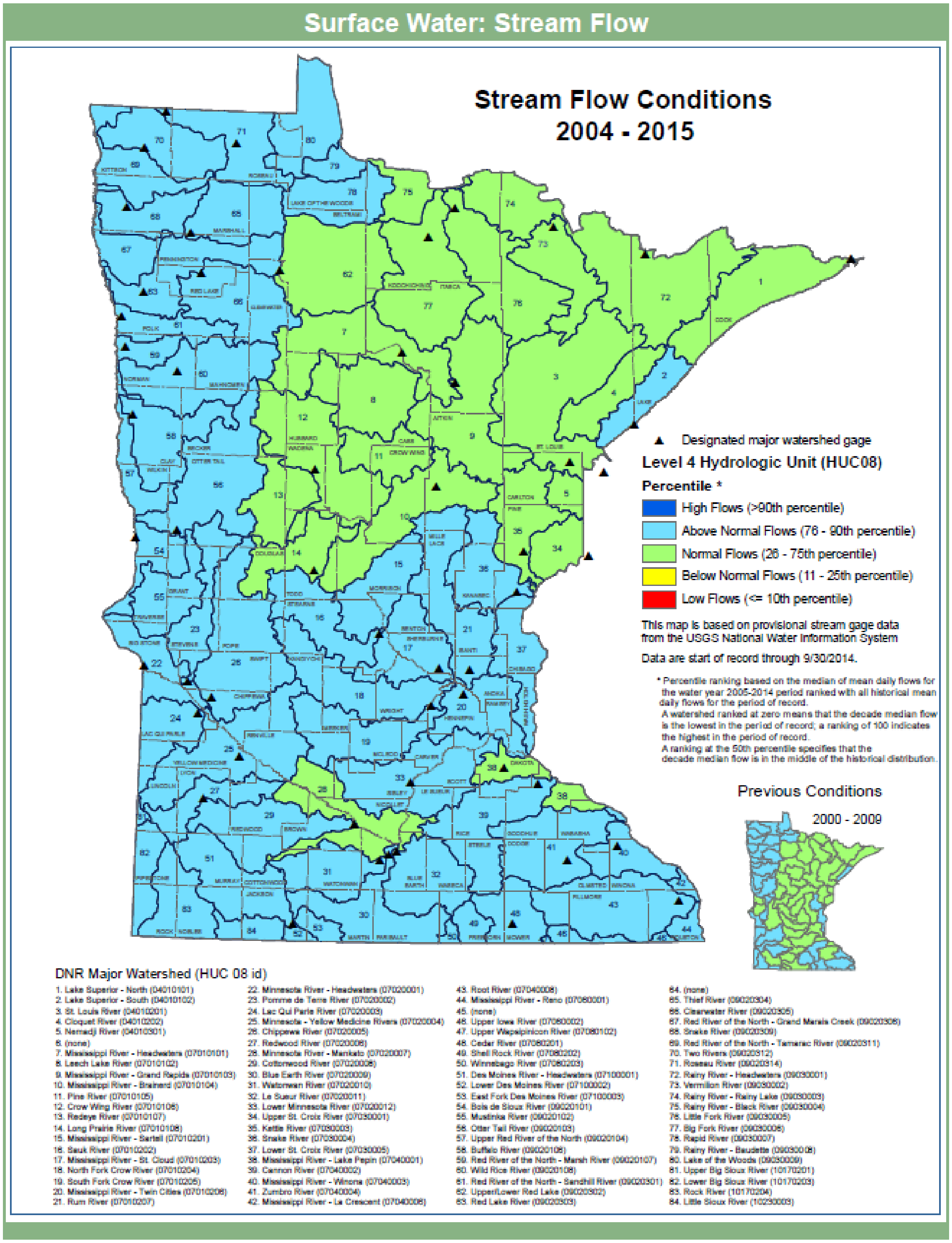


Figure 16. Stream Flow Conditions. 2004 – 2015

Watershed percentile ranking is determined by computing the average of mean daily flows at watershed indicator gages from the ten-year period of water year 2005 through water year 2014 and ranking that value against mean daily flows for complete years through each gage's period of record.

Three gages on major rivers with long-term records were selected to compare average mean daily flow from the ten-year period 2005-2014 to the average mean daily flow for the period of record through water year 2014. The mean annual flow for these locations masks seasonal variations in flow during the past decade where severe drought and major flooding was observed in the same year.

All three gages show higher than average flows for the ten-year period. The Mississippi River at St. Paul and the Minnesota River at Mankato both show a similar pattern over the last ten years, with wet years in 2010 and 2011 pulling the ten-year average above the long term mean. The St. Paul gage also reported a significantly wet year in 2014, driving its ten-year mean even higher. Each gage also had two years with mean annual flows less than the period of record mean. These drier years occurred in 2007 and 2009 for St. Paul and in 2009 and 2012 for Mankato.

The Red River of the North at Fargo, however, showed a much wetter trend in the last decade. The gage recorded three consecutive years well above the long term mean from 2009 to 2011. The mean annual flows for the remainder of the ten-year period were also above the long term mean, resulting in a ten-year average flow that was 174% above the long term mean.

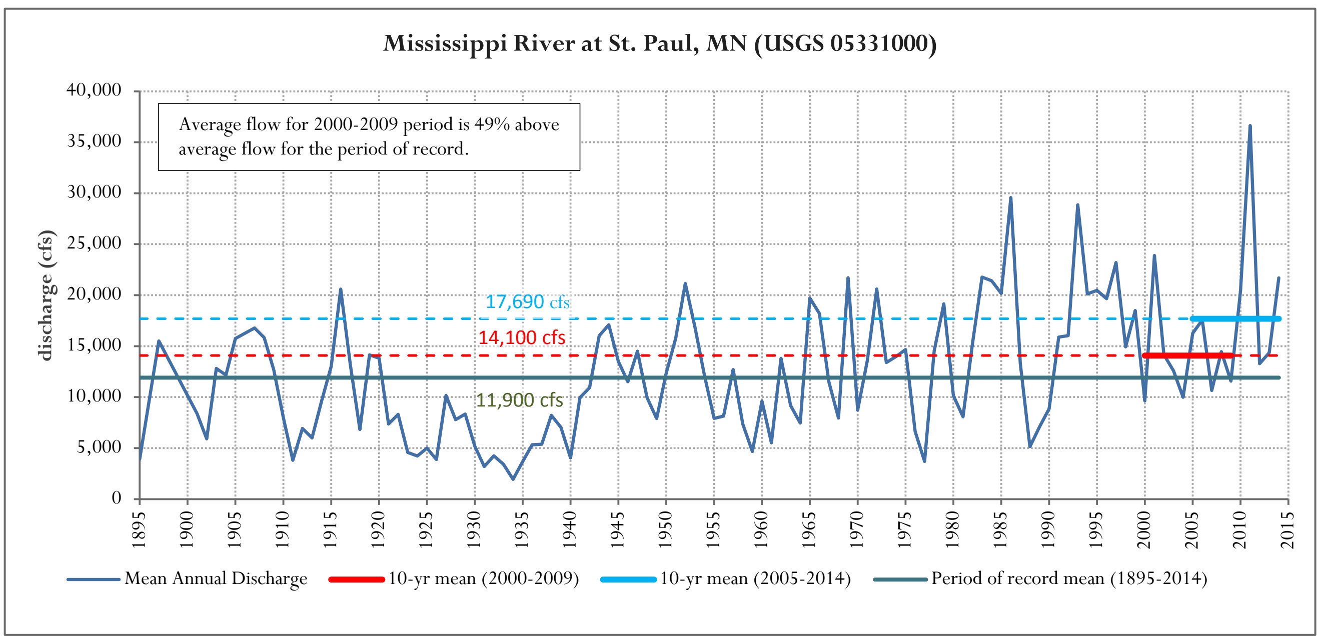


Figure 17. Stream Flow Conditions: Mississippi River at St. Paul

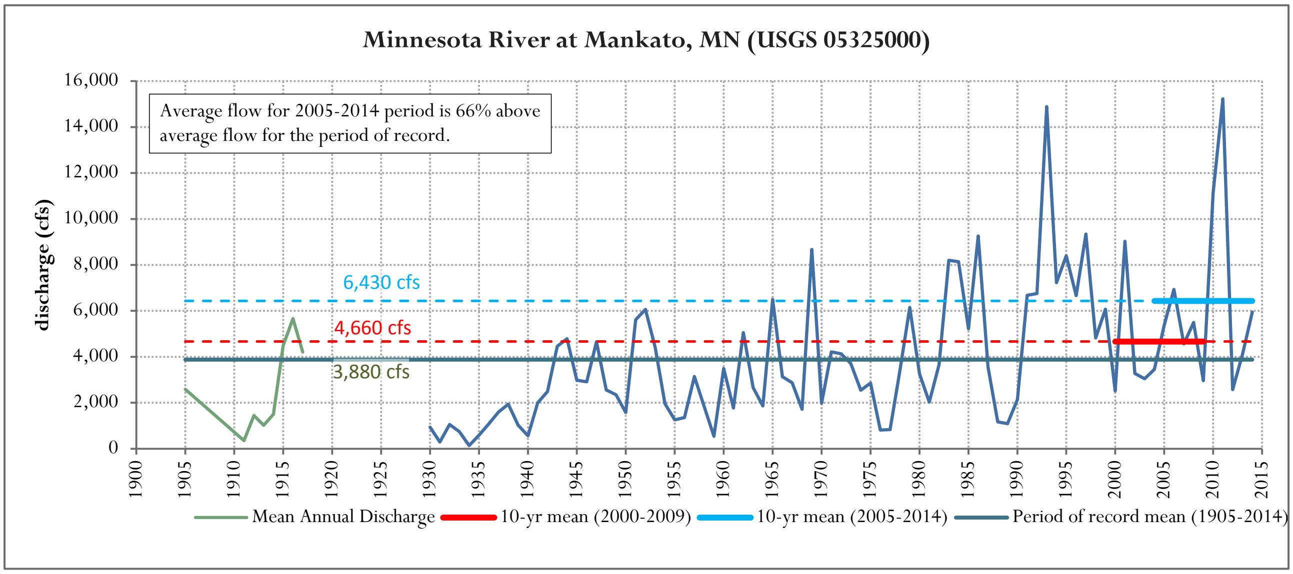


Figure 18. Stream Flow Conditions: Minnesota River at Mankato

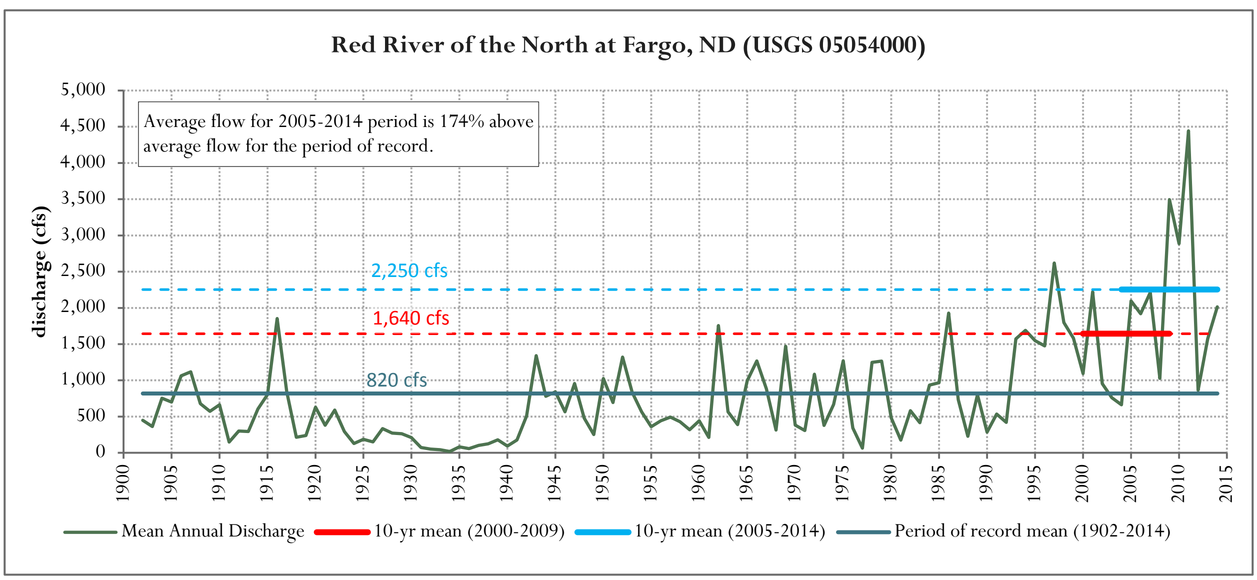


Figure 19. Stream Flow Conditions: Red River at Fargo, ND

SURFACE WATER: LAKE LEVELS

The following lake level summaries are derived from the DNR's Lake Level Monitoring Program. These lakes are selected based on their size and the length and quality of the lake level record.

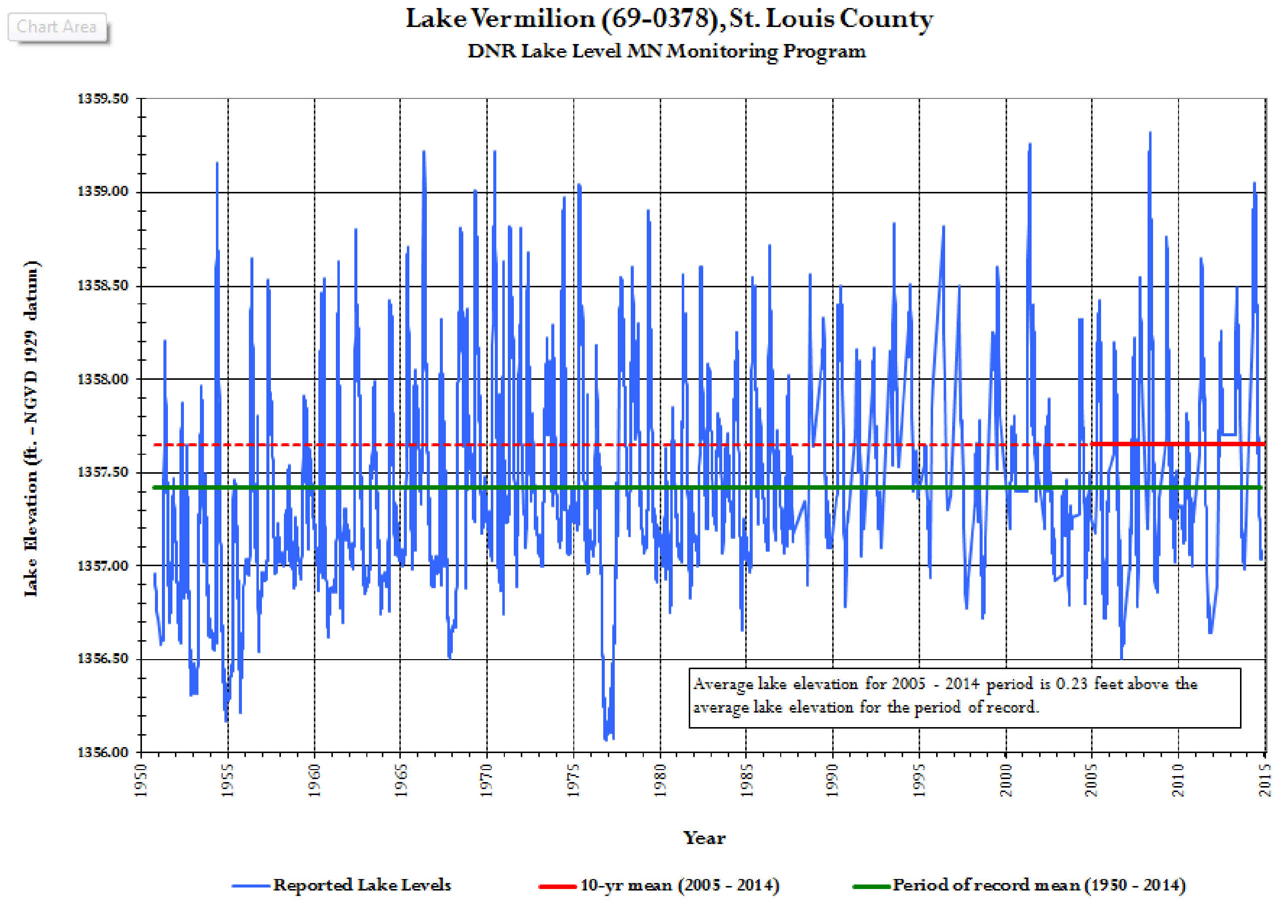


Figure 20. Lake Levels, Lake Vermillion

On **Lake Vermilion**, Minnesota's fifth largest lake, most of the 2005 - 2014 decade saw large annual lake level fluctuations between spring and fall. This is a common pattern in a majority of the years of lake records for this lake. Years of little annual lake fluctuation, such as 2010, are relatively uncommon. http://www.dnr.state.mn.us/lakefind/showlevel.html?downum=69037800

Otter Tail Lake, the largest lake in Otter Tail County, is part of the Otter Tail River chain of lakes. Although the lake has a maximum depth of 120 feet, over 50% of the lake is less than 15 feet deep. The lake experienced high levels in Spring and Summer of 2009 to 2014. The last half of the decade was above the 10-year and total record averages.
http://www.dnr.state.mn.us/lakefind/showlevel.html?downum=56024200

Most changes in water level in **Mille Lacs Lake** are influenced by usual weather patterns, as well as the size of the watershed. The lake has a relatively small watershed compared to the size of the lake, making it similar to landlocked lakes for multi-year trends. For this decade, high lake levels were sustained in 2005 to 2006, and in 2011 to 2014. The high water in July 2012 neared the reported highest lake levels in 1972. The lowest levels of the decade were during the droughts of 2007 and 2008. In 2014, a new water control structure was

permitted for construction at the outlet.
http://waterdata.usgs.gov/nwis/inventory/?site_no=05284000&agency_cd=USGS

Figure 21. Lake Levels, Otter Tail Lake

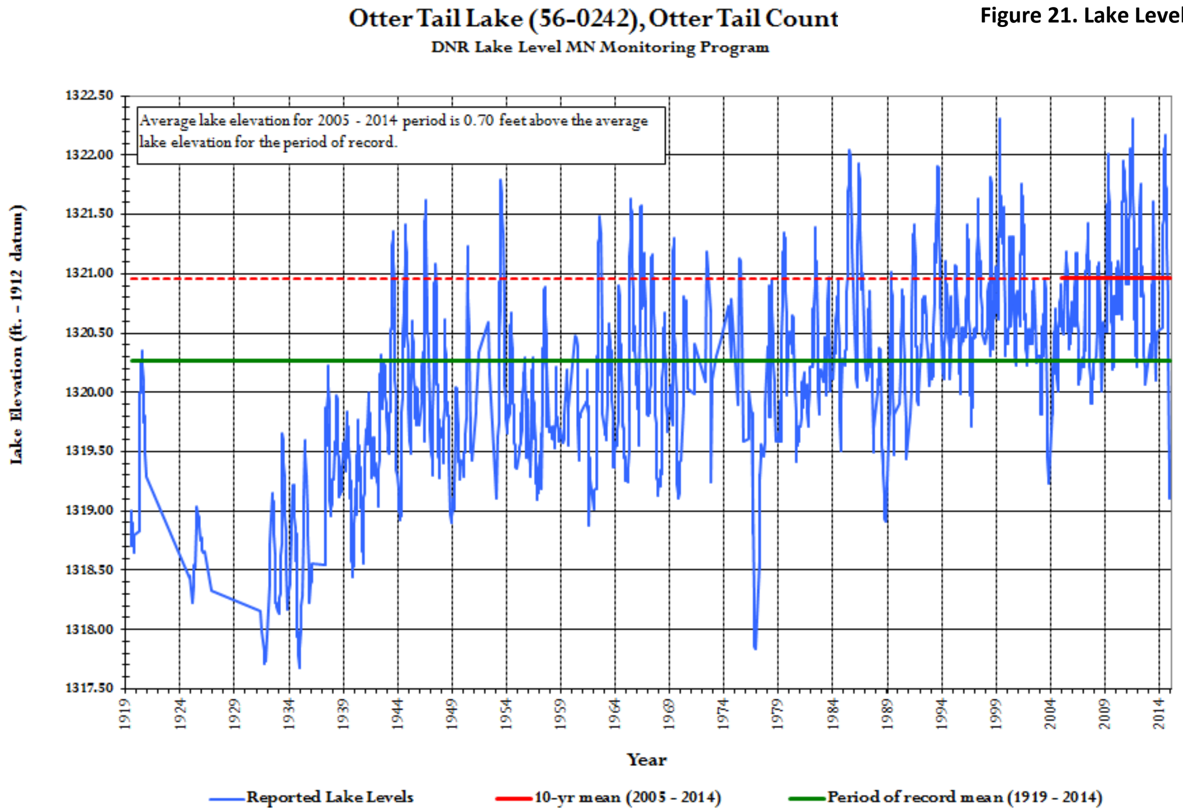
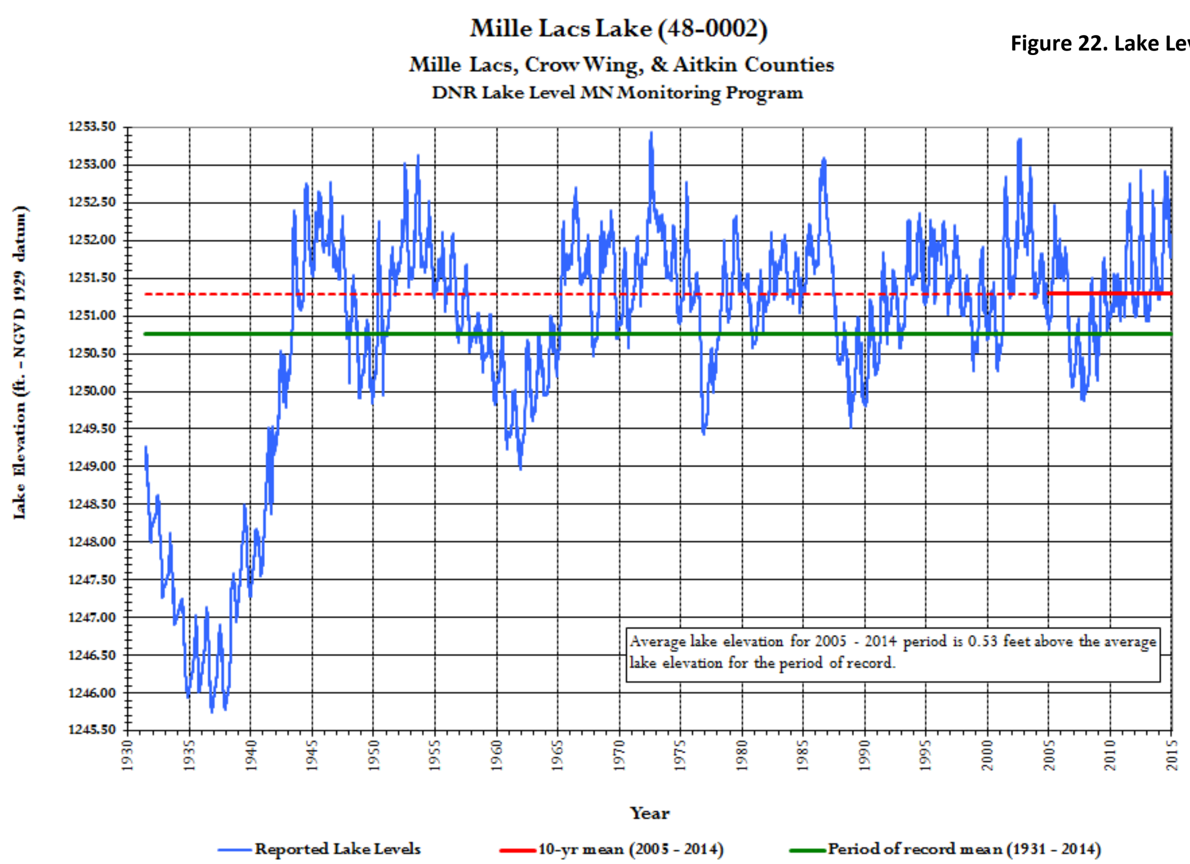


Figure 22. Lake Levels, Mille Lacs Lake



In association with the average to below-average yearly precipitation, **White Bear Lake** dropped 4.4 feet from Spring 2005 to Fall 2010. There was some increase in lake levels through Summer 2012, but the lake hit its historic reported lowest lake level during ice-free conditions at 919.17 feet on November 25, 2012. The eastern metropolitan area has experienced abnormally dry to severe drought conditions off and on during this decade, according to the National Drought Mitigation Center. During the dry conditions, White Bear Lake showed a lake level response similar to many other lakes in the eastern metropolitan area. After the 2014 wet spring, lake levels in Summer and Fall 2014 were higher than they had been since Fall 2008. The end of this decade showed the 10-year mean lake level falling 2.39 feet below the total record average. Continued lake level fluctuation on White Bear Lake should be expected over a multi-year time frame, similar to what one sees on other lakes with small watershed-to-lake area ratios and climate impacts throughout Minnesota.

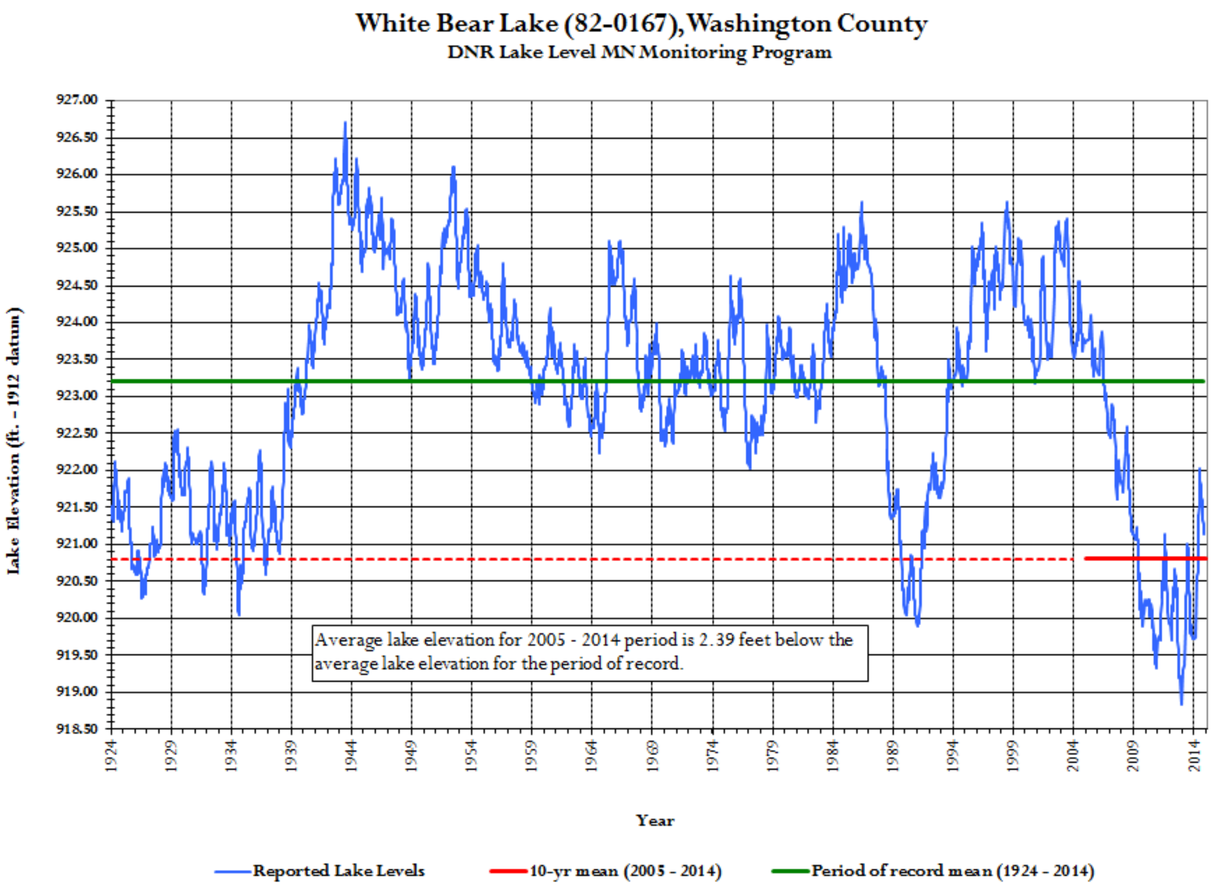
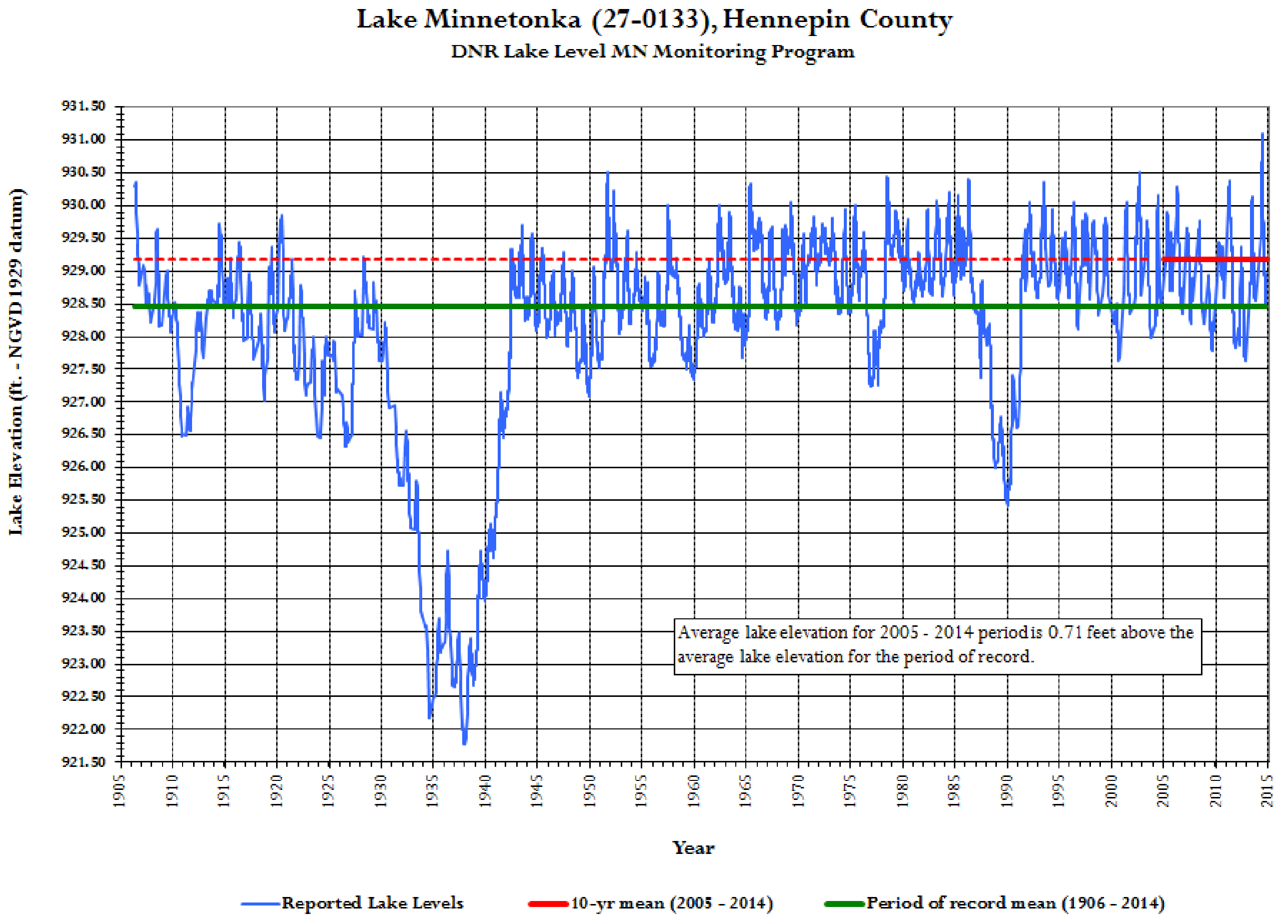


Figure 23. Lake Levels, White Bear Lake

Figure 24. Lake Levels, Lake Minnetonka



Lake levels and discharge have been controlled on **Lake Minnetonka** since 1897. In order to reduce flooding on downstream waters, water is usually stored in the spring, and then usually released at a controlled uniform rate during summer and fall. The dam closes when the lake level is at 928.6 feet and below, as it did during the droughts of 2008 and 2009. Lake levels are affected by precipitation and runoff entering the lake, as well as evaporation and controlled discharge leaving the lake.

The wettest June on record caused historically high water levels for Minnetonka in 2014. Lake Minnetonka reached an all-time record high of 931.11 feet on June 23, 2014. The lake broke its previous highest reported lake level record from September 2002 by more than seven inches. The volume of water submerged the dam from May 9 to July 30, 2014, so the dam was not able to have a significant impact on the level and resulting floods. Summer 2014 lake levels remained above the previous 2002 high level for 45 consecutive days. http://www.dnr.state.mn.us/lakefind/showlevel.html?downum=27013300

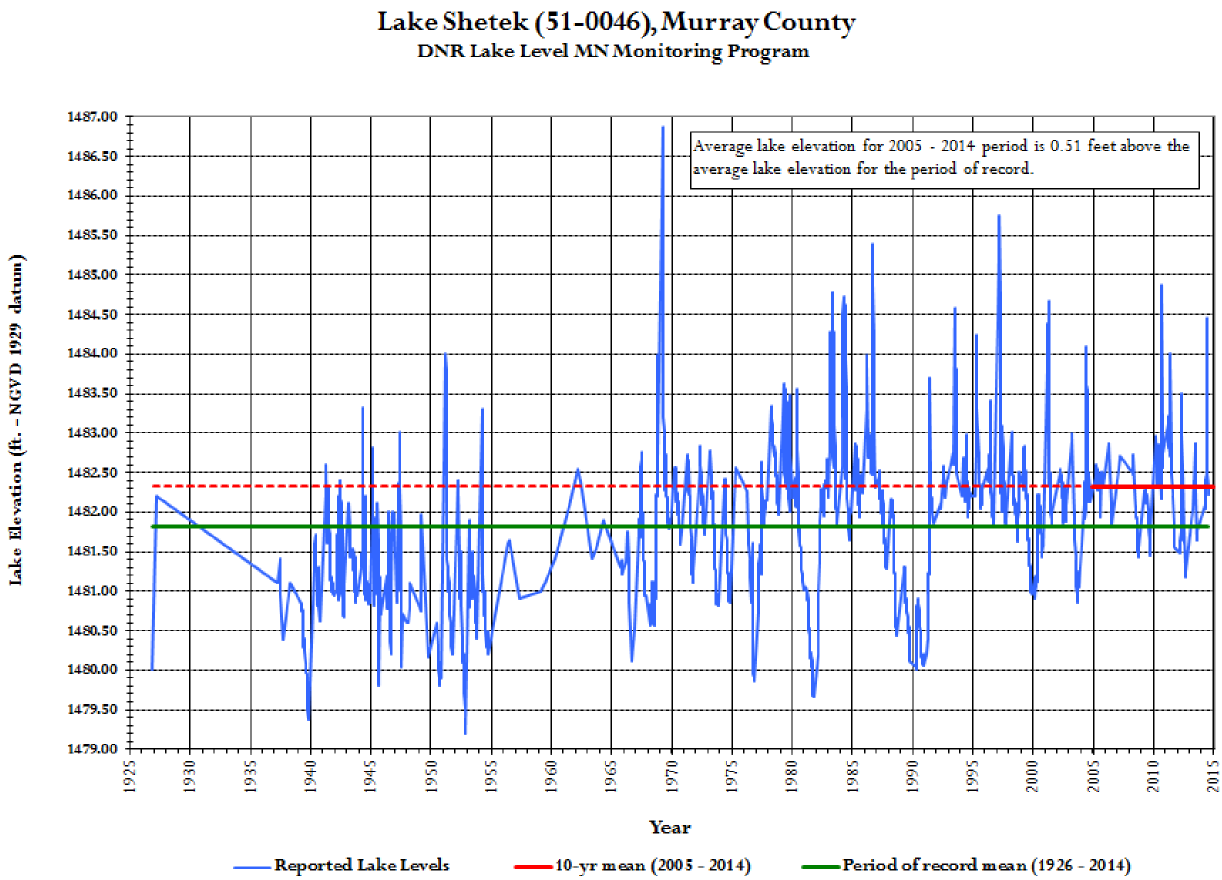


Figure 25. Lake Levels, Lake Shetek

At 3,596 acres, with an average maximum depth of 10 feet, **Lake Shetek** is one of the largest lakes in southwestern Minnesota and the headwaters of the Des Moines River. The first half of this decade showed a normal pattern around the average, while the last five years showed more extreme bounces in response to weather patterns. The lake rose 2.3 feet following 4.5 inches of precipitation from a 2 day event in late September 2010. A similar peak occurred in the wet June 2014 from a longer period of precipitation. The lake level increased almost 2 feet after six inches of rain fell during the last half of June.

http://www.dnr.state.mn.us/lakefind/showlevel.html?downum=51004600

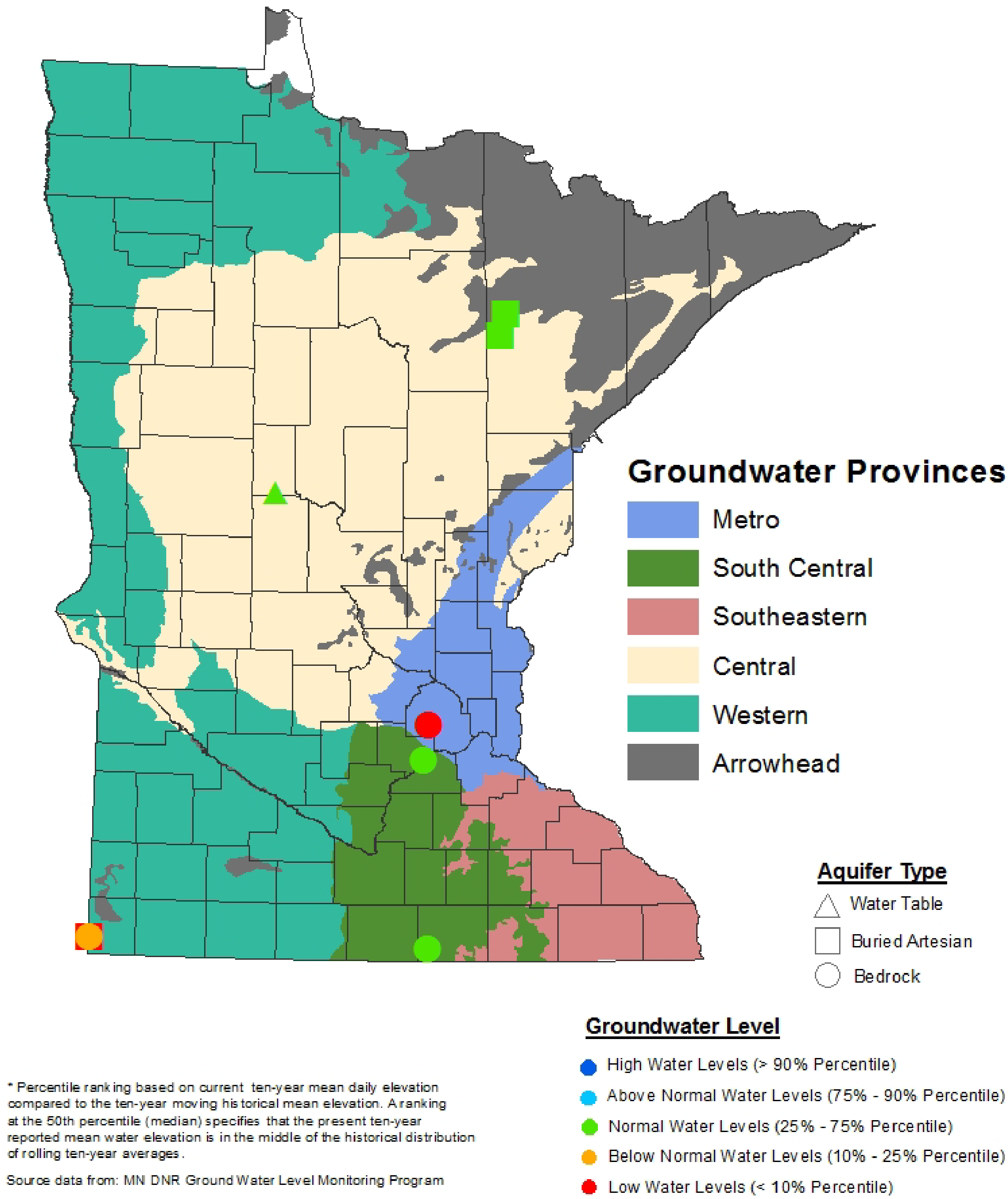


Figure 26. Groundwater Levels in Indicator Wells, 2005 - 2014

Minnesota is divided into six groundwater provinces that are defined by bedrock and glacial geology. Figure 24 shows the six groundwater provinces and the DNR observation wells that are chosen to represent each province. The hydrographs for the six observation wells are presented below. The hydrographs include the ten-year average daily water level and the average water level for the period of record. A high ten-year average indicates that the water levels from the past ten years have increased compared to the period of record in the well. The only well that has a higher ten-year average is a buried aquifer observation well in the Arrowhead Groundwater Province. A low ten-year average indicates that water levels have decreased over the last ten years when compared to the period of record. Three provinces show a lower ten-year average water level than the period of record (Metro, South-Central, and Western Provinces). The Southeastern and Central Provinces show no major change.

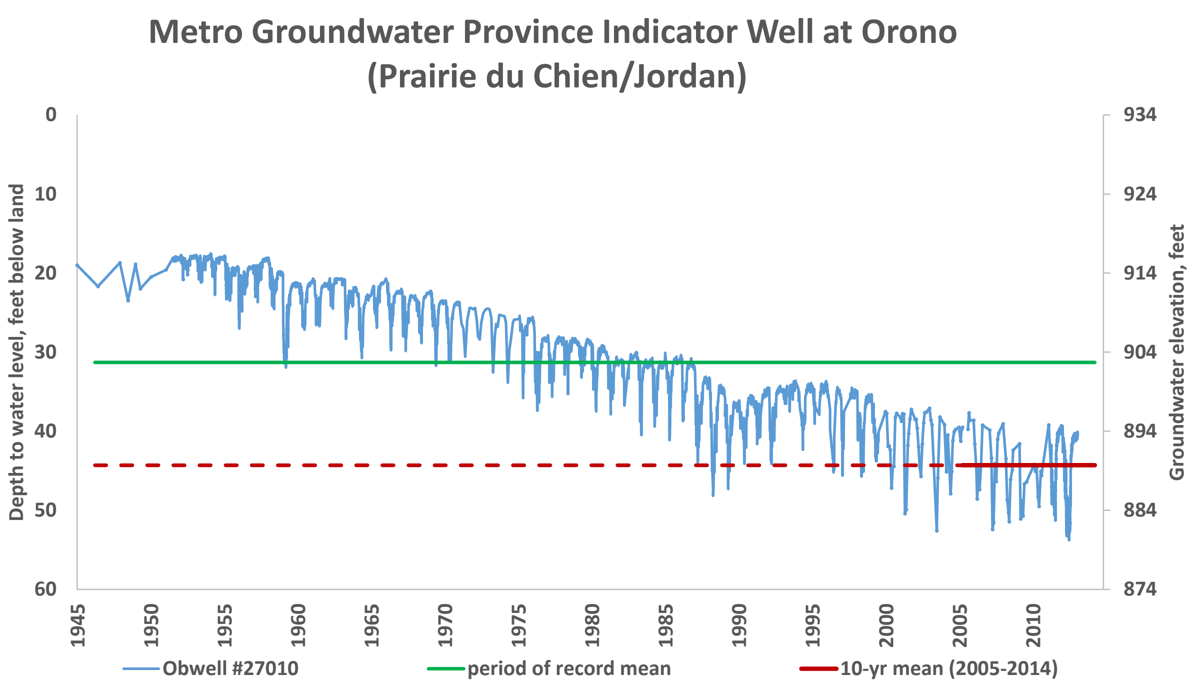


Figure 27. Hydrograph, Metro Groundwater Province Indicator Well

The observation well for the Metro Province monitors the Prairie du Chien and Jordan bedrock aquifers, which are primary water supply aquifers for the metropolitan area. This observation well shows an overall downward trend in water levels over the 70 years of record. Seasonal changes in water levels between increased summer water use and winter water use are also apparent over each year. The ten-year daily average water level for years 2005-2014 has decreased 1.7 feet from the ten-year average for 2000-2009.

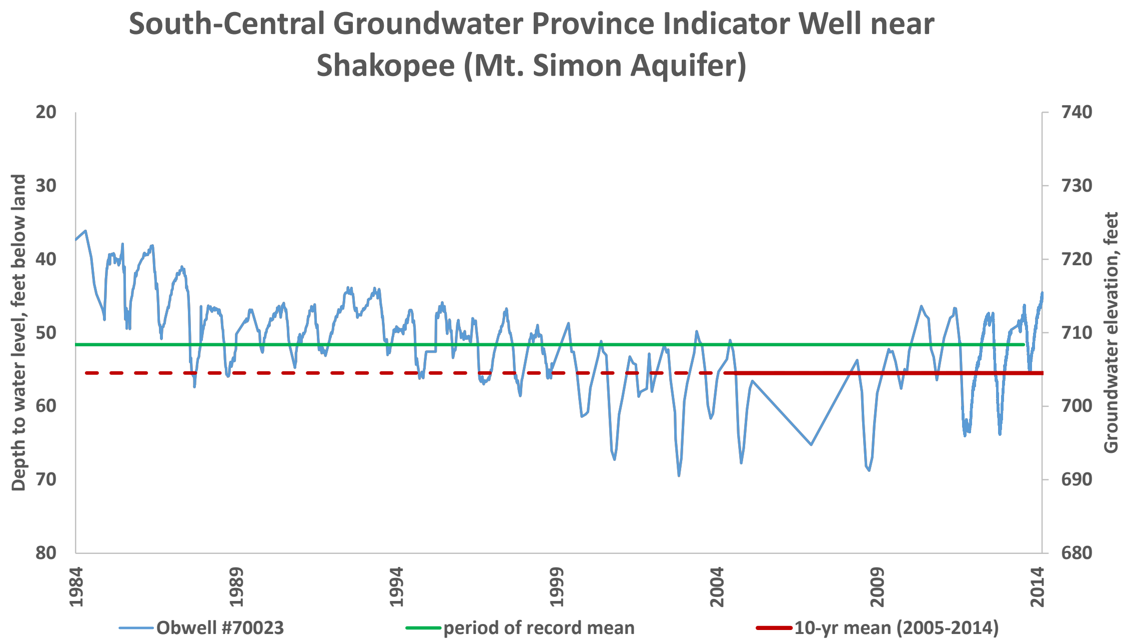


Figure 28. Hydrograph, South-Central Groundwater Province Indicator Well

The observation well in the South-Central Province monitors the Mount Simon Sandstone bedrock aquifer, which is typically the deepest aquifer in the state and a water supply aquifer for a number of communities. Water levels in this well were declining until about 2009, when water levels appeared to recover somewhat. The ten-year daily average water level for years 2005-2014 has increased 6 feet compared to the ten-year average for 2000-2009. The current ten-year average is still below the 30-year period of record average, but it appears that the decline observed in the previous report has stopped. This well also records the fluctuations in the aquifers over the course of one water year.

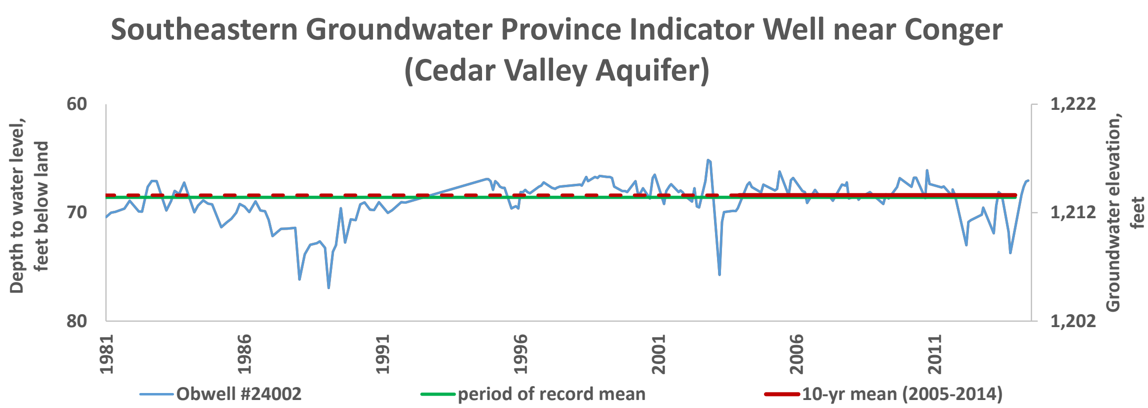


Figure 29. Hydrograph, Southeastern Groundwater Province Indicator Well

The observation well for the Southeastern Province has changed from the last report. The current well for this Province monitors the Cedar Valley bedrock aquifer, which is located only in this area of the state. There is no discernable trend for the period of record, though there are periods with lower water levels in the late 1980's and after 2011. Water levels did recover after the drought of the 1980s. The ten-year daily average water level is not different from the 33-year period of record average.

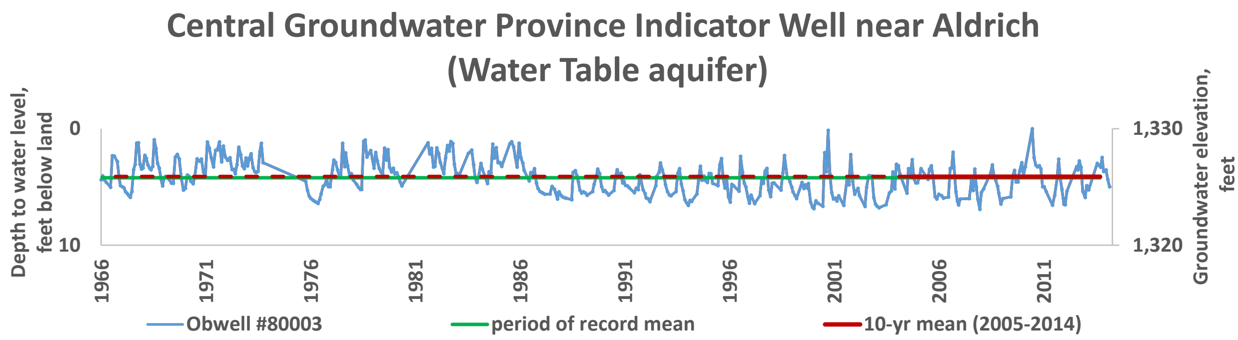


Figure 30. Hydrograph, Central Groundwater Province Indicator Well

The observation well in the Central Province monitors the water table, which in this part of the state is a major water supply for agricultural irrigation. Water levels in this well have fluctuated over the entire period of record. Being so shallow, this well is directly impacted by fluctuations in climate trends and large precipitation events. The ten-year daily average water level is not different than the average water level for the 48-year period of record.

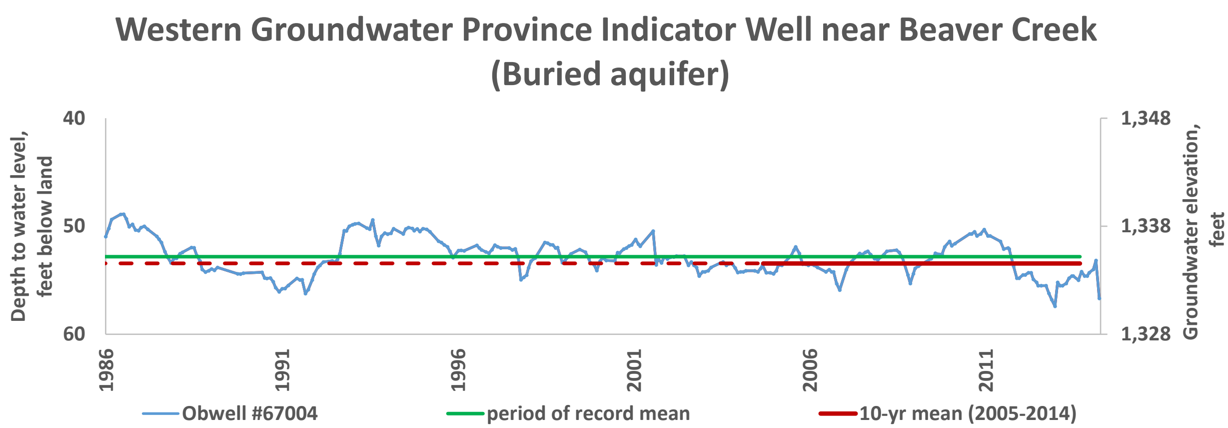


Figure 31. Hydrograph, Western Groundwater Province Indicator Well

The observation well in the Western groundwater province monitors the buried aquifer in the area. This well does not show a noticeable trend in water levels. The fluctuations that are observed in the mid-1990s and 2009 to the present are a result of climate variability. The drought of the late 1980s is apparent in the decreased water levels in the well, but the above average amounts of precipitation that followed the drought contributed to the rebound in the water levels. The ten-year daily average water level is less than 0.5 feet below the 28-year period of record for this well. There do not appear to be pumping impacts to this well, which adds to its value as an indicator of background conditions.

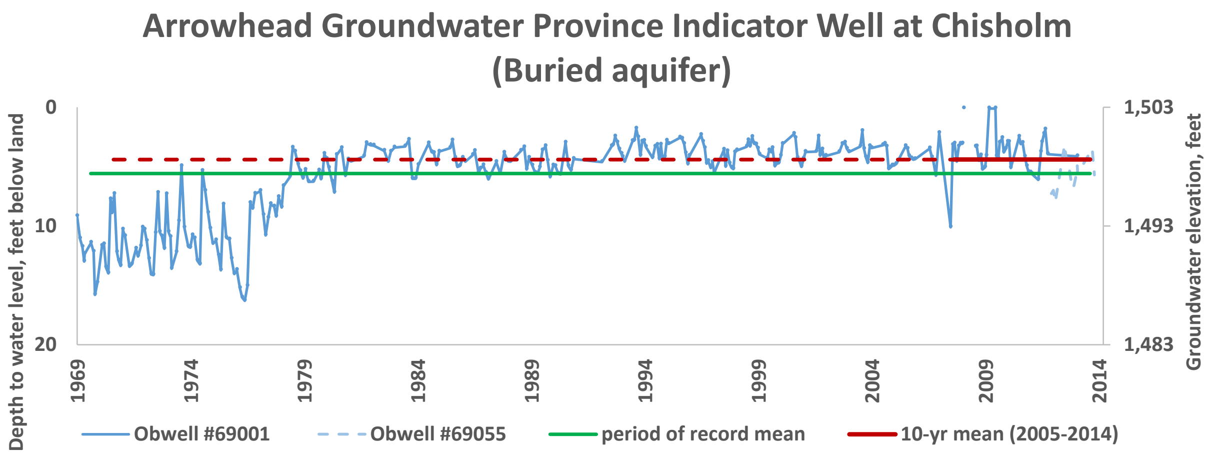


Figure 32. Hydrograph, Arrowhead Groundwater Province Indicator Well

This hydrograph is a synthesis of two wells. Observation well #69001 was sealed and replaced with well #69055. The new well is adjacent to the old well and extends into the same buried aquifer. The period of record shows a noticeable change in the level of the aquifer in 1977. There is no record of what caused this change, but it is possible that a nearby pumping well was turned off, which allowed the aquifer to recover to less impacted levels. The relatively larger fluctuations in water levels before 1977 indicate an impact from nearby pumping. Partly as a result of this change in the system, the ten-year daily average water level is a little more than a foot higher than the average for the 45-year period of record.

Water Use

The DNR regulates water use to ensure the long-term sustainability of the water resources for people and the environment. Water use (appropriation) permits are required for anyone who uses, removes, or transfers more than 10,000 gallons per day or one million gallons per year of surface water or groundwater. The DNR collects monthly water use data from these permit holders. This information is analyzed and compared with data from stream flow measurements, lake water levels, groundwater levels, and precipitation to provide a picture of the condition of Minnesota's water resources.

During the period from 2005 through 2014, Minnesota saw water use remain fairly level, in contrast to the 1999 – 2008 period, during which water use (excluding water used for power generation) increased by about 78 billion gallons per year.

Minnesota's population increased by an estimated 6.5% during the 2005 – 2014 period. If we compare growth within and outside the Twin Cities' metropolitan area, the growth in the Metro-area population, at 8.9%, was substantially greater than that of greater Minnesota, at 3.8%.

Overall water use has risen from about 850 billion gallons per year in the mid-1980s, when electronic water use data tracking began, to about 1,250 billion gallons in 2013 – 2014. The largest portion of water use is for power generation from surface water sources – a non-consumptive use, since most of the water is immediately returned to its source.

Water use varies by type of user. Industrial processing uses have remained fairly constant, as have "other" uses, which include livestock watering, snow-making, dewatering of quarries, sand and gravel washing, etc.

During the 2005 – 2015 period, total reported water use statewide has fluctuated, reaching a peak of 1,431 billion gallons in 2008 and then declining to 1,269 billion gallons in 2014. Part of this decrease can be attributed to a decrease in water needed for power generation: as a number of large power plants converted from coal to natural gas, their water use efficiency increased.

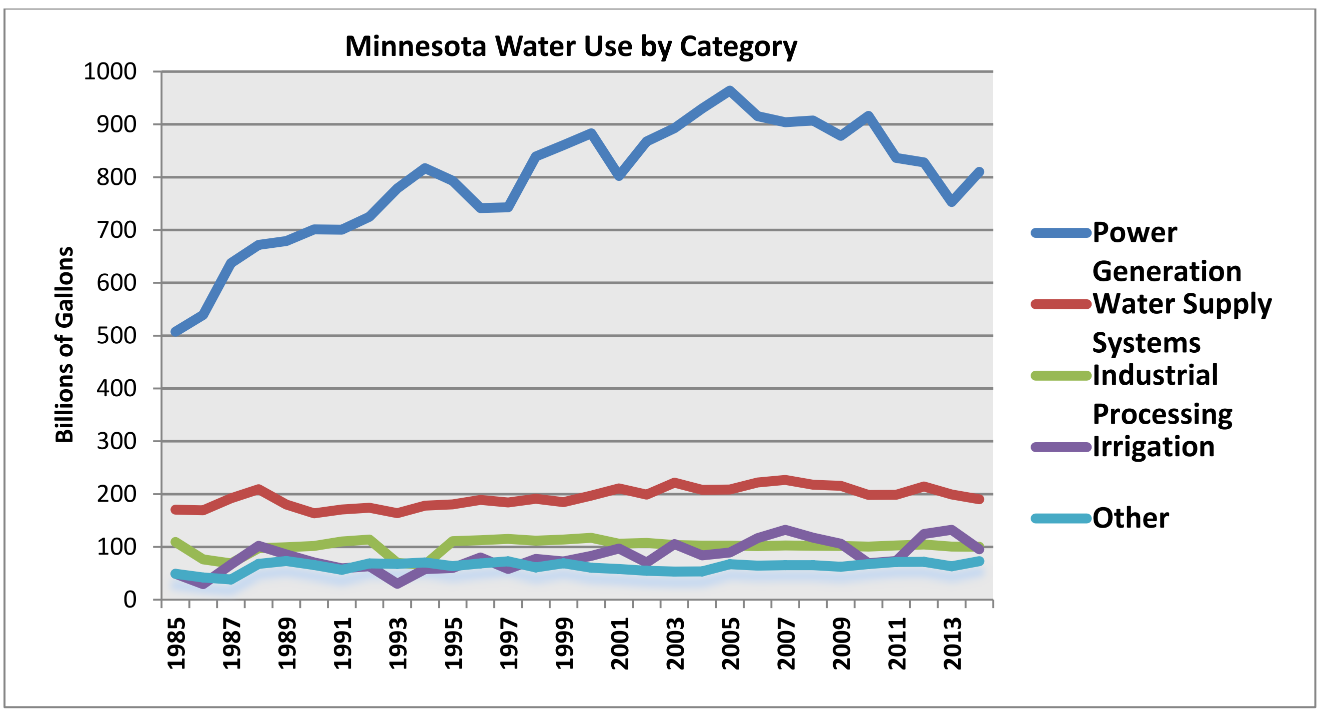


Figure 33. Minnesota Water Use by Category, 1985 - 2014

Irrigation water use has increased as more farmland acres are irrigated – the amount of irrigated agriculture in Minnesota has increased by about 140,000 acres since 2000, about a 30% increase. Both public water supply system and irrigation water use tend to rise and fall based on precipitation patterns, and seasonal drought conditions in 2007 and 2008 may contribute to the high water use in those years (see previous discussion under "Climate").

Residential water use per capita can be estimated by comparing household water use reported by public water suppliers with the population served. The quality of the reported information varies widely, and does not lend itself to comparison across multiple jurisdictions over time. According to a Metropolitan Council study, residential per capita use in the 7-county metro area ranged from 64 to 207 gallons per capita per day (GPCD), measured over the 2000 – 2012 period. The average was 80.4 GPCD and the median was 78.5. Residential water use varies from city to city based on factors such as lot size, income levels, social norms, water rates, and conservation efforts.[9]

(Note that residential water use volume only includes use by public water supply customers; it does not include private residential wells, since these generally fall below the regulatory threshold of 10,000 gallons per day or one million gallons per year.)

Groundwater use (reported) in 2014 was about 246 billion gallons. Like surface water use, groundwater use fluctuates from year to year depending on the amount of summertime precipitation, since a large fraction of the water we use is for irrigation (including residential lawns, golf courses, crop and non-crop irrigation). Water supply use of groundwater peaked in 2007, while irrigation use reached a high point in 2013, due in part to the increasing acreage of irrigated cropland. On average, we are using about 75 billion gallons more groundwater per year than we were 25 years ago, increasing by about three billion gallons per year.

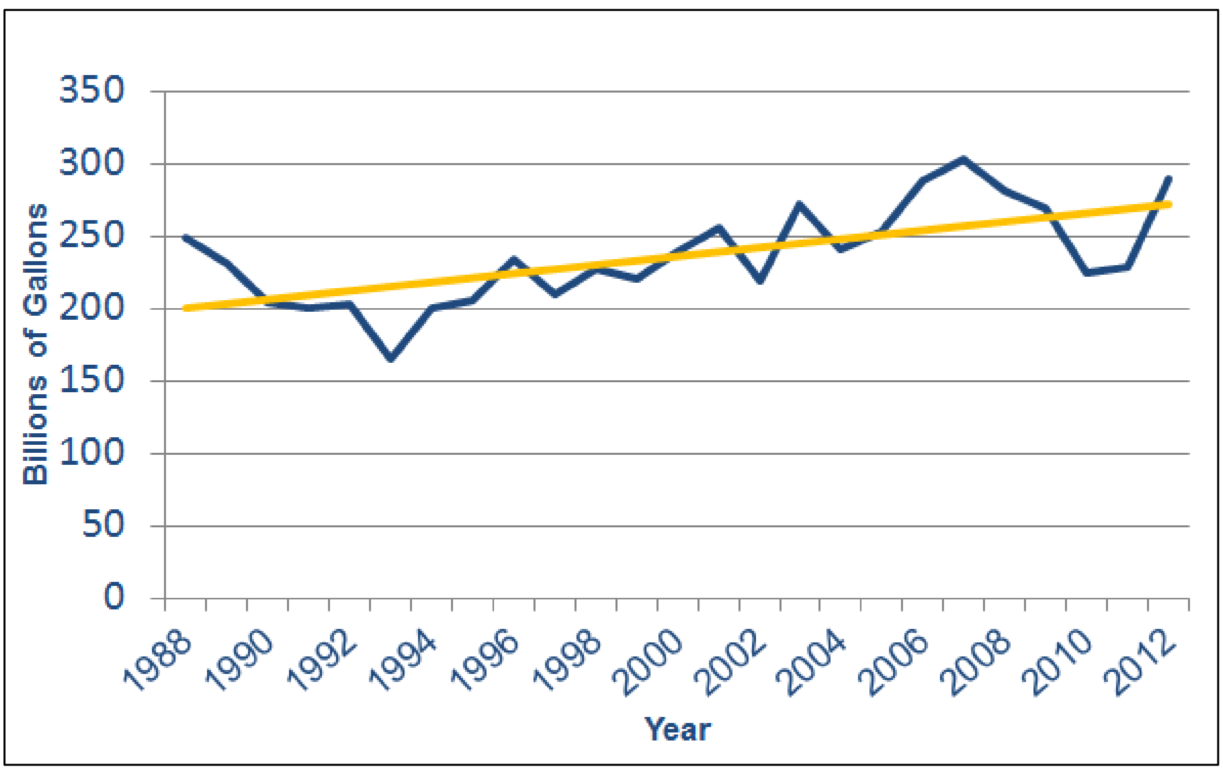


Figure 34. Statewide Annual Reported Groundwater Use

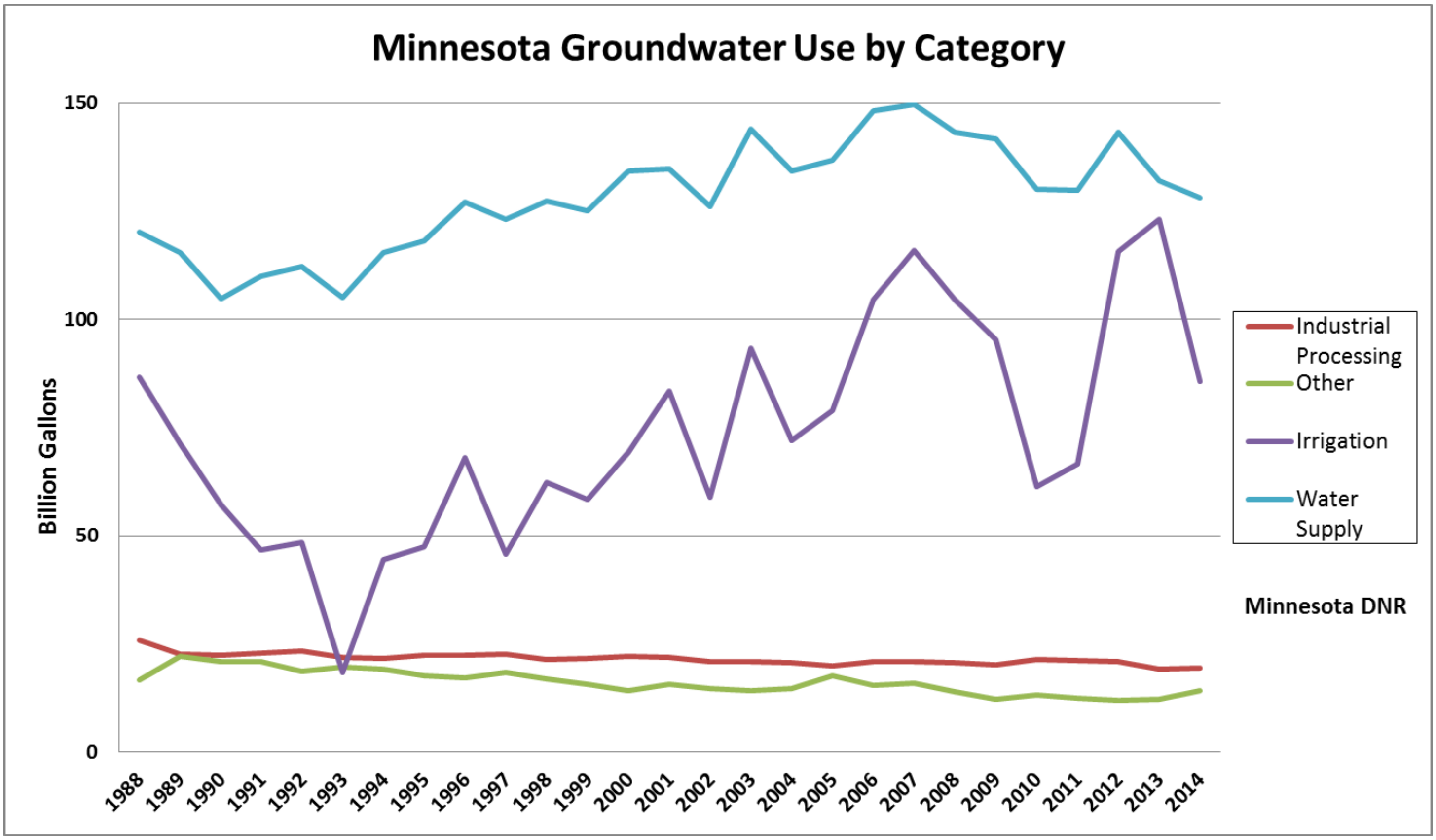


Figure 35. Groundwater Use by Category

In the 11-county metro area, four principal aquifers account for 98% of groundwater use. Since 1988, the Prairie du Chien-Jordan aquifer has been used for an average of 61% of groundwater demand. Surficial aquifers comprise about 20% of groundwater demand. The remaining water is drawn from the Tunnel City – Wonewoc (formerly known as Franconia-Ironton-Galesville) and the Mt. Simon-Hinckley aquifers. Use of the latter aquifer is restricted by statute in the seven-county metro area, and has decreased since 2007, while use of the Prairie du Chien-Jordan aquifer and surficial aquifers have increased (Figure 37).

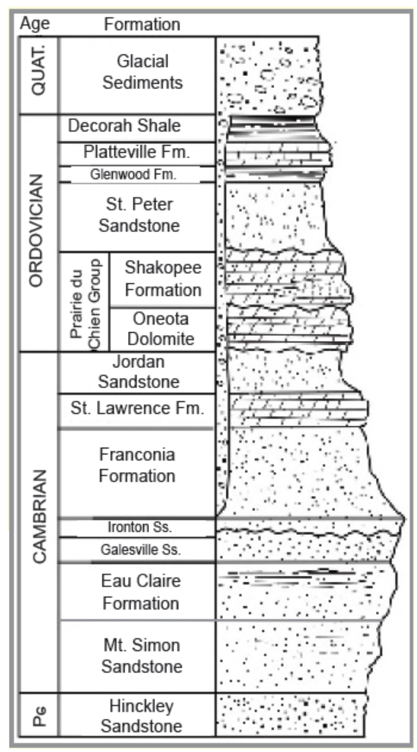


Figure 36. Generalized Geologic Column for the 7-County Metro Area. Franconia-Ironton-Galesville formation has been renamed Tunnel City – Wonewoc.

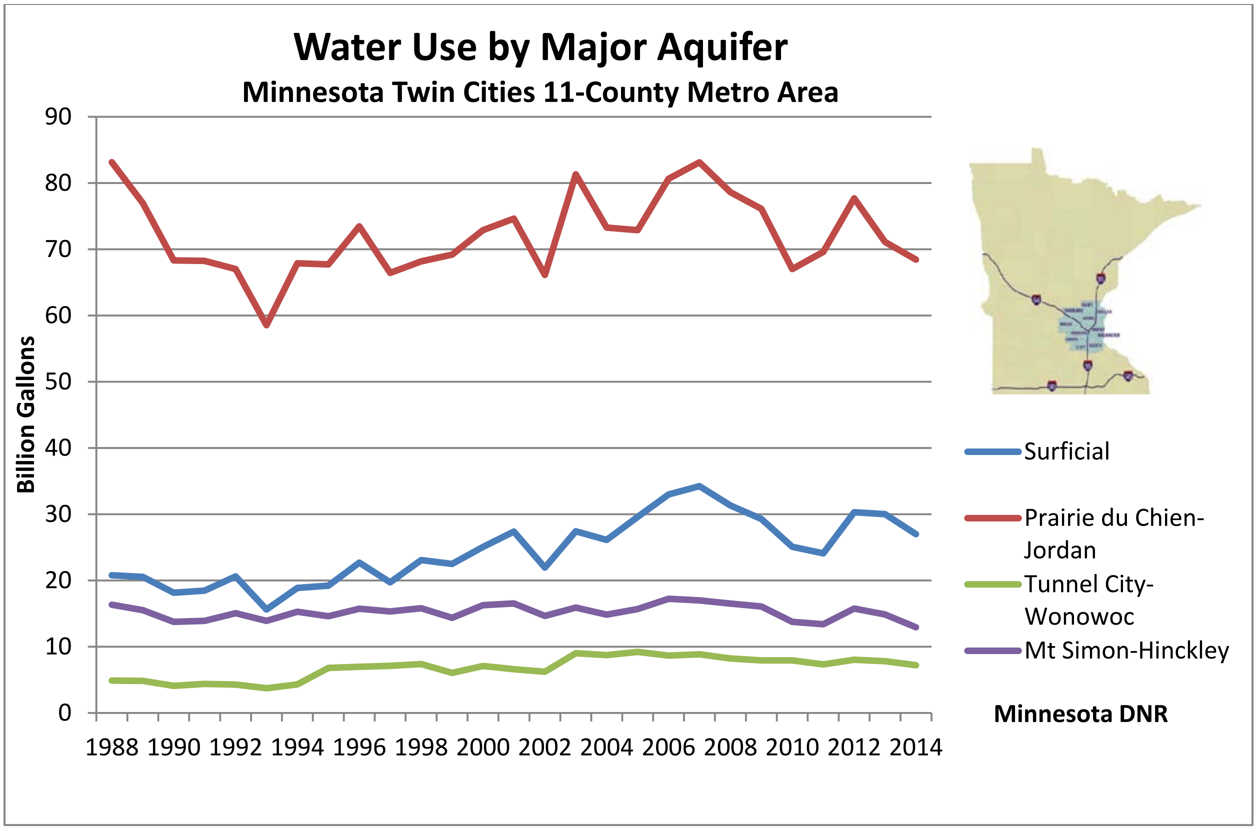


Figure 37. Water Use by Major Aquifer, 11-County Metro Area, 1988 - 2014

ENDNOTES

[1] Minn. Stat. 103A.43

[2] Minn. Stat. 103G.287, subd. 4

[3] Minn. Stat. 103G.287, subd. 1(c)

[4] Minn. Stat. 103G.291

[5] Melillo J., Richmond, T., and Yohe, G., 2014. An assessment from the U.S. Global Change Research Program to inform the public with scientific information and methods regarding climate change.

[6] Harding, K. J., and P. K. Snyder (2014), Examining future changes in the character of Central U.S. warm-season precipitation using dynamical downscaling, *J. Geophys. Res. Atmos.*, 119, doi:10.1002/2014JD022575.

[7] Harding, K. J., and P. K. Snyder (2015), Using dynamical downscaling to examine mechanisms contributing to the intensification of Central U.S. heavy rainfall events, *J. Geophys. Res. Atmos.*, 120, doi:10.1002/2014JD022819.

[8] Pryor, S. C., D. Scavia, C. Downer, M. Gaden, L. Iverson, R. Nordstrom, J. Patz, and G. P. Robertson, 2014: Ch. 18: Midwest. *Climate Change Impacts in the United States: The Third National Climate Assessment*, J. M. Melillo, Terese (T.C.) Richmond,and G. W. Yohe, Eds., U.S. Global Change Research Program, 418-440. doi:10.7930/J0J1012N.

[9] CDM Smith. Twin Cities Regional Water Billing Analysis. Pepared for the Metropolitan Council, June 1, 2015.