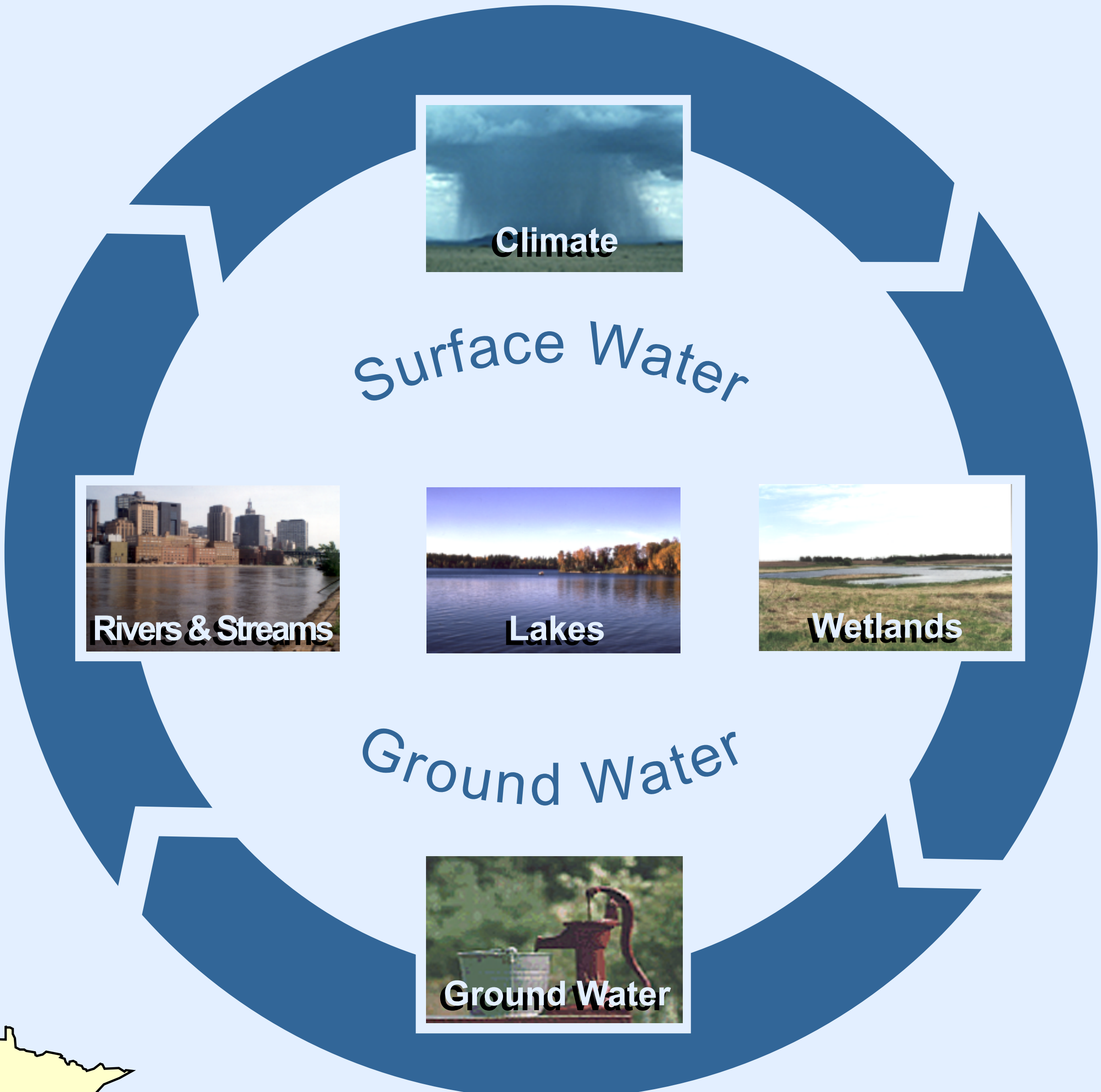
MINNESOTA'S WATER SUPPLY:

Natural Conditions and Human Impacts



DNR Waters

Information Paper

Helping people ensure the future of our water resources

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Minnesota's Water Supply:
Natural Conditions and Human Impacts

by DNR Waters Hydrogeologists and Hydrologists

St. Paul, Minnesota

September 2000

Minnesota
Department of Natural Resources
Waters

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Laurel D. Reeves and
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Director

INTRODUCTION

Managers of water resources face a continuing challenge. On the one hand, human activities require increasing amounts of water for drinking water supply, for industrial and agricultural needs, and for aesthetic purposes. On the other hand, a high quality, ongoing water supply is necessary to maintain the rich natural resource heritage that generations in this state have enjoyed.

The fair and wise allocation of the water supply in light of increasing, competing demands is one of the greatest challenges facing the Minnesota Department of Natural Resources (DNR). Withdrawals for public water supplies, domestic uses, irrigation, industrial processing, or power production can conflict with the need to maintain adequate streamflows and water levels for recreation, fish and wildlife habitat, and reliable ground water supplies.

A significant increase in the amount of water available for competing needs is not feasible. Therefore, expectations for future water use and demands must be managed using sound water resource information and a profound understanding of the relationship between human activities and natural conditions. Included in this report are discussions of the following key topics:

- current water budget and human impacts;
- an overview of water resource management concerns that are being addressed statewide and by geographic and hydrogeologic areas; and
- current strategies for water supply management, and planning and development suggestions.

MINNESOTA'S WATER BUDGET AND HUMAN IMPACTS

Minnesota is at the head of four continental watersheds and is the headwaters, the origin, of three of these watersheds. Water flows north (Red River of the North Basin), south (Mississippi River Basin), east (Great Lakes Basin), and west (Missouri River Basin) from our state (Figure 1). The state receives very little surface water from outside its boundaries.

Our management practices affect the downstream user, both human and natural resources. Through wise management of the resource, Minnesotans control the destiny of their own water resources and also influence the destiny of those who are downstream.

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 ground water (flow, storage), climate (precipitation and evaporation), and surface water (runoff, streamflow, and storage) (cover illustration). 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 ground water 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 causes concern for a variety of human endeavors.

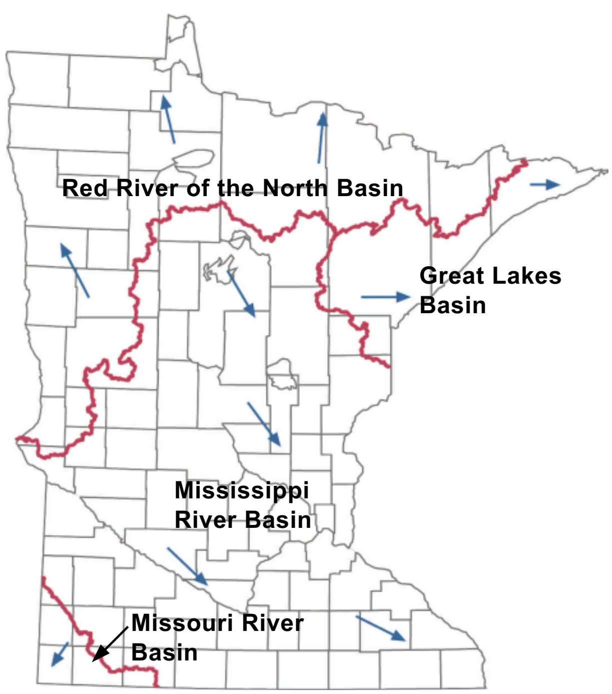


Figure 1. Major watersheds

Of the total water use in Minnesota from 1985 to 1997, an average of 18.6 percent came from ground water (Figure 2). These water uses include public water supply, agricultural and golf course irrigation, and industrial processing. The remaining water used comes

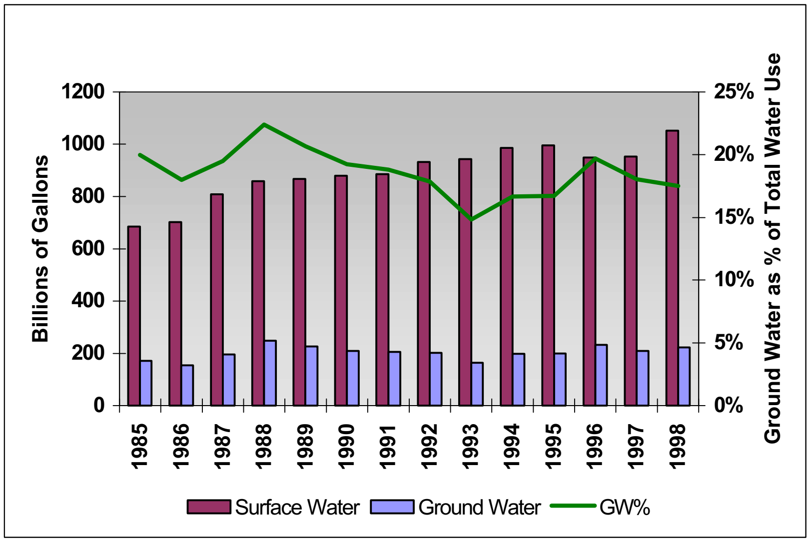


Figure 2. Comparison of surface water and ground water use

from surface water. Although surface water is used for a variety of purposes such as public water supply and irrigation, the majority is used for cooling in power generation.

All ground water withdrawals are considered consumptive, which means that the water is not directly returned to the same source. Consumptive ground water uses pose a resource management concern because the amount of water available for use from that resource is reduced and is only replaced through recharge. Recharge amounts are dependent on climate, primarily precipitation. The amount of recharge can be greatly affected by human actions.

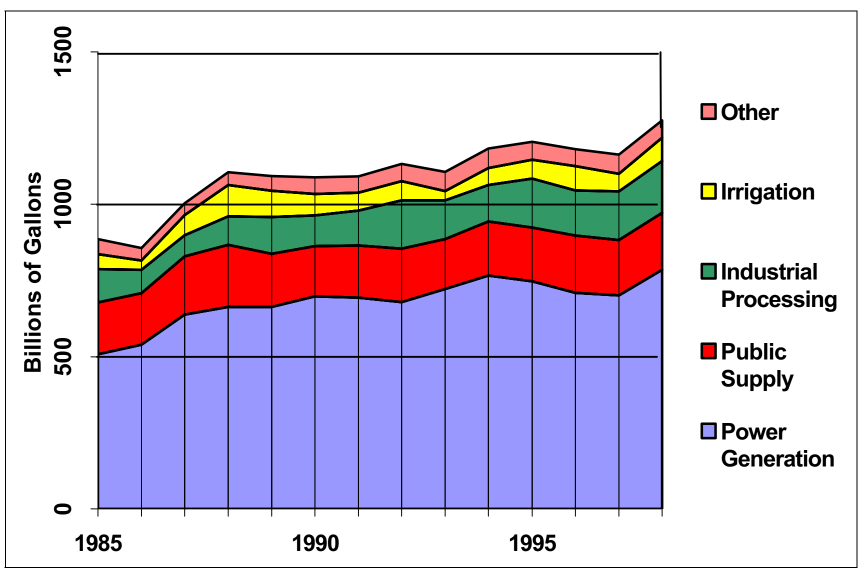


Figure 3. Total water use by type

Surface water used for power generation is usually a nonconsumptive water use because the water is returned to the same source from which it was withdrawn. Water used for power generation cooling water amounts to more than half of the total water use each year (Figure 3); however, most of that water is available for reuse since it is returned to the surface water source.

Ground Water Sources

Minnesota can be divided for the purpose of ground water supply concerns into hydrogeologically similar source areas: glacial drift sources, glacial outwash sources, and bedrock sources (Figure 4). While the geology across a source area may appear to be quite different, the water supply issues within each source area are quite similar.

Glacial Drift Sources. The glacial drift source area includes northern, western, and southwestern Minnesota. This area was covered by repeated glacial ice advances that deposited clayey glacial till, often several hundred feet thick. Interlayered in this till were lenses and layers of more porous sands. Sand and gravel were also deposited along ancient riverbeds and along the shoreline of ancient lakes. These sand and gravel deposits, some of which were then covered by subsequent layers of glacial till, frequently are water bearing and are the aquifers used for water supply in this area. To be used as drinking water, these waters often require treatment. They are isolated pockets, which may yield a reasonable water volume, but are not quickly recharged and thus are not easily renewed. Natural recharge can be and has been disrupted in many locations by artificial drainage patterns imposed for flood protection and for improvement of agricultural production.

The water supply needs of large volume users in northeastern Minnesota, where glacial drift deposits are thin or nonexistent, are often met using surface water sources such as mine pits, Lake Superior or other lakes and streams. Many of these surface water sources are supplied by ground water. Actions such as mining and other development that interrupt ground water flow can disrupt the water supply. As the landscape is changed by human activities, the quantity and quality of these water supplies can be threatened.

Best management of water resources in this area includes encouraging the distribution of water supply development throughout the glacial drift sources. Large volume water users should not rely too heavily on any single glacial drift source because that source may be unable to produce a sustained supply and because of water quality concerns in this source area. Limited availability of large water volumes should be carefully considered before beginning any business or activity that may require large water supplies over a long period of time. The effect of development on water flow patterns should also be considered before beginning those activities.

Glacial Outwash Sources. The second hydrogeologic area has glacial outwash sources. This area in central Minnesota was also traversed by several glacial advances. As the glaciers melted and retreated, water often ponded for long intervals at the front edge, along the sides of the glacier, or in meltwater pools on the glacier's surface. Thick sand and gravel deposits (outwash sands) were left as the ice melted. These water-bearing sand layers were not covered and remained at or near land surface. They are the source of significant water supplies. These areas are attractive for agriculture and other development including sand and gravel mining because they are level and have good soil characteristics for row cropping, building placement, and building materials. Glacial outwash aquifers are easily recharged making them a plentiful source of water. Due to their proximity to land surface, however, these aquifers are susceptible to contamination from human activity.

Care must be taken in the glacial outwash area to protect the ground water from the impacts of changing land use practices. Septic systems in unsewered housing developments, fertilizer, pesticides and herbicides from agricultural and residential applications, and hazardous materials disposal from manufacturing processes, to name a few, represent potential contamination threats to the aquifers of the glacial outwash area.

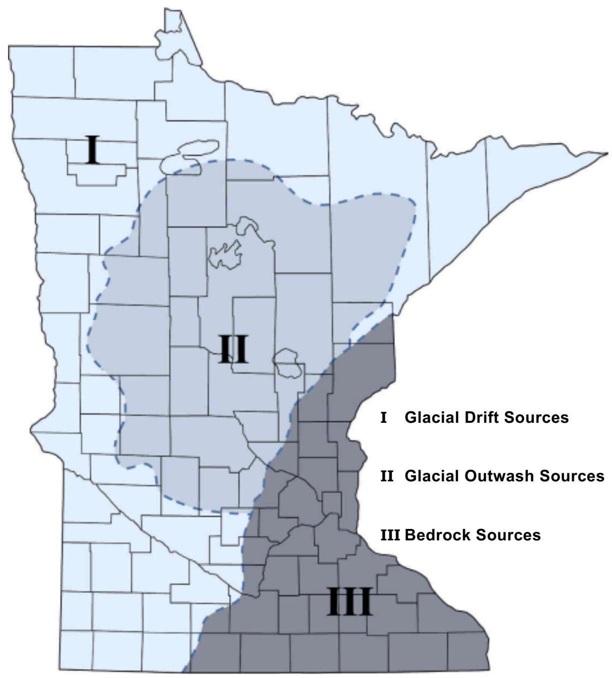


Figure 4. Ground water sources

Bedrock Sources. The third hydrogeologic area is the sedimentary bedrock sources of east-central and southeastern Minnesota. While the glaciers did advance over this area, the sand deposits left in their wake are only used for water supply on a limited basis. The bedrock layers deposited in ancient seas are the primary aquifers for this area that includes the Twin Cities metropolitan area. These aquifers generally produce great volumes of water with few limitations. Although some aquifers, such as the Mt. Simon aquifer, yield water that is very old,

Water Savings Due to Metering

The American Water Works Association recommends that every water supplier meter all water taken into its system and water distributed from its system to its users. The Cities of Farmington and Loretto serve as examples of the potential water savings due to installation of customer water meters. After customer water meters were installed in 1993-1994, the City of Farmington's customers reduced total water use by 25% during the first year of metering. The City of Loretto installed customer water meters in 1989; total water use declined 28% from 1988 to 1994 while the city's population increased 34%. Customers reduce water used because they pay for water based on their actual water use.

recharge historically has been available to resupply the aquifers.

This area also faces its challenges. Cave and sinkhole features found in southeastern Minnesota can allow quick contamination of the ground water. In the bedrock source area, water supply for an expanding population density competes with surface water features such as lakes, wetlands, fens, and trout streams. Many of these surface water features are connected to and supplied by the ground water sources. In addition, each community has developed separate water supply systems, which can lead to conflicts between communities and other uses including the needs within the surface water resources.

Urban development is increasing the amount of the land surface that is paved, which reduces the available seepage of water into the ground to recharge the aquifers. The paving of the land surface and the channeling of precipitation away from the land surface to run off as surface water through storm drainage reduce ground water recharge and, subsequently, the availability of water.

In the Twin Cities metropolitan area, most communities maintain their own water supply system. This method of public water supply can lead to wasteful and redundant water supply systems. Cooperative regional water supply systems drawing from both ground and surface water sources can result in greater efficiency and less stress on water resources. Water conservation techniques, such as restrictions on lawn watering and the reuse of water used in manufacturing, should be employed to reduce demand and preserve the water supply for future growing urban development. Reducing future demand for water through careful community and land use planning is also recommended.

Climate Variability

The impact of climate must be included in all evaluations of water availability in Minnesota. Human activity aside, surface and ground water quantity is driven by the balance between atmospheric input from precipitation and losses due to evapotranspiration. Minnesota's climate is highly variable from east to west and from north to south. 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 average (normal) annual precipitation across Minnesota is determined by proximity to these moist air masses coming northward out of the Gulf of Mexico. Therefore, southeastern Minnesota, averaging nearly 32 inches per year, receives more precipitation than northwestern Minnesota, averaging less than 19 inches. The normal annual precipitation for Minnesota (1961–1990) is 27.01 inches (Figure 5).

The presence of moist versus dry air masses also helps to determine the atmosphere's ability to absorb water vapor evaporating from soil and open-water surfaces, or transpiring from leaf surfaces (evaporation plus transpiration is called "evapotranspiration"). Western Minnesota, more frequently under the influence of dry air masses, has higher evapotranspiration rates than the eastern half of the state. Temperature plays an important role in determining the amount of energy available for evapotranspiration. Because spatial temperature patterns are determined mainly by latitude, southern Minnesota experiences more evapotranspiration than northern Minnesota.

Minnesota is on the boundary between the semi-humid climate regime of the eastern United States and the semi-arid climate regime to the west. Semi-humid climates are areas where average annual precipitation exceeds average annual evapotranspiration, leading to a net surplus of water. In semi-arid climates, evapotranspiration exceeds average annual precipitation, creating a water deficit. In Minnesota, the boundary between the semi-humid and the semi-arid climate regimes divides the state roughly into east-west halves as shown by the yellow transition band in Figure 6. In the transition and semi-arid zones the lesser precipitation plus increased evapotranspiration leads users to supplement precipitation by using more water from storage (i.e., ground and surface water).

Given the multiple weather scenarios affecting Minnesota, wide ranges of climatic outcomes are the norm. "Normal" is merely a midpoint about which climate fluctuates. Neither climate extremes nor long-term variability should be considered as aberrations, but rather treated as inherent components of a continental climate. Since climate records have been kept in modern times, dry periods have occurred over large areas of Minnesota in every decade of this past century. These dry periods are not abnormal and need to be factored into water use decisions.

Extremes are not only possible but also likely to occur. Such knowledge does not prevent their occurrence, but helps shape decisions and plans that lessen the impact of the extremes on human activity. When seen in this context, long-term efforts in water conservation, local water planning, flood damage reduction, identification of previously unknown aquifers, and use of all water supply sources take on increased importance.

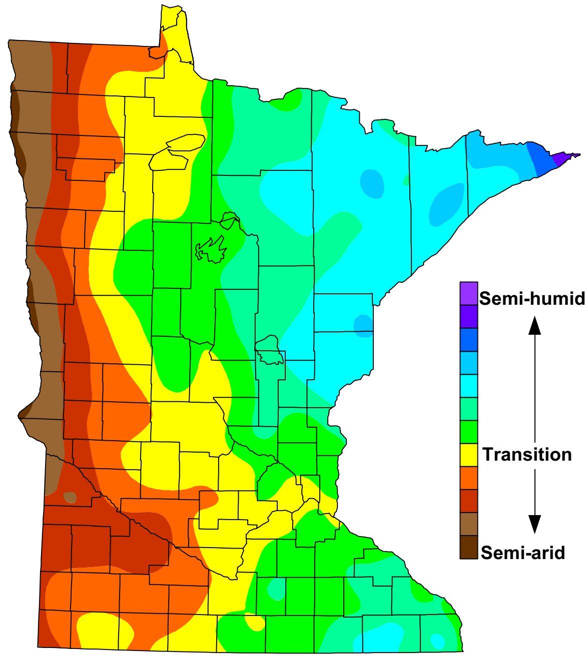


Figure 6. Precipitation minus evapotranspiration

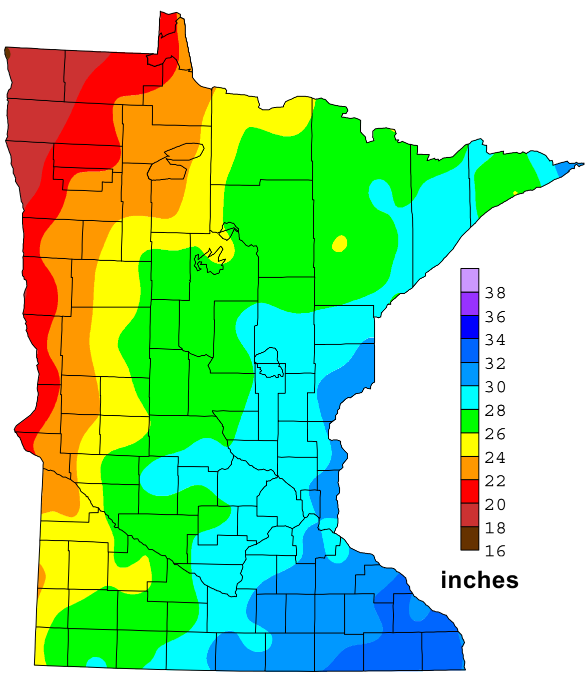


Figure 5. Normal annual precipitation

Surface Water

Minnesota has more than 20,000 protected water bodies and 870,000 wetlands*; 63,000 miles of natural rivers and streams**; and 23,000 miles of drainage ditches and channelized watercourses**. Of a total of 13.1 million acres in wetlands and lakes, 10.1 million acres are wetlands and the remaining 3 million acres are lakes. (*National Wetlands Inventory [NWI]; Based on the DNR Public Waters Inventory, there are 11,842 lakes greater than 10 acres in size and 10,029 wetlands. **Sources: United States Geological Survey [USGS] River Kilometer Index and Minnesota Department of Transportation Basemap surface hydrology project.)

Streamflow and Drainage Hydrology. Precipitation quantities (Figure 5) directly affect the amount and availability of streamflows, lake and wetland levels, and ground water supplies. Annual runoff (Figure 7) available to flow in streams is dependent on the amount of precipitation remaining after its consumption by human use, evaporation, and storage in lakes, wetlands, soil, and ground water. If, on average, more water is evaporated, stored, or consumed

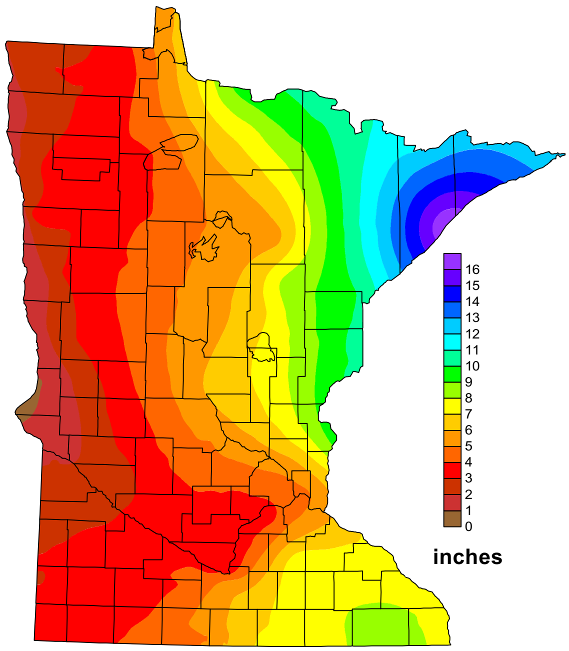


Figure 7. Average annual runoff (derived from USGS streamflow data)

than is available from precipitation, runoff or streamflow will be decreased and in the extreme case, the stream would go dry. Extremes can be the result of low precipitation (drought) or high consumption (human use exceeding supply, or high evapotranspiration) or both. Under scenarios that reduce streamflow, such as reduction in the amount of ground water augmenting the stream, precipitation may no longer be adequate to meet water supply and instream needs. (Instream needs include water needed to maintain flora and fauna, recreation, and ground water recharge.) The variable nature of the climate and water use over time and location results in water supply problems.

Land management practices designed to enhance land and resource use such as the installation of drainage ditches have significantly altered the surface water hydrology in Minnesota. To varying degrees, these changes have influenced the timing, rate, and volume of streamflows and water level fluctuations in lakes, wetlands, and ground water. Generally speaking, the loss of surface water storage and soil moisture can change the character of streams and wetlands. The watercourses shown in red on the surface hydrology and drainage patterns map (inside back cover) are the areas where most of the altered drainage has occurred.

Lakes. Pressures on Minnesota's lakes (Figure 8) continue to intensify as population grows and the demand for lakeshore residences continues to expand. Lakeshore use and development are often directly controlled by fluctuations in lake water levels and land use changes can adversely affect water quality.

All lakes experience water level changes. These changes are the result of precipitation variability, outlet and land use changes, ground water movement, and watershed size. Landlocked lakes have no surface outlet channels, often have small watersheds, and typically experience large, long-term water level fluctuations. As such, they can be good indicators of local ground water levels. Water uses that decrease ground water levels may have detrimental effects on these lake water levels.

Wetlands. Wetlands (Figure 8), like lakes, serve as water storage and transport systems and provide direct benefits to the environment. These benefits include floodwater storage and detention, nutrient assimilation, sediment entrapment, ground water recharge and discharge, low-flow augmentation of streams, aesthetics and recreation, shoreland anchoring and erosion control, and wildlife and fisheries habitat including habitat for rare plant and animal

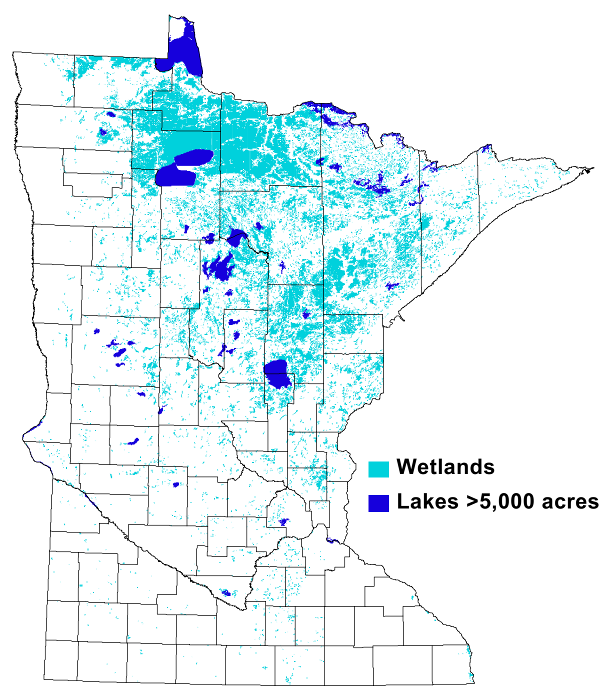


Figure 8. Lakes and wetlands of Minnesota

species. Benefits may vary according to the type, size, and location of the wetland or lake.

Wetlands once accounted for nearly one-third of Minnesota's total acreage. In the late 1800s and early 1900s, many wetlands of Minnesota's central forests and southern and western prairies were drained for agricultural development. Figure 9 displays the estimated pre-settlement wetland and water areas of Minnesota by defining the underlying soil conditions. Currently, less than half of Minnesota's original wetlands remain. They were lost primarily because of installation of drain tiles and ditches in the northwestern, western, and southwestern portions of the state (inside back cover).

Minnesota is nationally recognized for establishing a no-net-loss policy for wetlands. Local governments and state agencies such as the DNR and the Board of Water and Soil Resources, along with federal agencies, are

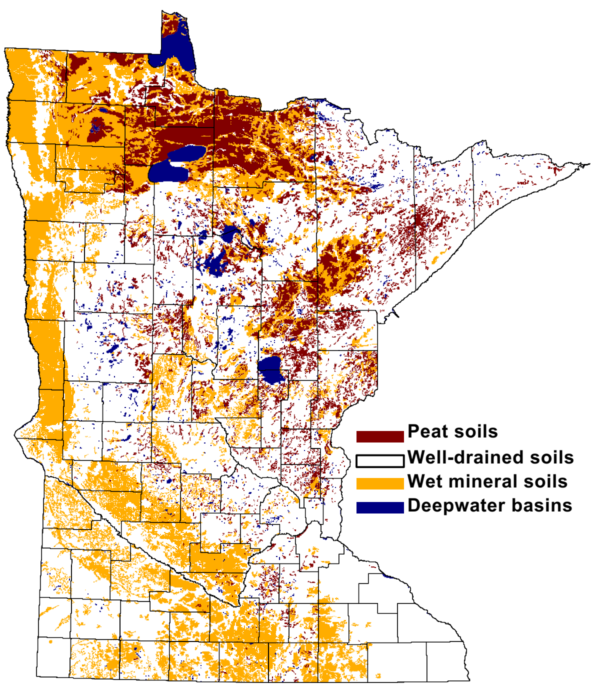


Figure 9. Pre-settlement mineral soils and wetlands

implementing programs aimed at protecting existing wetlands and restoring wetlands to replace those that are still unavoidably being destroyed. Restoration of wetland functions will benefit existing water and land resources of the state, as well as improve associated uses for humans and wildlife.

CONCERNS IN WATER USE AND PROTECTION

Increased demands on water resources create increased concerns and conflicts. Water supply sustainability, water supply interference, water quality issues related to water use, and ground and surface water interaction complexities are issues related to the impacts of development and growth.

Water Supply Sustainability

The distribution of the ground water supply does not necessarily match the distribution of demand, especially the demand for industrial and agricultural processing water use. The availability of a sustainable water supply should be a primary consideration in planning for development and economic growth.

Ground Water Sustainability. Sustainable ground water use requires "the development and use of ground water in a manner that can be maintained for an indefinite time without causing unacceptable environmental, economic or social consequences"*. (*USGS Circular 1186)

Ground water aquifers can be sustained by limiting the drawdown of ground water levels only to levels that will be replenished by future recharge. This goal is easier to achieve in some source areas than in others. In some parts of the state, excessive pumping of aquifers has resulted in negative impacts on both humans and nature. One example is overpumping in the city of Dilworth in northwestern Minnesota. In 1996, the city contacted the DNR to investigate the "drying up" of two of its four municipal wells. From Dilworth's pumping records, water level data from DNR's observation well network, and well construction information, the DNR determined that the city had, during the previous 30 years, pumped more water from the wells than was restored to the aquifer through recharge capability, resulting in a nearly complete dewatering of the aquifer (Figure 10). The result was that the city had to restrict the pumping from these wells and start an expensive water supply exploration program to find new sources of water outside the city limits.

Water Consumption Trends. Water use for public water supply has steadily increased since a brief decline following the peak use during the drought of 1988 (Figure 11 and Figure 3). The use trends of public water supply follow those of agricultural irrigation and are due to large peaking demands on public water systems caused by lawn watering. Water use for industrial and agricultural processing varies from year to year, but industrial processing use has doubled in the last decade. Other water supply uses include water level maintenance (use of ground water to augment lake levels), air conditioning (once through cooling – the practice of extracting ground water for cooling then discharging that water to a surface water body), and specialty uses such as pollution pump-outs and aquaculture. Water level maintenance uses have been phased out during the past decade. Once through cooling use has decreased from 11.1 billion gallons in 1989 to 5.1 billion gallons in 1999 and is projected to fall below 1 billion gallons per year by 2011. Irrigation use is dependent on the weather conditions and rainfall from year to year. The average irrigation use can double in a very dry year such as 1988 or halve in a very wet year like 1993. The greatest amount of water used is for cooling purposes associated with power generation; however, most of that water is returned to the surface water source after use. Use for this purpose has increased about 20 percent over the past decade.

Interbasin Transfer. Transferring water from one watershed to another is sometimes suggested as a method to supply water to the more arid western and southwestern portions of the state. Eight states including Minnesota and two Canadian provinces, all surrounding the Great Lakes, have a charter that addresses notification and consultation on requests for interbasin transfers out of the Great Lakes Basin. Minnesota has serious concerns about such interbasin water transfers. Instead, the state supports the sustainable use of our existing resources and encourages water users to live within the means of their naturally occurring water supply.

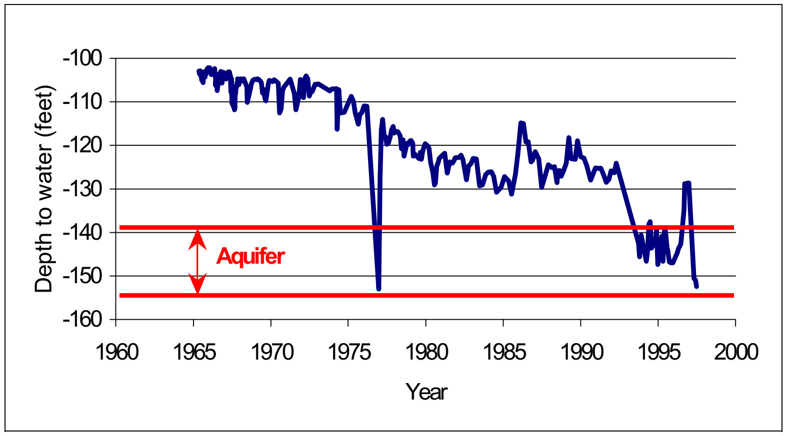


Figure 10. DNR observation well 14003

Water Supply Interference

Water supply interference occurs when water withdrawal affects a neighboring water resource. Most often this occurs when pumping from a high-volume well, such as an irrigation well, lowers water levels in a neighboring well (Figure 12). The potential impacts can range from short-term water

	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
Power Generation	508	539	637	663	664	698	694	679	722	765	747	710	701	785
Public Supply	171	170	192	203	174	164	170	175	164	178	176	187	182	188
Industrial Processing	109	76	69	94	120	102	115	158	127	120	161	148	159	169
Irrigation	49	30	67	103	86	71	60	63	30	56	62	80	58	77
Other	49	42	38	42	48	53	52	58	63	64	59	57	62	57
Total	**886**	**857**	**1003**	**1105**	**1092**	**1088**	**1091**	**1133**	**1106**	**1183**	**1205**	**1182**	**1162**	**1276**

Figure 11. Water use by type (billions of gallons)

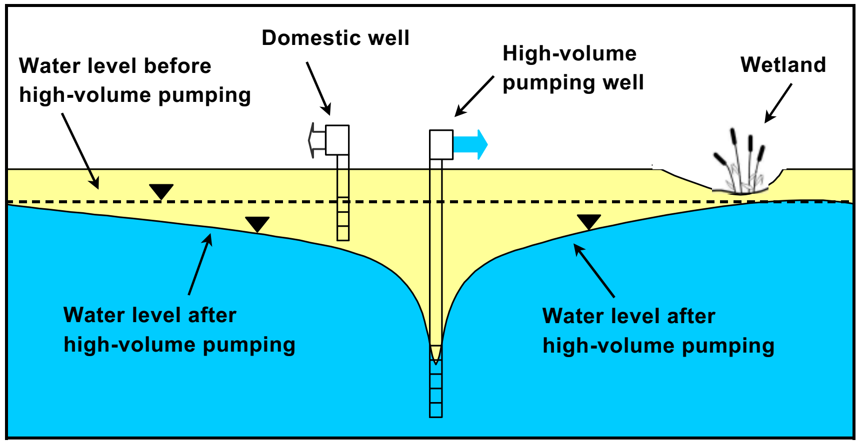


Figure 12. Water supply interference

level drops of a few inches to long-term declines of tens or even hundreds of feet in water level. These declines may affect neighboring wells in a variety of ways: no noticeable effect at all; dropping water levels below a pump intake or the bottom of the well; or, in a worst case, totally dewatering the aquifer near the neighboring well, rendering that well unusable (Figure 12, see domestic well). The DNR addresses approximately one dozen well interference complaints each year, of which approximately one third are found to be valid. In one 1992 case, the DNR received a well interference complaint from a domestic well owner in Benton County. An irrigation well drilled the previous winter was purported to be causing water levels in a domestic well to drop to the point where the well was out of water. Well construction information, historical water use data, and nearby water level data were reviewed, and a controlled pumping test of the irrigator's well was conducted by the DNR. This test showed that irrigation pumping had indeed caused the problem. To resolve the interference, the irrigator drilled a new well for the homeowner to an adequate depth so that the new well would not be put out of service by irrigation pumping.

Water Quality

High-capacity pumping and its direct and secondary impacts on water quality have become important issues in the past several years. Heavy pumping can cause changes in water quality within an aquifer. In particular, many concerns have been raised over the application of commonly used herbicides and pesticides on highly sensitive sand plain areas (glacial outwash source area). Near Rice in Benton County, the DNR is working with other state agencies, local irrigators, and domestic well owners to monitor the impacts of fertilizers, herbicides, pesticides, and septic systems on the ground water system and to ensure that all landowners employ the best management practices. Such practices as timing crop irrigation to soil moisture needs, adjusting both crop and lawn fertilization levels after soil nutrient testing, and properly constructing and maintaining animal waste handling facilities and home septic systems aid in limiting the extent of human impacts on the water supply. Urban sprawl with its increasing encroachment of residential development into traditionally agricultural areas, where irrigation may already exist, further complicates this issue.

Ground Water - Surface Water Interaction

Ground water pumping may affect a surface water body. The two most common effects are the direct capture or withdrawal of water from a water body, and the interception of water that normally would discharge at the land surface as springs or seeps, or flow directly underground into the wetland or stream (Figure 13).

Adverse effects on surface water bodies caused by ground water pumping have been documented throughout Minnesota. In the Twin Cities metropolitan area, the impacts of municipal pumping on trout streams and calcareous fens (unique wetland resources sustained by ground water) have caused several suburbs to relocate their wells to deeper aquifers or farther from a surface water body. Along the Minnesota River Valley and the historic Glacial Lake Agassiz shore in northwestern Minnesota, the rare plant communities supported by calcareous fens are in jeopardy from increased human activity and subsequent disturbance of ground water flow patterns. In northcentral Minnesota, several irrigation permits have been denied after documentation of pumping impacts on nearby wetlands. In some cases, deep aquifers not connected to the stream or wetland are available; in other cases, high-volume pumping is not a sustainable activity.

Quarry dewatering can affect nearby surface water bodies; instances of this are documented from the northern Iron Range pits, to the sand and gravel pits of western Minnesota, to the hard rock quarries of southeastern Minnesota.

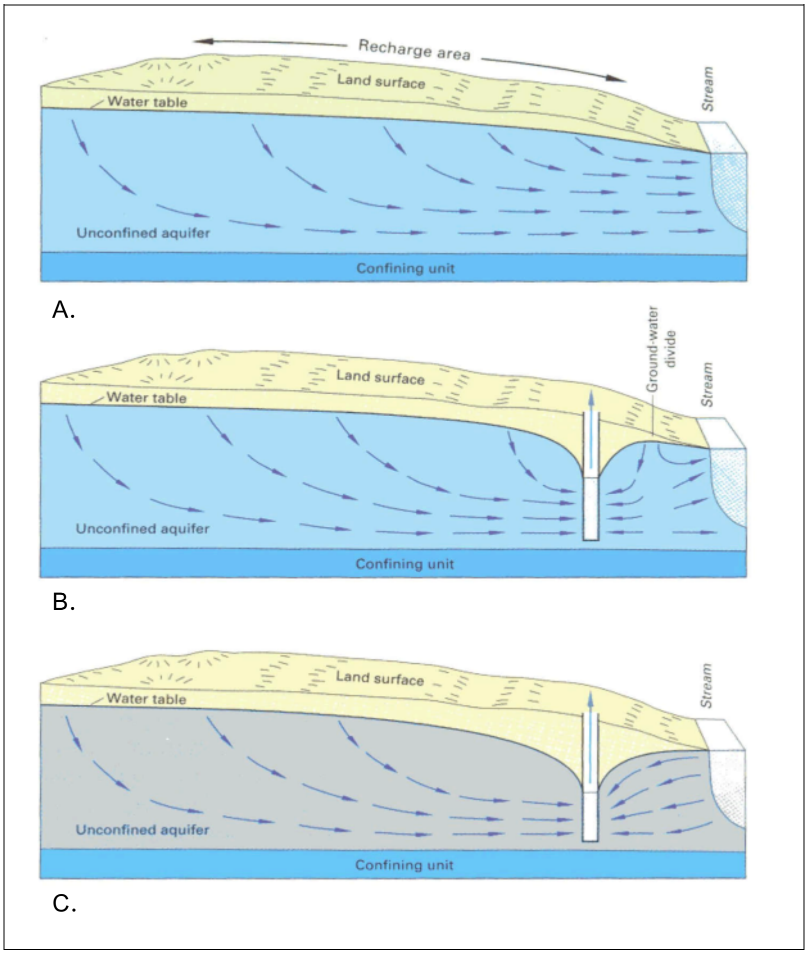


Figure 13. A. Normal streamflow, B. stream capture, and C. stream interception (USGS Circular 1139)

STRATEGIES FOR WATER SUPPLY MANAGEMENT

Although Minnesota appears to have a more than adequate supply of water, that appearance can be misleading. Increasing demand from domestic, agricultural, and industrial water users can strain water resources and municipal water supply systems, especially during periods of drought or emergency. The combined efforts of private citizens, special interest organizations, and government at all levels are leading to continual improvement in cooperative water resource management and wise use of the waters of the state.

Water Supply Assessment

For more than 50 years ground water, and surface water levels have been monitored in Minnesota, while climate records exist from more than 100 years ago. However, the historical monitoring record is limited in most of the state. Where monitoring records are available, they aid in resolving conflicts and planning for future uses. Monitoring networks are continually being evaluated. Recent increases in state funding have been used for additional monitoring in areas of increased ground water demand such as the metropolitan areas and areas of increased agricultural processing. In addition, efforts are being directed to locating new water sources in areas where growth is challenged by limited water supply or where water quality problems restrict water use from the commonly used aquifers. Monitoring of surface water has also been increased, and new efforts have been directed at understanding and resolving problems associated with flood warning, mine pit reclamation and renewed mining operations. Continued monitoring of all water resources is essential for their management.

During the last decade, the DNR and the Minnesota Geological Survey (MGS) have cooperated with several county governments to map their hydrogeology and geology. Local government planners and state agencies use these maps to understand human impacts on water resources and to manage those impacts.

When water supply conflicts occur or when a request for water use poses a potential conflict, evaluations of the water supply and demand are conducted by the DNR. These evaluations use data from many sources, including:

- DNR monitoring networks (climate, ground water, lakes, and streams),
- DNR water use data,
- DNR and Minnesota Department of Health (MDH) pumping tests,
- County Well Index,
- United States Geological Survey and MGS geologic and hydrogeologic studies, and
- MGS and DNR county and regional maps.

Suggestions for resolution of the conflict, which may include additional field investigations by the affected parties or the DNR, are then made to the involved parties. A limitation on the volume or pumping rates authorized by the water use permits is one of the alternatives that may be used to resolve the conflict.

Partnerships in Study and Protection

During the last several decades, numerous groups have cooperated in planning for the wise use of Minnesota's water supply. Groups such as irrigators' associations have funded studies of major regional aquifers. Other local, state, and federal agencies and private organizations have also worked together to understand, study, plan for, and resolve water issues. Recently in southwestern Minnesota, several cities, rural water districts, and the DNR cooperated in a program of exploratory drilling to identify previously unknown water supplies. In the iron mining district, the DNR, using Legislative Commission on Minnesota Resources and Iron Ore Cooperative Research funds, is leading studies to quantify the water balance components of enormous taconite pits. Also being studied are the effects of those mining operations on the downstream hydrology in populated areas, both during operation and after the mining operations cease.

In the last 15 years, local governments and individuals have increasingly participated in and directed the management of water resources in their areas. Local water plans have been written, rewritten, and revisited several times. This process has increased the awareness of the effect of land use decisions on human and water resource relationships.

Minnesota law requires that abandoned wells on private and public land be sealed to prevent ground water contamination. The DNR is charged with identifying and sealing unused wells on state lands. State managed land that was once in private ownership is being searched for old wells, which, when found, are sealed. In some instances, these wells are not sealed and are added to the observation well network to enhance the coverage of that monitoring network.

Two federal programs, Wellhead Protection and Source Water Protection, are being instituted in this state led by the MDH with participation by local governments and state agencies with water management responsibilities. The Wellhead Protection program is generating improved understanding of the physical impact of public water supply appropriations through pumping tests of wells and identification of land use practices that may affect the quality of the water supply. Data from these pumping tests are used by the DNR to investigate conflicts and to support permit requests. Water emergency and conservation plans approved by DNR also satisfy requirements for Wellhead Protection. Source Water Protection will help define land use practices that may affect all water supplies, both surface and ground water. Data collected through Source Water Protection Plan development may be used by communities to protect their water resources.

Conservation and Restoration

Water conservation plays an important role in balancing management objectives including both development and protection of Minnesota's water resources. The DNR is required by statute to develop and manage water resources to ensure an adequate supply to meet long-range seasonal requirements for domestic, municipal, industrial, agricultural, fish and wildlife, recreational, power, navigation, and quality control purposes. The increasing trend in water use illustrates a need for improved conservation efforts by all water users in the state to ensure the future

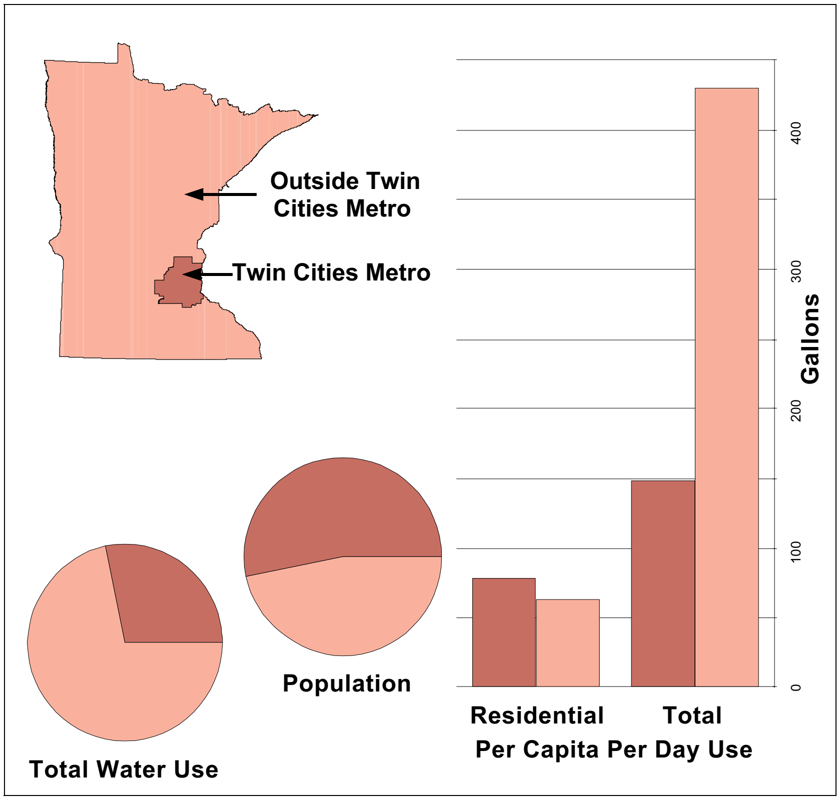


Figure 14. 1998 water use (excluding power generation)

use in a typical home can be reduced by nearly 20 gallons per person per day by using water-saving plumbing fixtures and practices. If just half of the state's population used water-saving fixtures and practices at home, domestic water consumption could be reduced by more than 17 billion gallons per year. Additional savings can be achieved through broader implementation of best management practices for lawn and landscape watering and other outdoor uses.

Balanced water conservation programs use a combination of voluntary and mandatory measures. Lawn watering schedules or emergency bans, home water audits, programs to retrofit water-saving fixtures, water recycling, and conservation rate structures can all be implemented to reduce water use. Education and information programs regarding the wise use of water are an important cornerstone to conservation efforts.

water supply. Since 1993, over 300 water utilities have developed water emergency and conservation plans to improve emergency preparedness and long-term water use efficiencies.

During the decade from 1989 to 1998, Minnesota's population increased by approximately 10 percent and overall water use in the state increased from 1,092 billion gallons per year to 1,276 billion gallons per year or approximately 17 percent. In 1989 (a drought year), total per capita use was 689 gallons per day. By 1998 (a normal precipitation year), total per capita use had increased 6 percent, to 731 gallons per day. On average, per capita water use in Minnesota is greater now than 10 years ago even though precipitation has returned to the normal range. Total per capita per day use is increasing faster than the population is growing due primarily to increased power generation and industrial processing.

There are many ways to reduce this growing pressure on our water resources. For example, research supported by the American Water Works Association indicates that water

As the population and economy of Minnesota grow, so will demands upon the available water supply. Effective conservation programs will become increasingly important for managing Minnesota's water supply for a sustainable future. The need to conserve water is not limited to the growing metropolitan areas. In 1998, while the residential per capita per day use was greater in the Twin Cities metropolitan area, the total per capita per day use was greater outside the Twin Cities (Figure 14). Further, more than half the state's population lived in the Twin Cities, however, the Twin Cities used only slightly more than one quarter of the total reported water used.

Many businesses and industries question the rationale for water conservation technologies. Nonetheless, money - possibly hundreds of thousands of dollars per year - may be flowing unnoticed out of their facilities. Water-using businesses in Minnesota that may be subject to such losses include dairies, grain processors, breweries, meat processors, and other food-related or industrial processing facilities.

For many managers, water is a little-noticed line item in the "cost of doing business" record sheets. When business managers learn that water sometimes costs the business owners a half a million dollars per year or more, they begin to take notice. Seeking the advice of competent environmental engineering experts has been paying off for several businesses and has stopped this "money drain".

One Minnesota business was able to reduce its costs by over $100,000 per year through improved technology and system redesign, and some businesses have saved considerably greater amounts (as much as $1 million in the first year). These savings can be realized by quantifying incoming and outgoing water and waste flows and then developing a plan to identify cost-cutting, water conserving opportunities such as water reduction, reuse or recycling options, updated plumbing or technology modifications, and training for plant operations personnel. All of these methods reduce water use and waste water generation.

The effects of growth and development on ground water levels generally lag behind the growth or development activities. For instance, as land is converted to urban use with storm sewers and paved surfaces or as drainage is redirected from wetlands to ditches for increased agricultural production, the patterns of ground water recharge are altered or interrupted. This decreases the amount of water that infiltrates into the ground to replenish the aquifers. Wetland restoration and preservation is one management technique that can be used to reduce the redirection of precipitation and surface water runoff that might otherwise have recharged the ground water. Safeguarding the natural recharge process in this manner can have a long-term positive influence on water supplies. A carefully planned approach to growth that considers the available water supply and water resource setting is the development strategy that can minimize the impacts on both the water and human resources.

Definitions of "per capita" terms

Total Per Capita Use – Total reported water use for all purposes divided by population. This term is not intended to reflect actual use by individuals.

Residential Per Capita Use – Municipal water supplied to residential customers divided by the population served by municipal water supply. This figure is intended to reflect average water use per individual in a household and includes indoor (bathing, clothes washing, etc.) and outdoor (lawn watering, car washing, etc.) use.

Regulation and Shared Responsibility

Historically, water resources have been managed using statutes and rules. Water use management by regulation has evolved since it was originally passed into law in 1937. Increased demand for water and subsequent conflicts have led the Minnesota Legislature to enact laws that establish water resource protection limits that help define the DNR's role in managing Minnesota's water resources.

Permits are issued for water appropriations, for work in public waters, and for dams. Under the water appropriation statutes and rules, priorities for water use (see insert box following) have been defined that protect higher priority water users from interference by other users. Other regulations protect natural water resources such as trout streams, calcareous fens, and major aquifers. Each statute helps maintain the potable water supplies necessary for everyday life while protecting natural resources. These statutes and rules are:

- Ground Water (M.S. 103G.261 and M.S. 103G.295, Subdivision 5). Domestic water supplies are protected from high-capacity water users. Statutes define water use priorities, and water uses may be limited to protect higher priority water users. Water allocation permit decisions are based on water use priorities established under statute.
- Water Courses (M.S. 103G.285, Subdivision 2). Water appropriations from water courses during low-flow periods may be suspended to protect water availability for instream uses and higher priority water users.
- Water Basins (M.S. 103G.285, Subdivisions 3 and 4). Water appropriations from basins

smaller than 500 acres are discouraged and require applicants to contact all riparian landowners on the basin. Water appropriations may not be allowed below a certain level (protection elevation), and the cumulative total volume of water that can be appropriated by all water users on the basin is limited to 6 inches off the surface of the basin.

- Trout Streams (M.S. 103G.285, Subdivision 5). Water appropriations from trout streams are limited to temporary projects during high-flow periods.
- Calcareous Fens (M.S. 103G.223). Calcareous fens are rare and unique wetlands that require persistent upwelling of ground water that is rich in calcium carbonates. Calcareous fens are home to a number of endangered or threatened plant species and are protected by statute from being filled, drained, or otherwise degraded, wholly or partially, by any activity. These resources are sensitive to changes in ground water levels caused by water appropriations.
- Mt. Simon-Hinckley Aquifer (M.S. 103G.271, Subdivision 4a). This is the deepest aquifer in the Twin Cities metropolitan area and has limited recharge. This statute protects this resource for potable water purposes and restricts new uses. New uses are allowed if there are no other alternatives and when conservation measures are being implemented.
- Natural Flows (MN Rules 6115.0220). DNR Waters is charged with maintaining natural flows and levels. Changing land and water use practices contribute to the difficulty in doing so.
- Interbasin Transfer (M.S. 103G.265). The DNR is required to develop and manage water resources including diversion out of state or out of the basin of origin. This specifically includes the Great Lakes Basin.

Regulations are one of the tools available to address ongoing management concerns throughout the state (Appendix A). These concerns range from limited water resource availability to increasing adverse impact to unique water resource features. Because water resources transcend governmental and private property boundaries, oversight and management of individual water uses through regulation and permitting is needed. This allows for consistent and equitable treatment for Minnesota water users and conservation of natural resources.

Water Use Priorities (M.S. 103G.261)

1. Domestic water supply, excluding industrial and commercial uses of municipal water supply, and use for power production that meets the contingency planning provisions of section 103G.285, subdivision 6;
2. a use of water that involves consumption of less than 10,000 gallons of water per day;
3. agricultural irrigation, and processing of agricultural products involving consumption in excess of 10,000 gallons per day;
4. power production in excess of the use provided for in the contingency plan developed under section 103G.285, subdivision 6;
5. uses, other than agricultural irrigation, processing of agricultural products, and power production, involving consumption in excess of 10,000 gallons per day; and
6. nonessential uses.

As an option consistent with regulation, appropriators have joined in the adoption of allocation plans, such as the Clearwater River Plan, which define restrictions and share the impact of those restrictions when the water supply is stressed by drought or increased demand. Similar plans have been implemented or encouraged in other areas where potential water use conflicts exist.
Another outgrowth of the need for shared responsibility is the evolution of local and regional water planning such as in the southwest Twin Cities area. A group of concerned community water suppliers and agencies meet regularly and have joined in research and planning to wisely allocate and protect limited water resources.

Unwise uses of ground water such as once through cooling and lake water level maintenance have been severely curtailed since 1989. This has resulted in a 6.4 billion gallons per year reduction in unwise water use. Implementation of water conservation measures such as water re-use technologies in industrial processing and the use of modified residential plumbing fixtures help to slow the increase in water use.

CONCLUSION

Industry, agriculture, housing, manufacturing, power generation, and well managed public water supply are all necessary elements to nurture and sustain communities. To maintain all the natural resource features that contribute to Minnesota's attractive quality of life, including fish and wildlife habitat and recreational opportunities, each growth and development decision needs to include consideration of its effect on the water supply and associated water resources. Careful consideration of the effect each use may have on the available water supply is essential for the sustainability of the water supply and the water supply's ability to be recharged for future growth, development, and enjoyment.

In order to ensure the future of our water supply, thoughtful water supply management, including conservation, restoration, study, and protection must be practiced. Only in this manner will Minnesotans continue to wisely control their water resource destiny.

FURTHER READING ON THIS SUBJECT

Water availability assessment reports - A biennial series of reports to the Minnesota Legislature. The 1998 report contains several localized examples of water supply issues:

- Minnesota Department of Natural Resources, DNR Waters, *1998 Water Availability Assessment Report, 1998*, 18p.

Water year data summaries - This biennial series of summaries contains a review and summary of basic hydrologic data gathered through DNR Waters programs including ground water, water use, climatology and surface water:

- Minnesota Department of Natural Resources, Division of Waters, *1997 and 1998 Water Year Data Summary*, 1999 (most recent publication), 80p.

Water plans and agency services– Sets the agenda for protecting and conserving water resources in the state and identifies service providers:

- Environmental Quality Board, Minnesota Planning Agency, *Minnesota Watermarks, gauging the flow of progress 2000 – 2010*, 2000, 45p.
- Environmental Quality Board, Minnesota State Planning Agency, *Minnesota Water Plan*, 1991, 44p.
- Minnesota Pollution Control Agency, *Ground Water, A Directory of Minnesota's Programs and Resources*, 1995, 13p.
- Local water plans available through county planning agencies.

Drinking water quality – Information about Minnesota's community water supply systems:

- Minnesota Department of Health, *Safeguarding a Precious Resource, A summary of Drinking Water Protection Activities in Minnesota for 1998*, 1999, 16p.

Hydrologic cycle – Discussion of the hydrologic cycle and the effects of land use practices on water quantity and quality:

- Wisconsin Department of Natural Resources through the Board of Water and Soil Resources, poster: *Ground Water and Land Use in the Water Cycle*;
- Soil and Water Conservation Society through MN DNR Waters, comic book: *Water in Your Hands*, 1990.

Aquifer sustainability – Concepts to consider to ensure the wise, sustainable use of our water supply:

- Alley, William M., Reilly, Thomas E. and Franke, O. Lehn, *Sustainability of Ground-Water Resources*, U.S. Geological Survey Circular 1186, 1999, 79p.;
- Minnesota Planning Environmental Quality Board, *Sustainable Development, the Very Idea*, 1998, 24p;
- Sophocleous, Marios,ed., *Perspectives on Sustainable Development of Water Resources in Kansas*, Kansas Geological Survey Bulletin 239, 1998, 239p.

Ground and surface water interaction – Understanding of ground water and surface water interactions:

- Winter, Thomas C., Harvey, Judson W., Franke, O. Lehn and Alley, William M., *Ground Water and Surface Water, A Single Resource*, U.S. Geological Survey Circular 1139, 1998, 79p.

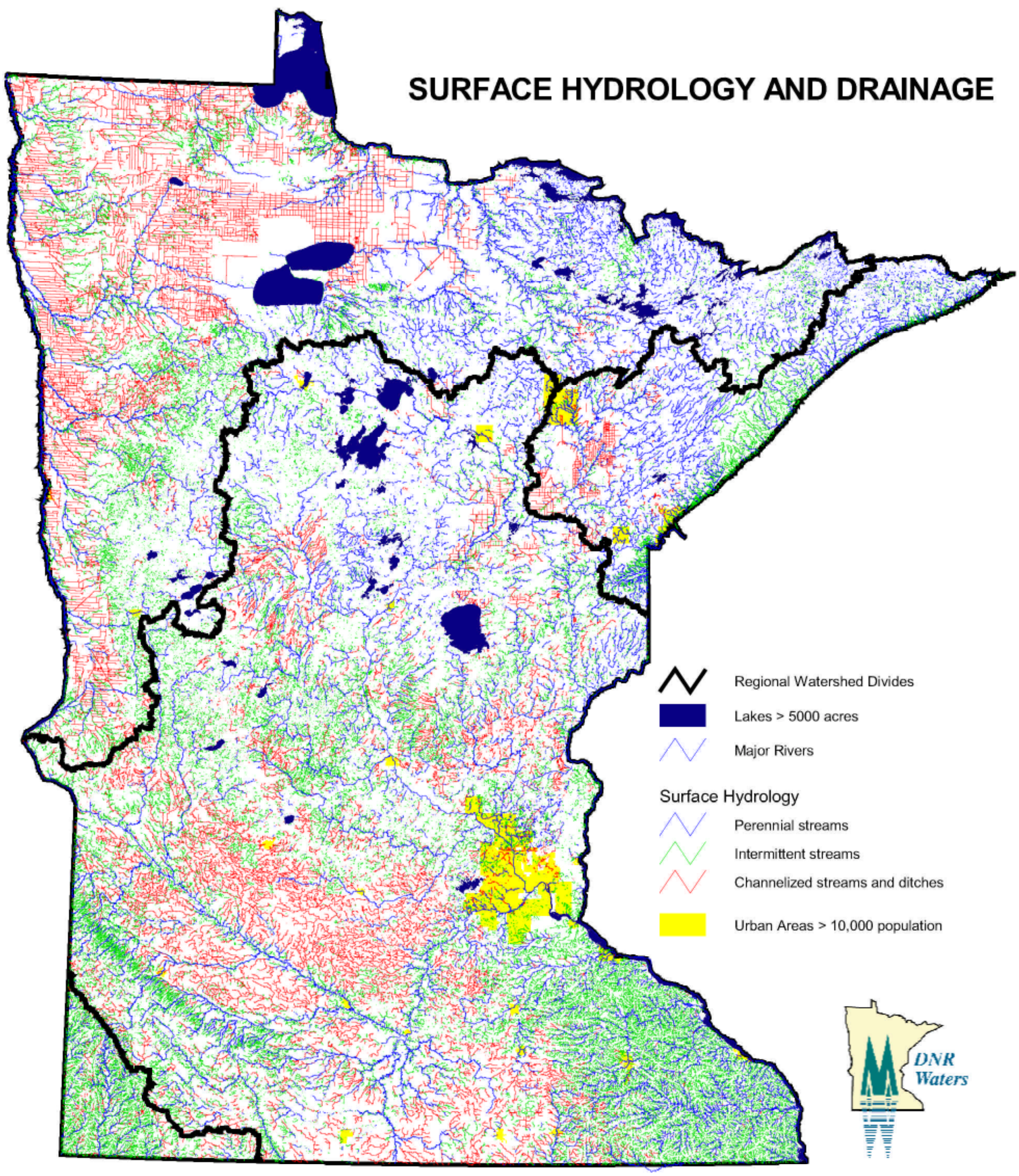
RELATED WORLD WIDE WEB SITES

- MN Department of Natural Resources, Waters Division – www.dnr.state.mn.us/waters
- MN Department of Natural Resources – www.dnr.state.mn.us
- MN Department of Health, Environmental Health – www.health.state.mn.us/
- MN Pollution Control Agency – www.pca.state.mn.us
- MN Department of Agriculture – www.mda.state.mn.us
- Minnesota Planning – www.mnplan.state.mn.us
- Board of Water and Soil Resources – www.bwsr.state.mn.us
- Minnesota State Government – www.state.mn.us
- Environmental Information – www.bridges.state.mn.us
- Metropolitan Council – metrocouncil.org
- Minnesota Geological Survey – www.geo.umn.edu/mgs/
- US Geological Survey – wwwmn.cr.usgs.gov
- US Fish and Wildlife Service – www.fws.gov
- American Water Resources Association – www.awra.org
- National Ground Water Association – www.ngwa.org
- National Water Resources Association – www.nwra.org/newsite
- US Environmental Protection Agency – www.epa.gov/
- Minnesota Rural Water Association – www.mrwa.com
- American Water Works Association – www. awwa.org
- Water Efficiency Clearinghouse – www.waterwiser.org
- Natural Resources Research Institute – www.nrri.umn.edu/cwe
- University of Minnesota Water Resources Center – wrc.coafes.umn.edu

Appendix A. Areas of water use and protection concerns (September, 2000)

Where or What	Use *	Water Supply Management Concern: Resource Sustainability	Water Supply Interference	Water Quality	Surface Water-Ground Water Interaction	Limitation	Water feature
Breckenridge (Wilkon Co.)	MU, IN	X				Limited recharge and over pumping	Wahpeton buried valley
Buffalo Aquifer (Clay Co.)	MU, IN	X	X			Limited recharge and over pumping	Buffalo aquifer
Buffalo Lake (Sibley Co.)	MU, E	X	X			Limited recharge and over pumping	
Camden State Park (Lyon Co.)	IN	X			X	Limited recharge and over pumping	
Dakota & Goodhue Counties	QD				X	Lk Byllesby, dolomite mine dewatering	
Dilworth (Clay Co.)	MU	X				Limited recharge and over pumping	Dilworth aquifer
Black Dog CF (Dakota Co.)	MU, IN				X	Legislative protection	calcareous fen
Felton Prairie CF (Clay Co.)	QD, IR				X	Legislative protection	calcareous fen
Ft. Snelling CF (Dakota Co.)	MU				X	Legislative protection	calcareous fen
Nichols CF (Dakota Co.)	MU, IN				X	Legislative protection	calcareous fen
Ogema CF (Becker Co.)					X	Legislative protection	calcareous fen
Ottawa CF (Le Sueur Co.)	QD				X	Legislative protection	calcareous fen
Savage CF (Scott Co.)	MU				X	Legislative protection	calcareous fen
Seminary CF (Carver Co.)	MU				X	Legislative protection	calcareous fen
Sioux Nation CF (Yellow Medicine Co.)	MU				X	Legislative protection	calcareous fen
Granite Falls (Chippewa Co.)	MU	X	X			Limited recharge and over pumping	
Great Lakes		X		X		Diversion/interbasin transfer	Great Lakes
Iron Range district	MU, QD	X		X		Mine reclamation & flooding, municipal	mine pits
land locked lakes					X	Aesthetic/growth/health (septic & wells)	
LPRW-Burr well field (Yellow Med. Co.)	MU	X			X	Legislative protection and no backup supply	Altamont, Pr. Coteau
LPRW-Holland well field (Pipestone Co.)	MU	X		X	X	Limited recharge and over pumping, water quality	
LPRW Verdi well field (Lincoln Co.)	MU			X		Legislative protection and no backup supply	
Luverne/Rock Co. RW (Rock Co.)	MU, IR		X	X	X	Limited recharge, water quality, legislative protection	Rock River aquifer
Marshall (Lyon Co.)	MU, IN	X	X		X	Limited recharge and over pumping	Dudley Aquifer
Missouri Basin/Hudson Bay		X		X		International boundary/diversion/interbasin transfer	Garrison Diversion
Mt. Simon aquifer (metro)	MU, IN	X				Legislative protection	Mt. Simon aquifer
Perham, Clitherall (Otter Tail Co.)	IR			X	X	Urban growth/agriculture conflict	upper sand plain
Straight River (Becker/Hubbard Co.)	IR				X	Legislative protection	
Renville (Renville Co.)	IN, MU	X			X		
Rochester (Olmstead Co.)	MU				X		Zumbro
Sedan/Glenwood (Pope Co.)	IR		X	X	X	Cumulative effect	
Stearns/Sherburne/Benton Cos.	IR	X	X	X	X	Urban growth/agriculture conflict	upper sand plain
Steele Co.	QD				X		
Swift Co.	IR		X		X		
TC Metro SW	MU, IN			X	X	Legislative protection-CF & Mt. Simon	
trout streams					X	Legislative protection, urban growth	Valley Cr., Browns Cr.
Windom (Cottonwood Co.)	MU, E	X			X	Limited recharge and over pumping	
Worthington (Nobles Co.)	MU, E			X		Limited recharge and over pumping	

* MU=municipal, IR=irrigation, IN=industrial, QD=quarry dewatering, E=ethanol production   CF=Calcareous Fen


SURFACE HYDROLOGY AND DRAINAGE
Regional Watershed Divides
Lakes > 5000 acres
Major Rivers
Surface Hydrology
Perennial streams
Intermittent streams
Channelized streams and ditches
Urban Areas > 10,000 population
DNR Waters

Minnesota
Department of Natural Resources
Waters

Helping people ensure the future of our water resources