STATUS OF GROUNDWATER QUANTITY IN WISCONSIN

WISCONSIN DEPARTMENT OF NATURAL RESOURCES

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LIST OF ABBREVIATIONS AND ACRONYMS

BCPC .... Brown County Planning Commission
BDWG .... Bureau of Drinking Water and Groundwater
Bgal/yr .... billion gallons per year
CWGC .... Central Wisconsin Groundwater Center
DNR .... Department of Natural Resources
GCC .... Groundwater Coordinating Council
GS .... Groundwater Section
LFRV .... Lower Fox River Valley
m^3/day .... cubic meters per day
Mgal/d .... million gallons per day
PPS .... Policy and Planning Section
PSC .... Public Service Commission
SEWRPC .... Southeast Wisconsin Regional Planning Commission
TAC .... Technical Advisory Committee
USGS .... U.S. Geological Survey
WGNHS .... Wisconsin Geological and Natural History Survey
WHP .... Wellhead Protection
Wis. Stats. .... Wisconsin Statutes

ACKNOWLEDGMENTS

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EXECUTIVE SUMMARY

Purpose of Report

In August of 1994, the Wisconsin Groundwater Coordinating Council (GCC) suggested that the Wisconsin Department of Natural Resources (DNR), in cooperation with the GCC and other interested parties, prepare a report describing groundwater quantity problems and issues in Wisconsin. This report was prepared by the Groundwater Section of the DNRs Bureau of Drinking Water and Groundwater with the assistance of a Technical Advisory Committee (TAC). The objectives of this report are to summarize what we know about Wisconsin's groundwater quantity problems; discuss information that is available on groundwater quantity and where more information is needed; and discuss potential options for addressing groundwater quantity issues.

Findings

Despite a general abundance of groundwater in Wisconsin, there is a growing concern about the overall availability of good quality groundwater for municipal, industrial, agricultural and domestic use and for adequate baseflow to our lakes, streams and wetlands. Groundwater quantity problems have occurred naturally and from human activities. Natural shortages of groundwater have occurred due to weather conditions (e.g., drought) and geologic setting (e.g., crystalline bedrock aquifer with low yields).

Human activities such as groundwater withdrawal and land use activities may also cause groundwater quantity problems. The effect of groundwater withdrawals are well documented on a regional scale in the Lower Fox River Valley, southeastern Wisconsin and Dane County. There are substantial declines in groundwater levels in these three areas.

Localized effects from groundwater withdrawals are not as well documented as the regional effects. Cases exist around the state where wells, springs and wetlands have gone dry; lake levels have dropped; streamflow has been reduced; and contamination has prevented installation of new wells.

The availability of groundwater may also be affected by groundwater quality. The presence of naturally-occurring substances in groundwater (e.g., iron, sulfate, arsenic) or human-caused contamination has limited groundwater use in some areas.

Information from the U. S. Geological Survey (USGS) indicates water use in Wisconsin has increased steadily since 1950. Groundwater use grew from 570 to 754 million gallons per day (Mgal/d) from 1985 to 1995.

Groundwater withdrawals can affect both groundwater and surface water. Declining groundwater levels from pumping may increase pumping costs due to the need to pump water from a greater depth, dewater or mine an aquifer until it no longer meets water supply needs, dry up nearby shallow wells (e.g., domestic wells), decrease baseflow (i.e., natural groundwater discharge) to lakes, streams, and wetlands and cause surface water to recharge a depleted aquifer. A loss of baseflow may harm fisheries or wildlife habitat.

There is an ongoing effort by state and federal agencies and university staff to gather data and information on groundwater quantity issues. The Wisconsin Geological and Natural History Survey (WGNHS) and the

USGS maintain a statewide groundwater-level observation network to evaluate short-term changes and long-term trends in groundwater levels. The USGS also maintains a network of streamflow gaging stations across the state to record surface water flow. Historical groundwater-level and streamflow data is valuable as we look at the relationship between surface water and groundwater.

Historically in Wisconsin, only a few research studies have focused on groundwater quantity issues. Currently, groundwater quantity studies are underway in Dane County, the Little Plover River Basin, the Lower Fox River Valley, and the Driftless Area. Because of the many factors involved, gathering definitive data on the effects of groundwater withdrawals is complex, time-consuming, and expensive. Additional information is needed to increase our understanding of groundwater-surface water interactions, identify areas with groundwater quantity problems and determine the impacts of groundwater withdrawals.

Under Wisconsin Law, chapter 281, Wis. Stats. (formerly ch. 144), the DNR is the "central unit of government to protect, maintain, and improve the quality and management of the waters of the state, ground and surface, public and private.” The DNR carries out these responsibilities through its Drinking Water and Groundwater, Watershed Management, Waste Management and Fisheries Management and Habitat Protection programs. The DNR regulates high capacity wells and surface water diversions. Other agencies involved in groundwater quantity issues include the WGNHS, Central Wisconsin Groundwater Center, GCC, Public Service Commission, the USGS, local units of government and water utilities.

Groundwater quantity will continue to be an issue of concern in Wisconsin. A coordinated effort is needed to determine appropriate management options for addressing groundwater withdrawals, to prioritize information needs and to implement information and education programs. Funding is needed for additional data collection and research to address groundwater quantity management issues.

INTRODUCTION

Approximately 70% of Wisconsin's residents and 97% of Wisconsin's communities rely on groundwater to meet their water supply needs. Groundwater is also the primary source of water for irrigated agriculture and is very important for industry. Streams, lakes, and wetlands are fed by groundwater; thus fish, other aquatic life, and wildlife are as dependent on abundant, clean groundwater as people.

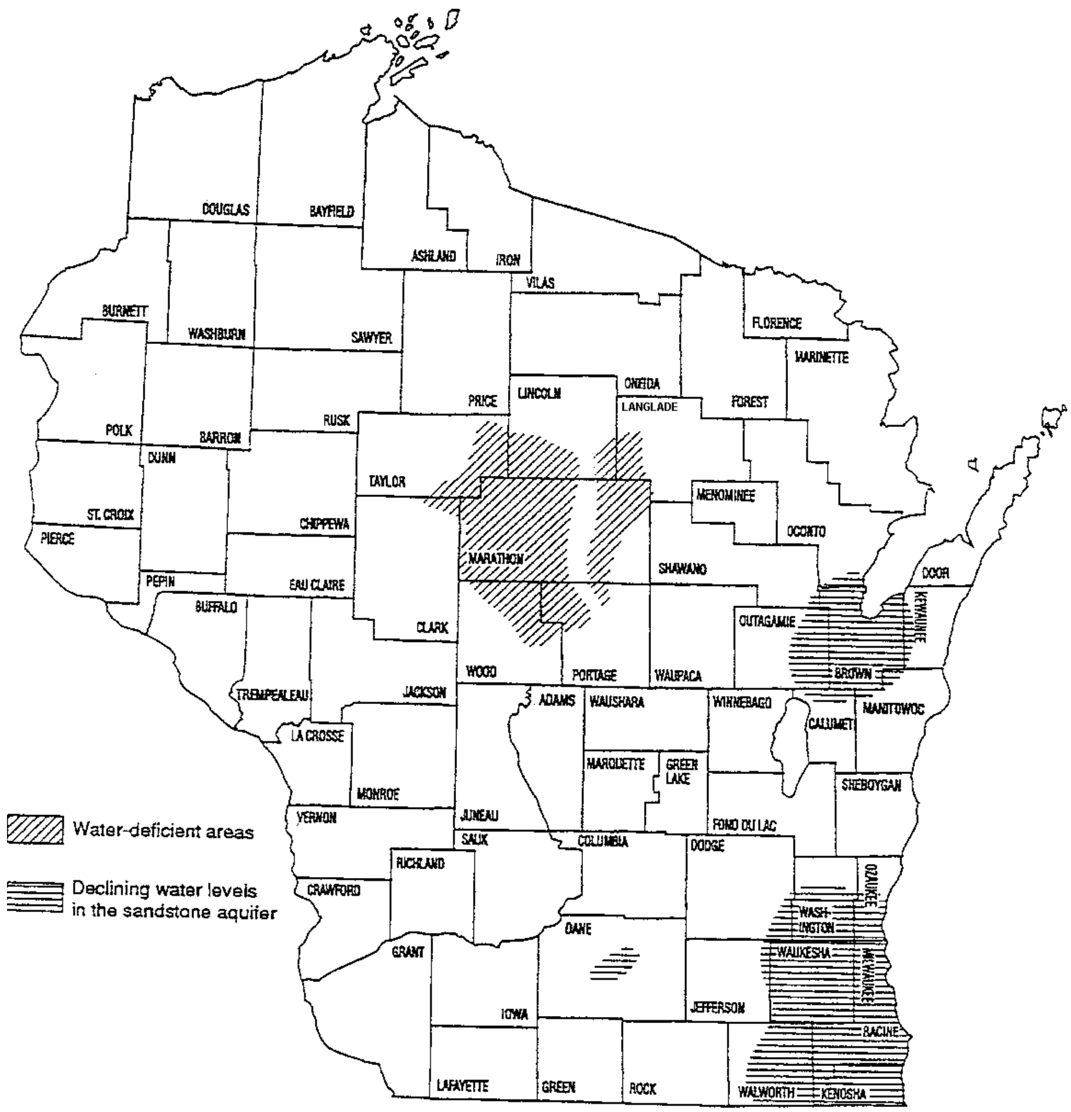
About two million billion (2,000,000,000,000,000) gallons of water are estimated to be stored underground in Wisconsin. That is enough water to cover the state to a depth of 30 feet (Ellefson, et. al., 1993). Despite this abundance of groundwater, there is a growing concern in certain areas of the state about the quantity of good quality groundwater available for municipal, industrial, agricultural, and domestic use, and for adequate baseflow, the groundwater that sustains our lakes, streams and wetlands.

There is concern about the regional effect of groundwater withdrawals on some aquifers of the state. For example, concentrated pumping by multiple high capacity wells in southeastern Wisconsin and the Lower Fox River Valley (Figure 1) have raised concern about the long-term effects of continued groundwater withdrawals from aquifers in these regions.

There are also several examples of local scale effects throughout the state from groundwater withdrawals by wells and groundwater dewatering operations. There has been a long-term interest in the impact of groundwater withdrawals, particularly high capacity irrigation wells, on flow in the Little Plover River in central Wisconsin. Groundwater levels in other local areas have declined due to quarry and mining operation dewatering. There are also concerns about effects on streams and wetlands in southeastern Wisconsin due to groundwater withdrawals from nearby high capacity wells.

In some areas of the state, it is difficult to find an adequate supply of good quality groundwater due to the existence of aquifer materials which do not yield much groundwater or groundwater that has been impaired by naturally-occurring substances or human caused contamination which make groundwater unfit for use. Parts of north-central Wisconsin are underlain by poorly productive, fractured crystalline rocks (see Figure 1) which yield sufficient groundwater for domestic wells but not for large water supply wells. In some parts of the state, groundwater contains naturally-occurring substances (e.g., sulfates, iron, chlorides, arsenic, radium) which limit water use. Human caused contamination has reduced the water quality in several areas throughout the state which limits the supply or accessibility of good quality groundwater. Nitrates and pesticides are common contaminants caused by humans in groundwater in agricultural areas. Shallow aquifers tend to be more susceptible to human contaminants whereas deeper aquifers are more likely to contain naturally-occurring substances which impair water quality.

In order to define the extent of groundwater quantity problems, the Wisconsin Groundwater Coordinating Council (see AGENCY RESPONSIBILITIES), at its August 1994 meeting, suggested that the Wisconsin Department of Natural Resources (DNR) prepare a groundwater quantity report. This report was prepared by the Groundwater Section of the DNR’s Bureau of Drinking Water and Groundwater with the assistance of a Technical Advisory Committee (TAC). The TAC members are listed on the inside front cover. The objectives of this report are to summarize what we know about Wisconsin's groundwater quantity problems; discuss information that is available on groundwater quantity and where more information is needed; and discuss potential options for addressing groundwater quantity problems and management issues. This report is the first step in addressing groundwater quantity in Wisconsin. It is hoped that this report will serve as a starting point for discussion and action to address the groundwater quantity concerns highlighted in this report.



HYDROLOGIC CYCLE

Only three percent of the world's water supply is actually available to humans as fresh water. Of this small amount, 98% exists as groundwater. To understand the occurrence and movement of groundwater in a particular locality, it is necessary first to understand the interactions between water, land and the atmosphere, which is called the hydrologic cycle (Figure 2). This cycle begins as water evaporates from water bodies, land surfaces, and vegetation. The water vapor moves through the atmosphere until it condenses into droplets, which then fall onto the land or water as precipitation.

Precipitation that falls on land continues through the hydrologic cycle via a number of different flow paths. If the ground is impermeable or saturated, some water will flow across the land surface to streams and lakes as overland flow. If the land surface is permeable and not fully saturated, water will filter into the ground. Some of that water will be taken up by growing plants and transpired back into the atmosphere. The rest of the water will continue to move downward under the influence of gravity. At some depth, the downward moving water will reach the water table where the subsurface geologic materials are saturated. Groundwater, the water contained in the subsurface, moves via gravity through porous geologic materials and primarily discharges to lakes, streams, springs and wetlands as baseflow or to wells when pumped.

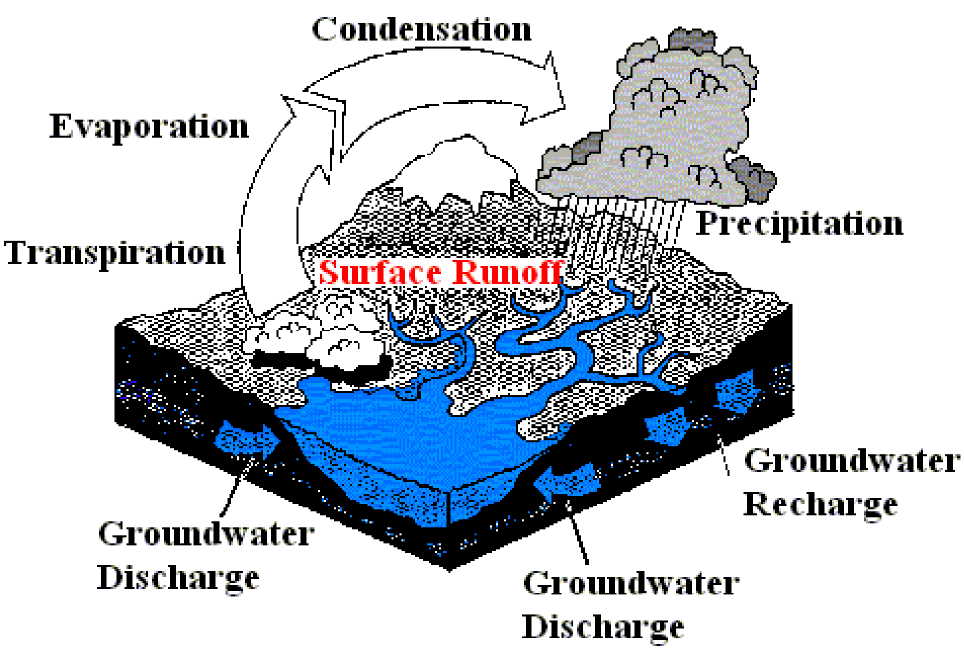


Figure 2. Hydrologic Cycle (Source North Dakota State Water Commission)

Geologic materials which yield useable amounts of groundwater are called aquifers. Sand, gravel, dolomite and sandstone are common aquifer materials. The upper surface of the saturated zone is called the water table and such aquifers are unconfined aquifers. Aquifers may be bounded at the top and/or bottom by impermeable layers called aquitards or confining beds; these aquifers are confined aquifers. Where the aquifer is overlain by confining beds, the water surface is called the potentiometric surface. The confined aquifer is under pressure so the potentiometric surface is likely to be above the top of the aquifer. Flowing wells are wells in confined aquifers in which the potentiometric surface is above the land surface. Typically deeper wells encounter confined aquifers.

WISCONSIN'S AQUIFERS

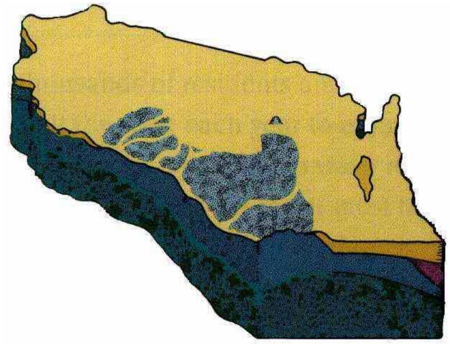
Wisconsin is favored with thick sequences of permeable deposits across most of the state forming four major aquifers that yield water to wells (Figure 3).

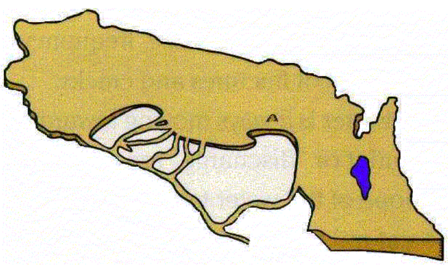
The **sand and gravel aquifer** consists of unconsolidated deposits of sand and gravel that occur over approximately 70% of the state. This aquifer includes primarily glacial deposits except in the Driftless area in southwest Wisconsin where this aquifer occurs as alluvial deposits (materials deposited by a river). The sand and gravel aquifer is not continuous, but consists of lenses and layers of sand and gravel interspersed with other fine grained or other low permeability deposits. Well yields are variable for this reason and depend on the permeability and thickness of the sand and gravel at a particular location.

The **Silurian dolomite aquifer** is limited to eastern Wisconsin and consists mostly of dolomite with some shale. Water yields from this aquifer depend on the number of continuous and connected fractures and solution openings that are intersected by a well. This aquifer is underlain by the Maquoketa Shale which doesn't transmit water easily and is, therefore, a confining layer between the dolomite aquifer and underlying sandstone aquifer.

The **sandstone aquifer** consists of alternating sequences of Cambrian and Ordovician age sandstone and dolomite with some shale. This aquifer underlies the Silurian dolomite and Maquoketa Shale in eastern Wisconsin and directly underlies the sand and gravel aquifers over the southern two-thirds of the state; in the Driftless area of southwestern Wisconsin it is near the land surface. Well yields from this thick, productive aquifer are high.

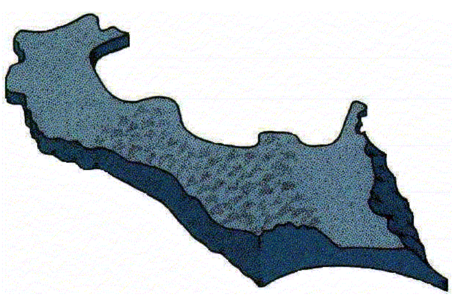
The **crystalline bedrock aquifer** underlies the entire state and consists primarily of granitic and metamorphic rocks of Precambrian age. It directly underlies the glacial deposits in the north central portions of the state, elsewhere it is covered by Cambrian age and younger sedimentary rocks. Groundwater comes from fractures that exist in the rock and yields are typically low (Ellefson, et. al., 1993).

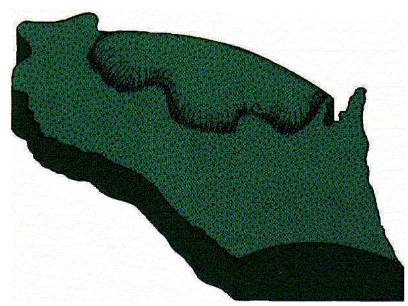




1) The Sand and Gravel Aquifer

2) The Silurian Dolomite Aquifer





3) The Sandstone Aquifer

4) The Crystalline Bedrock Aquifer

Figure 3. The occurrence of the four major aquifers in Wisconsin. The Silurian dolomite aquifer is present only in eastern Wisconsin. The crystalline bedrock aquifer underlies the entire state and is the only bedrock aquifer in the northern quarter of the state (see solid line).

GROUNDWATER QUANTITY PROBLEMS

PROBLEMS CAUSED BY NATURAL CONDITIONS

Generally, groundwater levels vary seasonally. Groundwater levels in shallow aquifers tend to fluctuate at greater frequency and extent than do groundwater levels in deeper aquifers and confined aquifers because recharge reaches the shallow aquifers more quickly. In spring, groundwater levels rise rapidly due to recharge from snow melt and rain. In summer, groundwater levels gradually decline because of uptake of infiltrating water by plants, decreased rainfall, increased evaporation, and groundwater discharge as baseflow to lakes, streams and wetlands. Groundwater levels often rise in the fall due to reduced evapotranspiration and increased precipitation. A decline during winter occurs because precipitation is stored on the surface as snow, frozen ground prevents infiltration and groundwater is still being lost by discharge to streams, lakes and wetlands.

Longer cycles (years, decades and longer) of gradual groundwater level changes can result from consecutive years of above or below normal precipitation. In 1977, unusually low precipitation reduced groundwater levels, causing many wells in Wisconsin to go dry. This forced residents to reconstruct wells to greater depths or truck water for livestock and personal needs. The lower groundwater levels also resulted in less baseflow, lower lake levels and the drying up of some wetlands. In 1994, water levels in many Wisconsin wells remained above normal levels after the 1993 flooding event which had a significant effect on groundwater levels in the state. Figure 4 shows the variation in precipitation and water levels from a series of Wisconsin wells over the period from 1986 to 1994 (Zaporozec, 1995).

Geologic conditions may also limit the availability of groundwater. For example, a portion of north-central Wisconsin is underlain by poorly productive, fractured crystalline rocks (Figure 1) where the sand and gravel aquifer is thin or absent. This area includes most of Marathon County and parts of Clark, Wood, Portage, Taylor, Lincoln and Langlade Counties. In these areas, yields of groundwater during dry seasons are too low in most places to sustain large water supplies, but there is generally enough water for domestic wells.

It is apparent that the availability and quantity of high quality groundwater differs considerably from area to area, depending on the character and thickness of water-bearing geologic formations, their connection with underlying and overlying rocks and soil characteristics, and discharges of groundwater to surface waters. The percent of precipitation (i.e., rain and snow melt) that recharges groundwater varies from nearly zero in parts of eastern Wisconsin where there are mainly low permeable soils, to well over 50 percent of annual precipitation in the central portions of the state where sandy glacial deposits allow significant infiltration (GCC, 1995).

Geologic conditions may also make certain portions of the state more susceptible to groundwater contamination which can impair groundwater quality and quantity. For example, Door County is underlain by thin soils over fractured Silurian dolomite which allow most contaminants to reach groundwater easily and quickly with little or no attenuation. Seasonal bacteriological contamination is common in Door County. Because of Door County's susceptibility to contamination, there are special well construction requirements for the county.

The central region of the state is underlain by sandy glacial deposits which provide little attenuation of

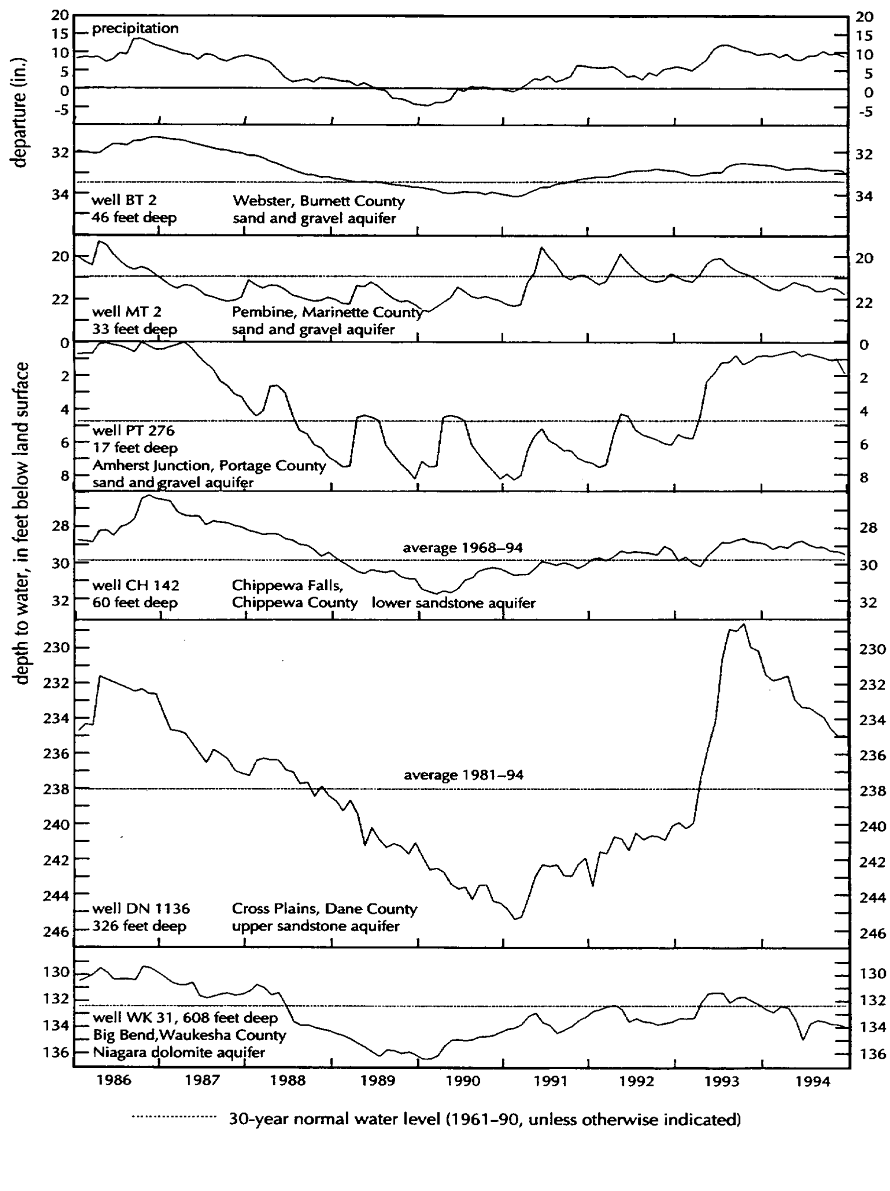


Figure 4. Cumulative departure from normal monthly precipitation in Wisconsin and fluctuations of water levels in selected key wells. (Source: WGNHS)

contaminants. Because of significant agricultural activity in this part of the state, pesticides and nitrate contamination of groundwater is an increasing concern (Wisconsin DNR, 1987).

The availability of good quality groundwater may also be limited by naturally-occurring substances in groundwater which are of concern for public health or welfare. See discussion of Groundwater Quality Effects on Groundwater Quantity for more information.

The examples listed above are illustrative of the groundwater quantity problems caused by natural conditions. The examples are not meant to be inclusive of all such problems.

PROBLEMS CAUSED BY HUMAN ACTIVITY

Human activities such as groundwater withdrawal, land use activities which reduce groundwater recharge, and contamination of groundwater can decrease the quantity of good quality groundwater for human use and other purposes.

Groundwater Withdrawal Effects on Groundwater Quantity

When groundwater is pumped by a well or set of wells, the groundwater level, either the water table or potentiometric level, will decline near the well as groundwater is removed from aquifer storage. This decline (typically referred to as "drawdown") is usually small when a domestic well is pumped; however, this decline may be quite large in areas where a single or multiple high-capacity wells (e.g., municipal, irrigation and industrial wells) pump large quantities of groundwater (Patterson and Zaporozec, 1986). Drawdown is greatest at the well withdrawing water and is smaller away from the well, creating a "cone of depression" around the pumping well. In general, the greater the pumping rate, the larger the cone of depression as water is pulled from greater distances from the well.

Groundwater quantity problems arise when wells are spaced too closely together (which can lead to interference between wells) or the aquifer is overpumped or both. In these cases, excessive drawdown occurs because of constraints on the aquifer due to the ability of the aquifer to transmit water or boundaries which inhibit groundwater movement. The practical implications of groundwater withdrawal that occurs due to well interference or pumping at too high a rate include: increased pumping costs because the pump has to lift water a greater height, lowered well yield, dewatering or mining of an aquifer until it no longer meets water supply needs, drying up of nearby shallow wells (e.g., domestic wells), and recharge of surface water to groundwater. Dewatering of a deeper aquifer may draw water from a more shallow aquifer, depleting the more shallow aquifer as well as inducing contaminants from the surface. Groundwater withdrawals may also decrease the amount of groundwater discharged as baseflow to streams, springs, lakes, and wetlands. Groundwater normally provides baseflow to surface waters; streams which receive groundwater as baseflow are called gaining streams.

Baseflow may make up the entire streamflow at times when runoff is not occurring. Excessive groundwater withdrawals may also reduce groundwater levels to the point that surface water recharges groundwater rather than the other way around. Such streams are called losing streams. A reduction in baseflow could also impact the habitat and change plant and/or animal communities, either because of a reduction or elimination of the amount of water available or a change in the water chemistry.

The degree and magnitude of these effects on groundwater and surface water vary depending upon several factors including, but not limited to: (1) the amount of groundwater stored in the aquifer and the ability of a well or wells to capture it; (2) the ability of the aquifer to transmit groundwater; (3) pumping rates, capacities, spacing, depths, and capture zones of the wells intersecting the aquifer; (4) the amount of recharge to the aquifer; and (5) the amount of groundwater that discharges to surface water that can be captured by the well's cone of depression.

Regional Scale Effects

The effects that groundwater withdrawals have on aquifers are seen at both the regional and local scale in Wisconsin. The most noticeable and best documented regional scale effects of groundwater withdrawals occur in the Lower Fox River Valley, southeastern Wisconsin, and Dane County.

Pumping from high-capacity wells in the Lower Fox River Valley (LFRV) in northeastern Wisconsin is causing a substantial drawdown in the sandstone aquifer which is the principal source of water supply for the LFRV. The LFRV includes two major areas of groundwater pumping - the Green Bay metropolitan area and the Fox Cities area near the north shore of Lake Winnebago. Recent groundwater level measurements indicate that the cones of depression from these pumping areas have merged so that pumping in one area affects the other (Figure 5).

The City of Green Bay pumped large quantities of groundwater until 1957 when it switched to Lake Michigan to supply most of its water needs. Green Bay currently uses groundwater wells only as a supplemental supply to meet summer demands. Between the late 1800s and 1957 pumping caused the potentiometric level in the sandstone aquifer in Green Bay to decline from 95 feet above the land surface (i.e., flowing well conditions) to 200 to 250 feet below the land surface. After the city switched to Lake Michigan as its water source, groundwater levels rebounded to approximately 50 feet below land surface by 1961. However, since 1961, there has been a gradual decline in groundwater levels due to increased groundwater pumping from nearby industrial and municipal wells. The cone of depression in the potentiometric surface is centered near De Pere where water levels have declined over 400 feet since pumping began.

Water use estimates for the Green Bay metropolitan area predict an increase of approximately 27 percent between the years 1990 and 2015 (Consoer, Townsend & Assoc, Inc. 1992).

DNR Public Water Systems staff have worked with the Brown County Planning Commission (BCPC), local municipalities, utilities and the USGS for several years to address water use in the Green Bay area. Under the leadership of the BCPC, a report was prepared which recommended that the suburban area

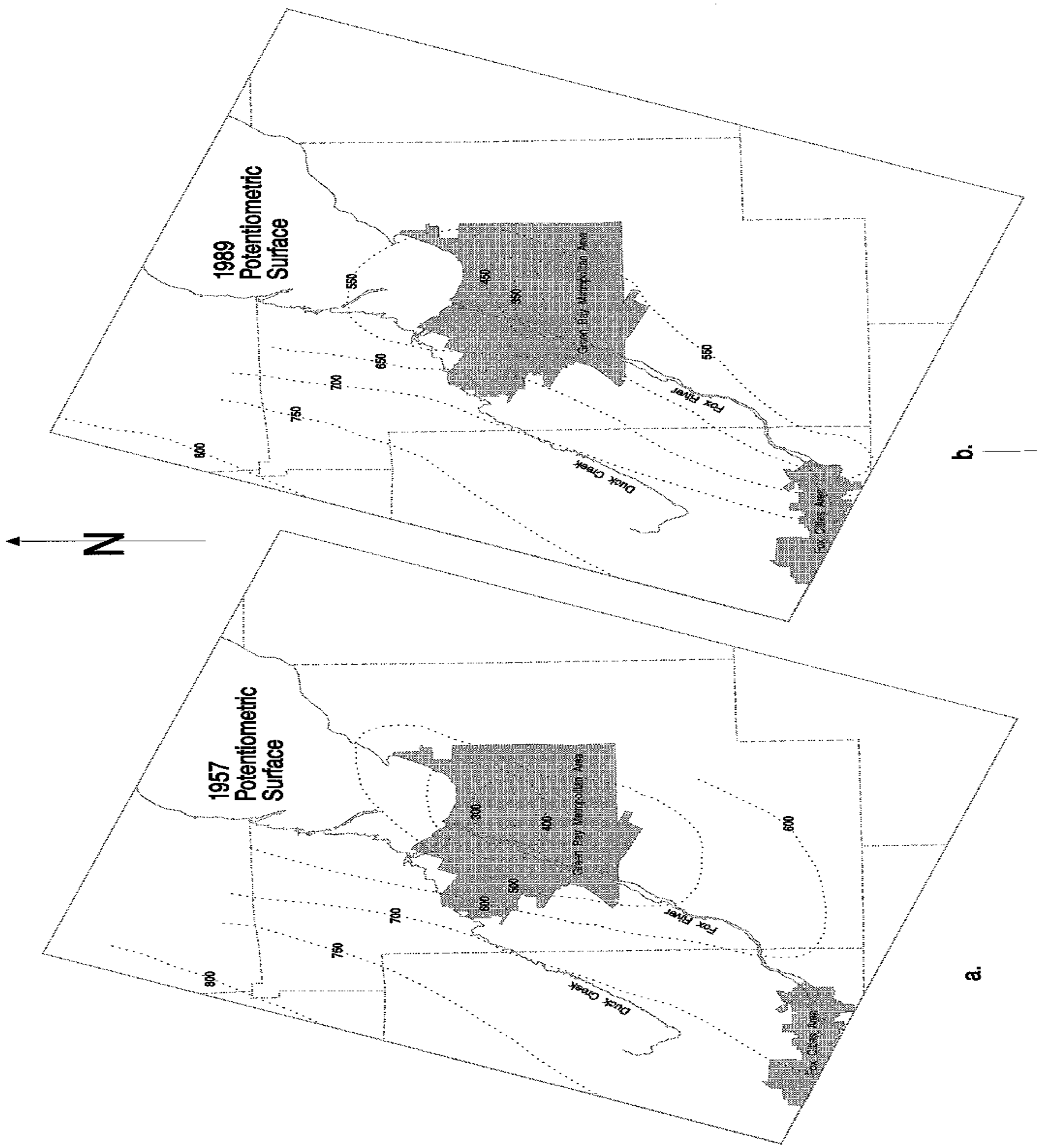


Figure 5. Measured water levels in the sandstone aquifer: a) prior to installation of pipeline in 1957 and b) in 1989. Altitude of water level is relative to mean sea level (Source: USGS).

consider use of surface water to meet the anticipated water demand in the future. At the present time, this option is being investigated.

There has been some preliminary discussion on water use in the Appleton area but no local agency or organization has taken a leadership role in organizing action to address the issue in a coordinated manner.

Another area experiencing declining groundwater levels as a result of groundwater pumping is southeastern Wisconsin (Figure 1). Pumping from the sandstone aquifer in the Milwaukee-Waukesha area began in the late 1800s. The potentiometric surface was near the land surface and in some cases above the land surface. Since the 1880s, groundwater pumping in the Milwaukee-Waukesha area and northeast Illinois has reduced the potentiometric surface by as much as 350 feet in the Milwaukee-Waukesha area and 275 feet or more near the Wisconsin-Illinois state line (SEWRPC, 1995). Originally, groundwater flowed east and discharged into Lake Michigan. Now, Lake Michigan recharges groundwater in the Milwaukee area.

Groundwater levels have also declined in the City of Waukesha. Historical drawdowns in municipal wells constructed from 1927 to 1980 range from 69 feet in one well to as much as 336 feet in another. The groundwater level in one City of Waukesha well was 40 feet below land surface in 1915. By 1980, the water level in the same well had dropped to between 450 and 475 feet below land surface. The average rate of water level decline in this well is about 6 feet/year. These decreases in groundwater levels cause aquifer dewatering and increased pumping costs due to the greater water lift requirements (Schaver, 1995).

DNR Public Water Systems staff have worked with municipalities and utilities for a number of years to address water use in the Milwaukee area. Although there has been discussion on the issue, no local agency or organization has taken a leadership role in organizing action to address the issue in a coordinated manner.

Drawdowns in the LFRV and southeast Wisconsin are the result of significant groundwater withdrawals by closely spaced wells and slow recharge to the sandstone aquifer. Along eastern Wisconsin, the Maquoketa Shale is present as a confining layer between the Silurian dolomite and the sandstone aquifer. Recharge to the sandstone aquifer is severely restricted where the Maquoketa Shale is present.

Dane County has also experienced historical groundwater level declines resulting from groundwater pumping. Large withdrawals from the deep sandstone aquifer, beginning in 1882, produced a significant drawdown. McLeod (1978) modeled the maximum drawdown in the sandstone aquifer from 1882 to 1975. The drawdown was estimated to be 75 feet. Although this is a large drawdown, it has not significantly dewatered the aquifer. The drawdown has increased pumping costs due to increased lift requirements and decreased baseflow to some springs, streams, and wetlands in the area. An aquifer pumping test conducted in 1973 of a City of Madison well finished in the sandstone aquifer showed a hydrologic connection between the shallow sand and gravel and deep sandstone groundwater systems (Krohelski, 1995). Recent aquifer simulations performed by the USGS and WGNHS indicated reductions in baseflow to most of Madison's area streams and springs. Available information also indicates that the lakes in the Madison area are recharging groundwater due to groundwater pumping.

The situation in Dane County is complicated in that most groundwater withdrawn from the aquifer in the Madison area is not returned to the same drainage basin. Effluent from the Madison Wastewater Treatment

Plant discharges into Badfish Creek which carries the effluent out of the Yahara River drainage system. This diversion, along with induced recharge from the Madison area lakes to the pumped aquifer, has reduced baseflow in the lower Yahara River.

Because of concerns about drawdowns in the aquifer, the WGNHS, USGS, and Dane County Regional Planning Commission began a cooperative study in 1992 of the hydrogeology of Dane County to increase the understanding of groundwater/surface water relationships, and in particular, the effects that groundwater withdrawals have on surface waters. This effort is nearly complete. See the RESEARCH section for more details.

Local Scale Effects

Groundwater quantity problems are also seen at the local scale. An example is the historical mine dewatering activities in the lead-zinc mining region of southwest Wisconsin. Historical groundwater levels from a well near Shullsburg in Lafayette County illustrate the effects of different magnitudes of mine dewatering. From 1952 to 1957, groundwater levels near the mine declined from approximately 65 feet to 95 feet below land surface due to mine dewatering. In 1958, mine dewatering activities increased in the area to make it possible to expand the mine shaft; by 1959, the groundwater level had dropped to approximately 130 feet below land surface. After completion of the mine shaft, dewatering activities continued at a reduced rate as mining resumed in late 1959. Initially, groundwater levels rebounded rapidly, then slowed, and stabilized in the mid-1960s. Between the mid-1960s and 1979, groundwater levels reflected minor variations in pumping rates. In 1979, all mining in the area stopped and groundwater levels began to recover towards pre-mining levels (Patterson and Zaporozec, 1986).

Another example of a local effect occurred in Waukesha County. Residents of Lisbon Township in Waukesha County contacted the DNR in 1994 concerning decreases in groundwater levels of private wells. The DNR investigated these complaints and found that 19 private wells constructed between 1958 to 1976 had experienced approximately 30 feet of drawdown since the wells were first constructed. The suspected causes of these drawdowns were eight high-capacity wells distributed throughout the Town of Lisbon and dewatering activities by two nearby quarries (Schaver, 1995). Results of a three-dimensional groundwater flow model simulation indicated that over time, quarry expansion, accompanied by increased dewatering, will significantly lower groundwater levels in the area requiring the lowering of pumps in many private wells (Clite, 1992).

In an effort to examine the scope of local scale effects of groundwater withdrawals, a questionnaire was sent to DNR District offices in 1995. The thirteen questionnaires returned described a number of local impacts, including decreased lake levels, reduced streamflow, reduced water levels in wetlands and wells going dry. For most of the cases, there was a suspected cause but not enough information to prove a connection.

Refer to the discussion of Groundwater Quality Impacts on Groundwater Quantity and Lakes and Streams for more examples of local effects from groundwater withdrawals. While these examples show evidence of impacts from groundwater withdrawals at the local scale, these impacts are typically not as well studied or as well documented as the regional effects discussed previously. Although the effects may be known, it is often difficult to determine with certainty the cause. These examples are not meant to be inclusive of all groundwater quantity problems caused by human activity.

Groundwater Quality Effects on Groundwater Quantity

Naturally-occurring substances in groundwater or groundwater contamination by human activity can limit the quantity of potable groundwater available. Naturally-occurring substances which impair groundwater include sulfates, arsenic, fluoride, radon, radium, uranium, chlorides, iron and manganese (Kammerer, 1981, 1995). High concentrations of naturally-occurring substances are common for bedrock aquifers where groundwater has been in contact with the rock formations for hundreds or thousands of years and minerals have had time to dissolve in groundwater. For example, groundwater collected and analyzed from private water wells and monitoring wells finished in the St. Peter Sandstone formation and the overlying Platteville/Galena Dolomite formation in northeastern Wisconsin contains elevated arsenic concentrations. These two formations supply most of the drinking water to a large portion of northeastern Wisconsin (Stoll, et. al., 1994). It appears that the arsenic contamination is related to a mineralized zone at the top of the St. Peter Sandstone of Ordovician age.

Naturally-occurring substances can create a number of groundwater quantity or quality concerns. For example, high sulfate levels found in the sandstone aquifer in Calumet County caused decreased milk production in dairy cows (Hennings, 1996). High levels of iron and manganese can cause encrustation of wells and subsequent decreased well yields; iron bacteria can form on the well casing to form a biofilm with similar results. Radon has been found in wells across the state, but most commonly in the north-central part of the state (Mudrey and Bradbury, 1993). Radium and uranium have also been found in groundwater from crystalline bedrock in north-central Wisconsin (Hahn, 1984).

Groundwater contamination can also limit the availability of good quality groundwater. Contaminated wells may need to be deepened or abandoned and replaced. Depending on the extent of contamination, there may be restrictions as to where a new well can be installed to avoid contamination of the new well. Records indicate about 60 municipal wells which are no longer in use because groundwater quality exceeds current water quality standards. Nitrate, volatile organic chemicals, and naturally-occurring radioactivity are the most common substances which exceed standards in these wells.

In some cases, contaminated well water has been mixed or blended with water from uncontaminated wells. For example, the City of Oconomowoc lost the use of its best producing shallow well when nitrate levels exceeded the drinking water standard. In an effort to obtain water of an acceptable quality, water from the contaminated shallow well is blended with water from a new, deeper well. The new deep well has naturally-occurring iron which requires the blended water to be treated for iron to make the water quality acceptable. The City of Chippewa Falls is another example where high nitrate concentrations led to blending of the high nitrate wells with other wells.

The cities of Janesville and Wausau both have abundant water supplies and also have contaminated wells. For both cities, Superfund sites are present within the zone of influence of at least one municipal well. In both cases, the cities are blending water from different wells as well as using air strippers to treat for volatile organic chemicals in groundwater.

These are a few but no means all of the situations in which groundwater quality has affected the availability of good quality groundwater.

Effects on Surface Waters from Groundwater Withdrawals

Lakes and Streams

Groundwater withdrawals not only lower groundwater levels but can also reduce the amount of baseflow discharging to surface waters. If there is good hydraulic connection between an aquifer and a surface water body, pumping can capture baseflow that normally discharges to the surface water body and, in some cases, induce flow from or dry up the surface water body (Krohelski, 1995). If baseflow to surface water is reduced, there may be a change in or loss of wildlife habitat or a decline in the fishery. For example, groundwater is normally colder than surface water. A decline in baseflow may raise the stream temperature and reduce the habitat for cold-water fish species. This reduction in quantity may ultimately result in a change in possible uses of the surface water, stream classification and/or more stringent discharge requirements for facilities which discharge to the river or stream. In those cases where surface water actually recharges groundwater, there may be a greater susceptibility of groundwater to bacterial contamination from surface water, especially in fractured bedrock.

The impact of groundwater withdrawals on surface water is of much concern in the Little Plover River basin in the Central Sand Plain of Wisconsin. The Little Plover River is a class 1 trout stream. Because of the permeable deposits, the Central Sands has been an area of extensive irrigated agriculture for many years. In addition to the large number of irrigation wells, the Village of Plover began making withdrawals from the Little Plover River groundwater basin for municipal use beginning in 1989. See the RESEARCH section for information on research in the Central Sands.

In 1989, the DNR Public Water Supply Section issued an approval that allowed for the installation of a high-capacity municipal well to serve the City of Wisconsin Rapids near a Class I trout stream. There were concerns raised by interested parties that the groundwater withdrawal from the proposed well might reduce baseflow to the trout stream; however, the DNR did not believe it had the specific legal authority to deny the permit request. The DNR did require the City to monitor streamflow and precipitation. In addition, the DNR conducted an aquatic and terrestrial survey of the stream in the early 1990s which indicated it continues to be a viable trout stream. Because of water quality concerns, Wisconsin Rapids has, to date, pumped the well at less than capacity (Falkowski, 1996).

Another potential effect of groundwater withdrawals is the transfer of groundwater from one basin to another. This is most likely to occur where there are withdrawals near the divide between two groundwater basins. There is evidence of this in western Dane County (see the RESEARCH discussion).

Some other examples are below:

- Work by the USGS indicates that Duck Creek and the Fox River in northeastern Wisconsin are recharging groundwater in places instead of groundwater recharging surface water because of groundwater withdrawals (Krohelski, 1994).

- The aquifer system and City of Black River Falls municipal wells, located adjacent to the Black

River, were simulated in a modeling study conducted to determine possible sources of microbial contamination to the wells. The study indicated a majority (70%) of water pumped from the city's water supply wells was coming from the Black River (Rheineck, 1995). These wells have now been abandoned. The results highlight the need to consider the potential effects of groundwater withdrawals on nearby rivers and streams.

* There is evidence that a spring near Madison dries up when the nearby municipal well is turned on (Hennings, 1994).

* The potential impacts of mine dewatering are a concern for the proposed mine near Crandon in northeastern Wisconsin. Detailed groundwater modeling is being conducted to evaluate potential impacts that mine dewatering may have on groundwater quantity and quality, and potential effects on baseflow discharging to nearby lakes, streams, and wetlands.

The examples listed above are illustrative of the impacts of groundwater withdrawals on surface water. The examples are not meant to be inclusive of all such effects.

<u>Wetlands</u>

Groundwater withdrawals may also adversely affect wetlands. Depressional wetlands, which receive little surface water runoff, and wetlands hydraulically connected to an aquifer are at the greatest risk from aquifer dewatering practices. Baseflow may contribute up to 70% of a wetland's water budget.

Where shallow sand and gravel deposits directly overlie another aquifer, the aquifers are hydraulically connected. This means groundwater withdrawals from the deeper aquifer affect shallow groundwater that may discharge to wetlands. This occurs in southeast Wisconsin where shallow glacial deposits overlie Silurian dolomite, and to the west where shallow deposits overlay sandstone. Reduced spring flow and decreased baseflow to wetlands in Dane County are attributed to withdrawals from the underlying sandstone aquifer (Krohelski, 1995). In southeast Wisconsin, proposed withdrawals from high-capacity wells in the Silurian dolomite aquifer were limited by the DNR, and supplemented with wells from the sandstone aquifer to avoid damaging nearby wetlands (Kline, 1995).

Decreased water levels in a wetland also affect the type of plants and animals that live in the wetland. Most of our game and non-game wildlife depend on wetlands for some stage in their life cycle. Lower water levels in ponds and marshes affect waterfowl by reducing open water area for breeding habitat; they affect amphibian populations when aquatic larval stages have insufficient time to mature into adults. These shallow water areas also supply food at a critical stage for breeding animals since they are the first to warm up and they support aquatic life when deeper waterways are still frozen. Water level reduction over the long term allows woody plant species to encroach into wet meadows and out-compete the vegetation favored by grassland birds and invertebrates.

For wetlands which receive both groundwater and surface water, a reduced groundwater contribution results in larger water level fluctuations associated with surface water runoff. This encourages invasive, non-native plant species at the expense of native species, and may reduce the ability of the wetland to improve water quality.

Groundwater withdrawals can change not only the water level in a wetland, but also the water chemistry if less groundwater is being discharged to the wetland. The mineral poor bogs of northern Wisconsin and the mineral rich fens and wet meadows of southern Wisconsin depend mainly on very different groundwater sources. This difference is reflected in the different vegetation, the animal communities they support and how nutrients are cycled through the ecosystem.

In general, decreased baseflow discharge reduces the level of biodiversity a wetland can support. In the extreme, the wetland shrinks and wetland habitat is lost. The adverse effects of decreased baseflow to a wetland may take several years to become apparent. This lag time, combined with the local nature of the effect, and the influence of other coincident hydrologic factors, such as natural variations in rainfall, make the impacts difficult to document.

Effects on Surface Water From Reduced Recharge to Groundwater

Land development typically increases paved areas which increases the amount of runoff during storms and, as a result, reduces groundwater recharge. Precipitation which falls on paved areas runs off to storm sewers and discharges to lakes, streams, or wetlands instead of infiltrating into the ground. Reduced groundwater recharge may cause one or more of the following: (1) an increase in stream, lake or wetland flood levels because of increased runoff; (2) an increase in contamination and organic matter discharging to surface water bodies via storm sewers (e.g., oil, grease, leaves, grass clippings, etc.,); and (3) a decrease in groundwater recharge and subsequent decrease in baseflow to the surface water. Modeling by the USGS of a proposed development in Dane County predicted that baseflow in Black Earth Creek would be reduced by 2-3 cubic feet per second by development; this could reduce trout spawning areas (Gebert, 1994).

INFORMATION ON GROUNDWATER QUANTITY

WATER USE DATA

Major water users report water use to state agencies as part of approval requirements. The DNR collects water-use information for public, industrial and irrigation practices, sewage treatment, and power consumption. The Public Service Commission (PSC) collects information on public water supply use.

Every five years beginning in 1980, the USGS has gathered data and published a report called, "Water Use in Wisconsin" (Lawrence and Ellefson, 1982; Ellefson, et. al., 1987; Ellefson, et. al., 1993). Each report contains a summary of groundwater and surface water use, including trends in use. The USGS collects information from state agencies and estimates use when information is not available. The data is stored in the Site Specific Water Use Data System. This database includes information on water use, sources of water and amount returned (Ellefson, et. al., 1993).

Figure 6 shows that water use (from both surface water and groundwater) has increased steadily from 1950 to 1995. Public water supply withdrawals doubled during this time while the population grew by 24 percent. Industrial withdrawals grew from around 80 to nearly 450 million gallons per day (Mgal/d). Irrigation (for agricultural purposes) increased from 5 to over 160 Mgal/d between 1950 and 1995. Non-irrigation agricultural use (livestock watering, dairy sanitation and other on farm water uses) increased from 75 to nearly 100 Mgal/d during the same time. Groundwater withdrawals from all sources in 1995 were estimated to be 754 Mgal/d as compared to an estimated 570 Mgal/d in 1985 (Ellefson, et. al., 1993; Ellefson, 1997). These trends of increased withdrawals suggest that groundwater quantity problems will continue to be an issue of concern for the foreseeable future.

1985 Wisconsin Act 60 requires the development of a water withdrawal registration system to keep track of water use data in Wisconsin. High capacity well owners not already reporting water use estimates are required to submit this information annually to the DNR. Data collection from approximately 5,000 high capacity well owners began in 1988. However, because of the costs associated with collecting this data, as well as its limited use and accuracy, the DNR stopped requesting this information in 1994. A water use fee was originally included as part of this initiative but was removed by the Legislature.

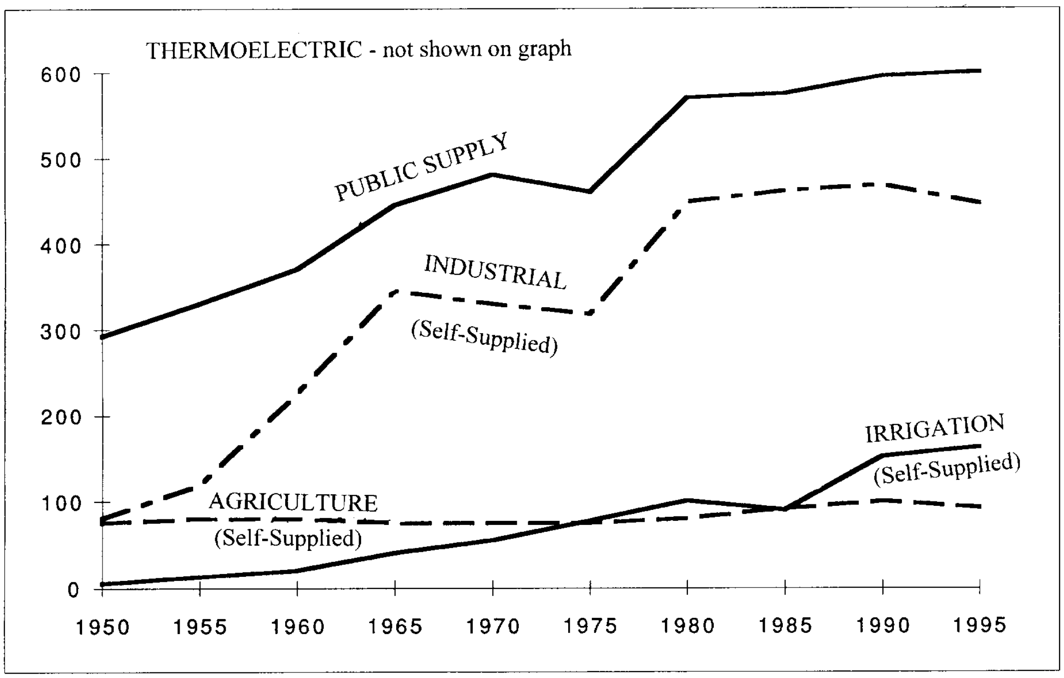


Figure 6. Water withdrawals (both surface water and groundwater) in Wisconsin in millions of gallons per day (Source: Ellefson, et. al., 1997)

STATEWIDE NETWORK OF GROUNDWATER OBSERVATION WELLS

There is an ongoing effort by state and federal agencies and university staff to gather data and information on groundwater quantity issues. Effective management of groundwater in Wisconsin requires up-to-date information on fluctuations and trends in groundwater levels throughout the state. In 1946, the WGNHS and USGS initiated a statewide groundwater-level observation network to gather such information (Zaporozec, 1982). The purpose of this network is to collect data on and evaluate short-term changes and long-term trends in groundwater levels due to variations in precipitation and groundwater pumping. The location of observation wells in the statewide network, the type of aquifer they represent (shallow or deep) and the frequency of water level measurements are illustrated in Figure 7 (Maertz, 1995).

Groundwater-level measurements are made monthly and entered into a computer database. During 1994, systematic observations of groundwater levels were made on 184 wells (Zaporozec, 1995). A joint committee of representatives from both surveys meet regularly to evaluate the need to modify the observation network.
Besides groundwater level data, other data such as well location, well ownership, well construction (casing

and borehole specifications), well depth, and geologic information on the formations a well intersects can be readily accessed from a USGS computer database. Groundwater level data can be retrieved from this database in either graphical or numerical form. Selected water-level measurements and hydrographs are also available on the World Wide Web at the USGS home page (wwwdwimdn.er.usgs.gov). The USGS and WGNHS publish several types of reports that list and interpret groundwater level data. The USGS distributes a monthly report showing water levels of selected water table wells for the 12 months preceding publication and long-term average, maximum and minimum water levels for the 12-month period. The WGNHS publishes an annual summary of groundwater level data which includes precipitation and long-term trend data. In addition, the WGNHS publishes technical reports and popular pamphlets describing and interpreting groundwater level data (Zaporozec, 1995).

STATEWIDE NETWORK OF GAGING STATIONS

The USGS also maintains a network of streamflow gaging stations across the state to record surface water flow information. Historical streamflow data is valuable as we look at the relationship between surface water and groundwater. The earliest stations were installed prior to the turn of the century. Data is presently being collected from 96 continuous streamflow stations and 6 lake level stations (see Figure 8). Stations are established based on requests from other agencies which normally assist in funding of gaging stations. In 1996, the DNR and U.S. Army Corps of Engineers are cooperators in funding a large percentage of the gaging stations. Over the years, a total of over 300 gaging stations have been established in Wisconsin. The USGS publishes an annual summary of gaging station information and the information is used by a number of cooperators, including the Wisconsin DNR, the U. S. Army Corps of Engineers and other federal agencies, the Southeast Wisconsin Regional Planning Commission (SEWRPC), indian tribes and local municipalities.

Due to budget cuts, a number of stations have been discontinued and more are in jeopardy. In 1997, for example, funding cuts will result in the loss of 70 groundwater-level observation wells and 20 gaging stations. These cuts represent a 30% loss in observation wells and a 20% cut in stream gages. The ability to substantiate surface water/groundwater interactions and establish trends in stream flows and groundwater levels will be lost in many parts of the state.

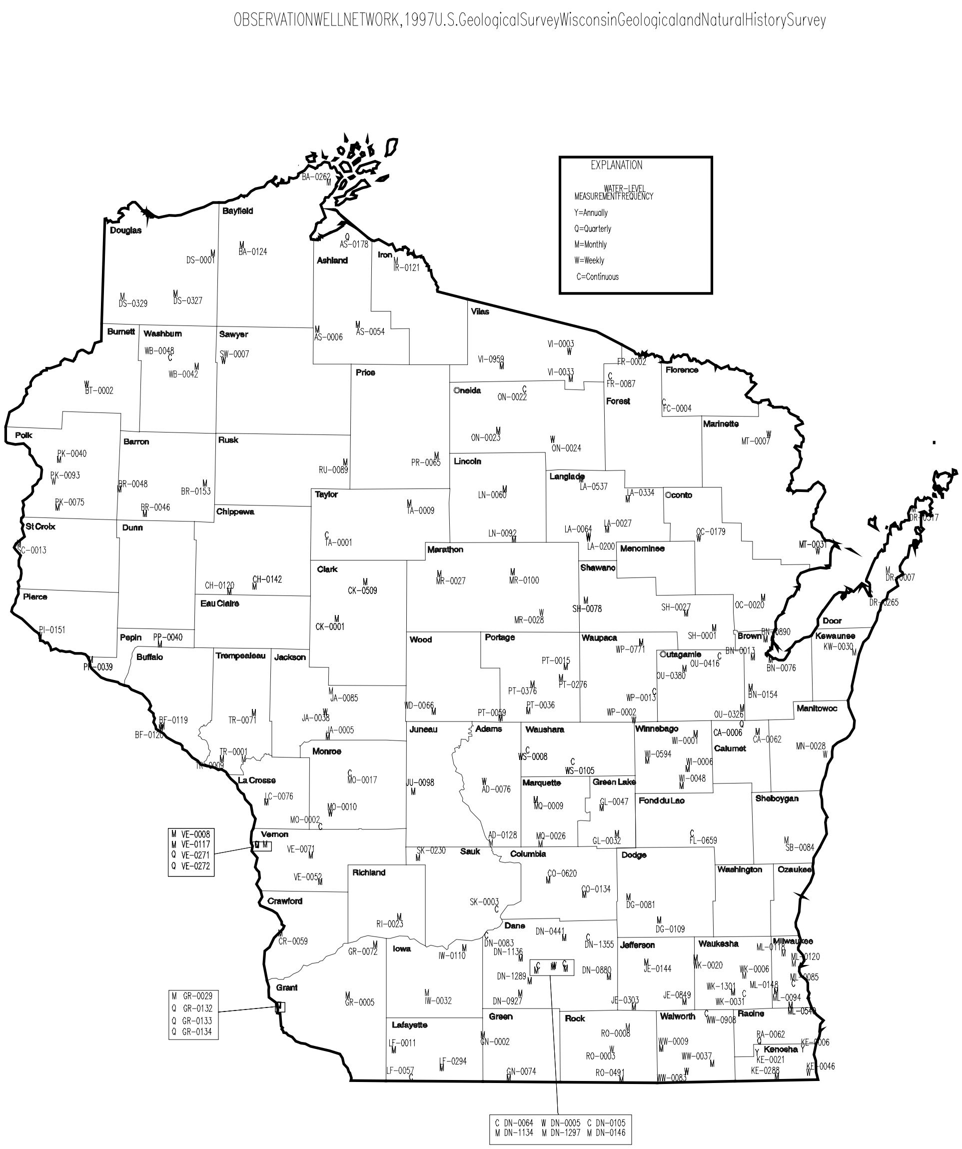


Figure 7. Location of state-wide network of observation wells monitored by the U.S. Geological Survey and the Wisconsin Geological and Natural History Survey (Source USGS)

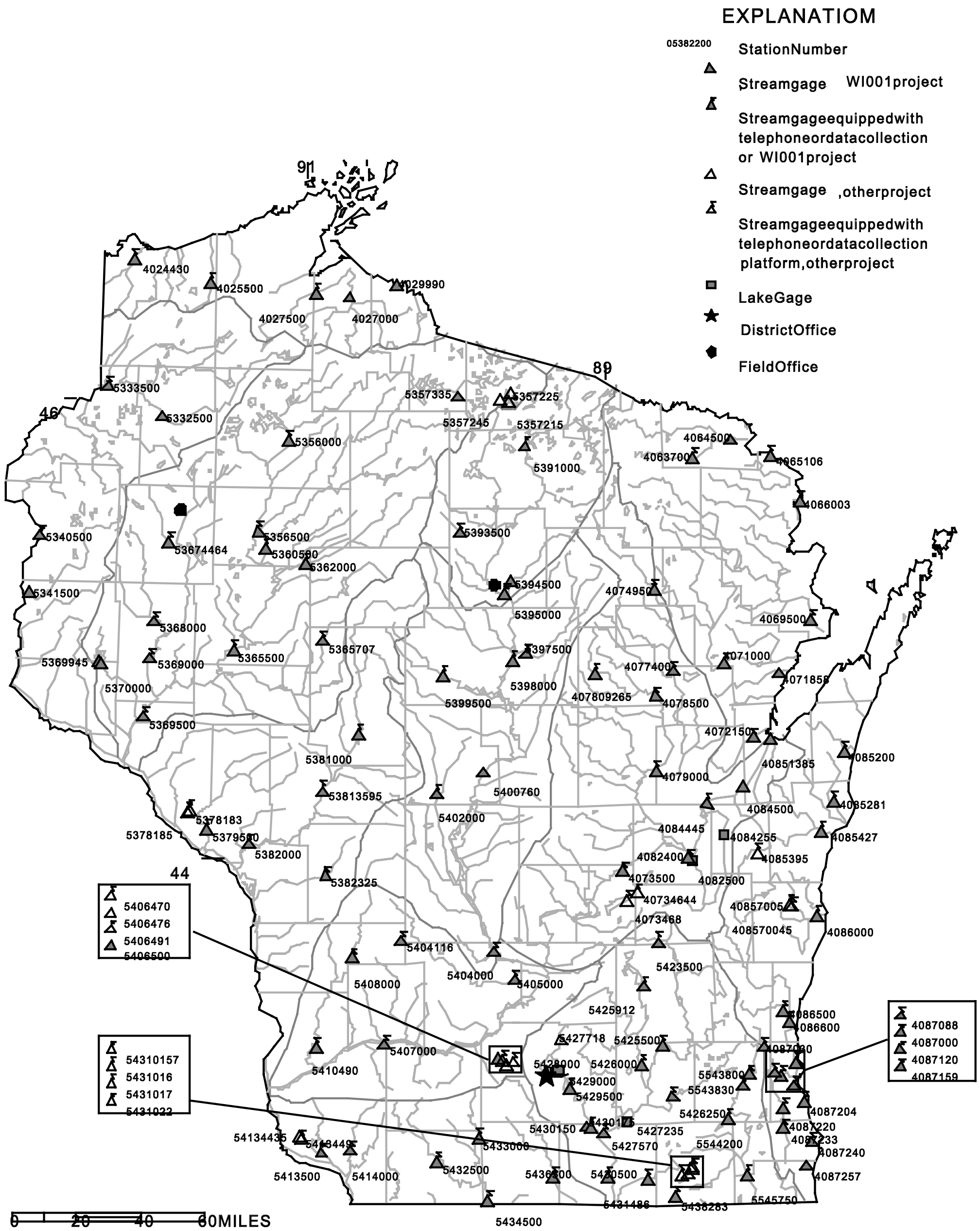


Figure 8. Locations of continuous-record data-collection gaging stations (Maertz, 1996).

RESEARCH

Historically in Wisconsin, little research has focused on groundwater quantity problems, issues and management. In the water-rich midwest, groundwater *quality* has been considered a much higher priority and has overshadowed groundwater *quantity* concerns. There have, however, been some studies of groundwater quantity problems, not surprisingly in areas where groundwater quantity has been a concern. As early as 1953, researchers acknowledged that well interference was a problem in the Green Bay area, causing unnecessary and accelerated declines in groundwater levels (Drescher, 1953). In 1953, Drescher suggested that future wells be located as far west as possible which would reduce the decline in groundwater levels in the Green Bay metropolitan area.

Krohelski (1986) used a groundwater flow model to predict that groundwater levels near the center of the cone of depression at Green Bay will decline more than 250 feet below the top of the sandstone aquifer by the year 2015 and leave only approximately 330 feet of saturated aquifer thickness. This would result in increased pumpage costs (i.e., due to increased lift requirements) and a reduction in the amount and rate of water that can be pumped from the sandstone aquifer in the Green Bay metropolitan area.

In 1992, data collected by the USGS and the WGNHS showed that the sandstone aquifer remains about 600 feet thick as far west as the Village of Seymour in Outagamie County and that the amount of groundwater that can flow through the aquifer (i.e., transmissivity) appears to increase to the west of the Green Bay area (Batten and Bradbury, 1996). Because of the substantial quantity of groundwater to the west, supplementing the Green Bay area's water supply with groundwater withdrawals from the west could minimize the Lower Fox River Valley water supply problems.

A study, titled "Optimum management of ground-water resources in the Lower Fox River Valley" (DNR funded for fiscal years 1996-97) will attempt to determine whether groundwater pumped under controlled conditions is a viable alternative to using Lake Michigan water for future water supply needs in the Lower Fox River Valley. A large cone of depression exists there now and aquifer dewatering is significant (see Figure 5). An optimization model will be used to evaluate potential groundwater management plans. This model will evaluate the placement and optimal pumping schedule for wells with respect to meeting future demand while minimizing water-level declines in the sandstone aquifer and adverse effects to streams and wetlands. This will build on previous groundwater research in the area.

In southeastern Wisconsin, Cherkauer (1995) assessed the interaction of Milwaukee County's Northshore stormwater tunnel with Lake Michigan and the Milwaukee River. Groundwater flow is normally expected to be towards and into Lake Michigan. However, the tunnel was found to induce recharge from Lake Michigan to groundwater between the Milwaukee Harbor breakwater to north of Silver Spring Drive. Recharge into the dolomite and glacial aquifer was estimated to be at least 1600 cubic meters per day (m^3/day) (422,620 gallons/day) . Along the Milwaukee River, groundwater flow was more complex. The low conductivity Milwaukee Formation at the top of the bedrock restricts exchange between the sediments and bedrock. It limits vertical outflow from the river and causes horizontal flow in the sediments towards the river. During the summer of 1994, 534 m^3/day (141,070 gallons/day) was induced to flow from the river downward toward the tunnel, while another 720 m^3/day (190,216 gallons/day) flowed from the bank sediments into the river. Flow from both the lake and the river contribute to a total flux to the tunnel on the order of 4300 m^3/day (1,135,990 gallons/day). The tunnel's influence extends up to 4 kilometers (2.5 miles) away from it under the lake and about 2 kilometers (1.2 miles) upstream in the river.

To improve the definition of the extent of declining water levels in southeastern Wisconsin, two consulting firms are working on updating a two-dimensional computer screening model of the sandstone aquifer. The model will include seven counties in southeastern Wisconsin plus northern Illinois and northwestern Indiana.

In 1992 the WGNHS, USGS, and Dane County Regional Planning Commission began a cooperative study of the hydrogeology of Dane County to increase the understanding of groundwater/surface water relationships, and in particular, the effects that groundwater withdrawals have on surface waters. One of the primary products of this study has been the creation of a new county-wide numerical groundwater flow model. Once the associated hydrogeologic data bases are completed, assessment of such issues as high-capacity well siting, wellhead protection, effects of land-use changes on groundwater quantity, and groundwater recharge in Dane County will be improved. Final reports on this study will be available in 1997.

Several studies have focused on the Black Earth Creek watershed in the Driftless Area in conjunction with the Dane County Regional Hydrologic Study described above. The Driftless Area's water resources include trout streams which are highly dependent on baseflow contributions for maintaining the stream's health.

Potter (1993) first developed a conceptual model of the spatial distribution of groundwater recharge. Since recharge is the source of all groundwater, an understanding of recharge is critical in addressing groundwater quantity concerns. The study documented substantial groundwater recharge along a hillside gully draining a farmed upland. This helps to explain the widespread contamination of wells in the Black Earth Creek watershed by nitrates and pesticides. Potter also demonstrated that there is significant underflow of groundwater from the Sugar River surface watershed to the Garfoot Creek watershed. This showed that efforts to protect the baseflow of trout streams must be directed to recharge areas, some of which lie outside of the watershed.

A second study (Potter and Bradbury, 1995) developed a simple quantitative model for predicting the areal distribution of groundwater recharge and applied the model to some gaged watersheds in the Driftless Area. The study supported a landscape model consisting of wooded hillslopes with high recharge and virtually no runoff, and valley bottoms providing virtually no recharge. Potter concluded that any loss of wooded hillslopes and uplands will decrease recharge and subsequent groundwater discharge in similar Driftless Area watersheds. The cumulative effect of many such losses will be the drying up of spring-fed wetlands, reduced baseflows to surface waters and decreased groundwater supplies. Potter suggests that these findings can be generalized to the entire Driftless Area.

The importance of gullies to groundwater recharge and contamination will be evaluated and the flow of groundwater from the Sugar River surface watershed to the Garfoot Creek surface watershed will be quantified in a third on-going study by Potter.

Other research has looked at the connection between groundwater withdrawals and surface water impacts in the Central Sands. A USGS study (Weeks and Stangland, 1971) evaluated the effects that groundwater pumping for irrigation had on streamflow in the Central Sand Plain. The authors of the study concluded that irrigation of crops from high-capacity wells increased the evapotranspiration by 2-5 inches per year which reduced streamflow by 25-30%. The authors predicted that streamflow could be reduced by as much as 70-90% during drought conditions due to increased crop irrigation and increased evapotranspiration.

Weeks, et. al., (1965) performed a detailed study of the Little Plover River watershed and quantified the relationship between withdrawals for irrigation and impacts on streamflow. Kraft (1996) used the Weeks, et. al., data to calculate baseflow declines under present land uses and agricultural management in the basin. This analysis indicates that irrigation has reduced baseflow in the stream by approximately 10%. Beginning in 1989, the Village of Plover began making withdrawals from the Little Plover groundwater basin for municipal use. A groundwater flow model that includes the Little Plover predicts that greater than 40% of Little Plover baseflow will be lost due to Village of Plover pumping at project year 2005 pumping rates (Mechenich and Kraft, 1996). Losses on this order would probably make the Little Plover River unsuitable as a viable fishery. The authors caution that their model was not specifically designed to examine potential impacts to the Little Plover, so that the projected baseflow should be considered a rough estimate. However, major impacts on the Little Plover appear unavoidable given current trends. Additional research is being conducted on the basin.

In response to discussions regarding groundwater quantity beginning in 1994, the DNR targeted groundwater quantity as a priority topic for groundwater research in the joint solicitation process for fiscal year 1996 beginning July 1, 1995. The joint solicitation process is a mechanism for funding groundwater research or monitoring activities by four state agencies. The joint solicitation process brought in several new proposals which have been funded in an effort to address groundwater quantity problems. This new interest reflects a growing recognition of the importance of groundwater quantity management.

In addition to the recent studies mentioned above, Potter and Randy Hunt from the USGS have begun to characterize the role of evapotranspiration on groundwater movement and the effects on solute chemistry in groundwater-fed wetlands. Although evapotranspiration is likely the predominant mechanism of water loss from a wetland, it is poorly understood and needs to be accurately estimated to understand wetland hydrology. This study will help quantify evapotranspiration in terms of a wetland's water balance and solute transport. The project is focusing on a natural and constructed wetland in southwestern Wisconsin.

INFORMATION NEEDS

This report indicates that there are a number of issues related to surface water-groundwater interactions for which we don't have adequate data. While we have some well documented studies and information related to groundwater quantity and groundwater-surface water interactions, most incidents of groundwater quantity problems are not well documented, are anecdotal and are not well understood. We do not know how extensive groundwater quantity problems are throughout the state, especially at the local level. The cause of a particular problem is usually suspected, rather than confirmed, as described earlier in this report.

Groundwater-surface water interactions are not well understood. Some of the factors that influence groundwater and surface water connection and interaction include: seasonal water table and surface water fluctuations; groundwater flow rates; soil types and conditions; geologic setting; land use; extent of groundwater pumping and dewatering practices; vegetation type, density and related evapotranspiration; and precipitation amount, timing and frequency. These factors are very difficult, expensive, and time consuming to quantify, measure, and model. Even detailed investigations may not conclusively prove a connection between groundwater withdrawals and surface water effects.

Data collection necessary to document groundwater quantity problems and to study groundwater quantity in general is, like many endeavors, subject to tightening budgets of government agencies. The numbers of groundwater level monitoring wells and streamflow gaging stations have both been reduced in recent years due to budget cuts. In some cases these cutbacks have resulted in the interruption of many decades of continuous data. State agencies generally don't have the resources to adequately investigate complaints or to document the cause of adverse impacts on either groundwater or surface water.

Below are some of the additional information needs.

1. Identification of the areas of the state where groundwater quantity problems have occurred, are suspected or are likely to occur. A Geographic Information System (GIS) database would be helpful to keep track of groundwater quantity problems and areas where groundwater withdrawals should be managed carefully.

2. Identification of the environmental, economic and land use implications for the current trends in groundwater use. This is especially true for the Lower Fox River Valley, southeast Wisconsin and Dane County which are experiencing substantial groundwater withdrawals.

3. Determination of the level of detail needed to make informed decisions about groundwater withdrawals in Wisconsin. How much information would be needed and at what cost to properly evaluate the potential impact of a groundwater withdrawal on both groundwater and surface water resources? Are resources available (personnel and financial) to gather and evaluate the data?

4. Identification of the management options available for addressing groundwater quantity concerns. There are different scales of groundwater quantity problems. A range of options will be necessary to address different circumstances. Some options may be regulatory and others non-regulatory. Also needed is an assessment of the environmental, economic, social and political impacts of different management options. It is important that we understand the impacts likely to occur from a particular management strategy. For example, there may be some merit in considering groundwater pumping restrictions or water conservation goals in a particular county where development is occurring to minimize aquifer impacts. However, the impact of such an action should be carefully considered to make such there won't be an unexpected and undesirable affect.

5. Quantification of the social, economic and environmental costs associated with groundwater quantity problems. While it may be relatively simple to quantify the cost of increasing lift requirements for a well if groundwater levels drop, social, economic and ecological costs are harder to identify and quantify with any degree of confidence. For example, what is the cost of a lost or degraded habitat when groundwater withdrawals cause baseflow to a surface water to be significantly reduced? This is important because the people of Wisconsin rely on the state's natural water resources for tourism and recreation and to maintain their high quality of life.

6. Determination of the effect of withdrawals from large numbers of low capacity wells in the same area. We don't know the impact of this situation or how widespread a circumstance this is. Research is needed to define the extent and significance of this situation and potential options to mitigate its effect.

7. Determination of the impact of buried man-made structures on groundwater flow. Some subsurface structures like sewer lines may influence groundwater flow by allowing groundwater flow into them or permitting flow of liquids out of them. These structures can have significant impacts on both groundwater quantity and quality. The deep tunnel is the largest such structure in Milwaukee for controlling stormwater flow. Research is needed on the impact of these structures on groundwater flow which may also affect baseflow.

MANAGEMENT OF GROUNDWATER QUANTITY

LEGAL FRAMEWORK IN WISCONSIN

The current groundwater quantity legal framework in Wisconsin was established in 1974 in the landmark case of *State of Wisconsin v. Michels Pipeline Construction Company*. Up to that time, a property owner was allowed to use all the groundwater he or she was able to pump, regardless of the effect on other property owners, a decision made by the state Supreme Court in the case of *Huber v. Merkel* in 1903.

However, in the early 1970s, Michels Pipeline, under contract to the Milwaukee Metropolitan Sewerage Commission, dewatered soil to install a sewer line. This action also lowered the water table, dried up several private wells, decreased the capacity and quality in other private wells, and cracked foundations, driveways and basement walls due to subsidence. The state Supreme Court eventually overruled the *Huber* decision and established the current legal framework of reasonable use, that is, that a property owner's use of groundwater is not absolute but must be reasonable, considering effects on the water table and other uses (Bochert, 1991).

Different approaches are followed by eastern and western states in managing water resources. Eastern states follow riparian law which developed in response to conditions of water abundance and the interest in accommodating multiple water users. The doctrine allows all riparians (land owners adjacent to a water resource) an equal share of available water for "reasonable use."

Many eastern states have modified their riparian rights doctrine over time due to decreasing water quality, depleted groundwater, increasing water usage and concerns over better allocations of supply. Wisconsin and other states have adopted permit systems to place requirements on unrestricted reasonable use of the state's water. These programs require permits for interbasin diversions and consumptive losses, irrigation, groundwater pumping and diversion of surface water for mining, maintaining or restoring a navigable lake or stream (Beeman, 1987).

Western states follow the prior appropriation doctrine which assigns water based on a first come, first served basis. In the arid western states, water is scarce and irrigation a widespread practice. An equal share of water for all users could make irrigation difficult in drought conditions. In drought conditions, the earliest rights holders can claim all the water they need.

A detailed description of water rights laws and doctrines which most eastern and western states follow is included in the Appendix.

AGENCY RESPONSIBILITIES

Department of Natural Resources (DNR)

Under Wisconsin Law, chapter 281, Wisconsin Statutes (formerly ch. 144), the Department of Natural Resources is instructed to serve as the "central unit of government to protect, maintain, and improve the quality and management of the waters of the state, ground and surface, public and private ... The purpose of this section is to grant necessary powers and to organize a comprehensive program under a single state agency for the enhancement of the quality, management and protection of all waters of the state..."

The DNRs groundwater quantity responsibilities have traditionally included the Water Supply, Water Resource Management, Water Regulation and Zoning and Solid and Hazardous Waste Management programs. With the DNRs reorganization in 1996, these responsibilities are incorporated into other programs. The Water Supply and Groundwater programs are combined in a Bureau of Drinking Water and Groundwater. Some of the Water Resources Management responsibilities are now in the new Bureau of Watershed Management; Water Regulation and Zoning program responsibilities related to water quantity have moved to the new Bureau of Fisheries Management and Habitat Protection. The mining responsibilities of the former Bureau of Solid and Hazardous Waste Management are now in the Bureau of Waste Management. These responsibilities are described below.

<u>Drinking Water and Groundwater (formerly Water Supply)</u>

The DNR Bureau of Drinking Water and Groundwater (BDWG) consists of the Public Water Systems, Private Water Systems and Groundwater Sections. The Public Water program regulates over 1,200 community water supply systems, as well as some 12,000 other noncommunity systems. The Private Water program regulates well construction and pump installation requirements for the 600,000 plus private water supply systems in the state, registers well drillers and pump installers and approves high capacity wells. Some water supply regulations (e.g., well construction and abandonment, high capacity wells and well compensation) apply to both public and private system programs.

A key BDWG program relating to groundwater quantity is their high capacity well permit program which has been in operation since 1958. High capacity wells are wells where the rate of withdrawal of all wells on one property exceeds 100,000 gallons a day or 70 gallons per minute. Private Water program staff review approximately 150 high capacity well applications per year. Program regulations are contained in section 281.17(1), Wis. Stats., (formerly s. 144.025(2)(e), Wis. Stats.), and ch. NR 812, Wis. Adm. Code. As of 1996, there are over 8,000 high capacity wells in the state. Approximately 1,700 are public water supply wells, 3,800 are irrigation wells and 800 are industrial wells; the remainder serve schools, commercial establishments, wastewater treatment plants, and other purposes (Furbish, 1996). Most irrigation wells are near major glaciated river basins. The highest concentration of irrigation wells in the state is located in the Central Sands with smaller concentrations located in the Eau Claire/Buffalo/Barron county area and the lower Wisconsin River area.

The high capacity well program has been the subject of extensive discussion in recent years regarding the impact of these wells on groundwater and surface water. This is described in more detail later in this report.

The BDWG maintains a water supply database sorted by system type as follows: 1) municipal, 2) other than municipal, 3) non-community and 4) high-capacity wells. The database contains facility and water quality data but not water use information. The BDWG receives monthly water use data from municipal water utilities and annual use data from the PSC as described below.

The Groundwater Section (GS) of the BDGW assists in coordinating groundwater activities of the DNR, as well as other state agencies. The GS is responsible for adoption of groundwater quality standards included in ch. NR 140, Wis. Adm. Code; development of an annual groundwater monitoring plan; coordination of the joint solicitation process for groundwater monitoring and research; review and management of groundwater monitoring projects; coordination of groundwater components of basin plans and of non-point source priority watershed projects; coordination of WHP activities; implementation of activities of the GCC; regulation of monitoring well construction and abandonment; and maintenance of a data management system for groundwater data.

The BDWG is responsible for developing and implementing the wellhead protection (WHP) program. The specific goal of the program is to promote localized groundwater protection measures in public water supply wellhead areas consistent with the state's overall goal of groundwater protection. To achieve this goal, the DNR requires that a WHP plan be developed for any municipal water supply well constructed after May 1, 1992. Part of an approved wellhead protection plan is an active water conservation program. There is a voluntary program which covers any municipal water supply well approved prior to May 1, 1992. The DNR has initiated a statewide public information campaign aimed at encouraging water purveyors to proactively protect their water supplies from potential sources of contamination. The DNR actively promotes WHP efforts in the state and works with the Wisconsin Rural Water Association to develop community plans and provide technical assistance through conferences and training sessions for community officials and water system operators who want to develop WHP plans for their wells.

<u>Watershed Management (formerly Water Resources Management)</u>

Responsibilities related to water quantity in the Bureau of Watershed Management are contained in the Great Lakes and Planning Section (formerly the Policy and Planning Section (PPS)). These responsibilities have followed from the 1985 passage of the Water Resources Conservation and Management Act (1985 Wisconsin Act 60). Passage of Act 60 fulfilled Wisconsin's commitments under the Great Lakes Charter, signed in 1985, which required each Great Lake state and province to enact legislation providing authority to regulate and manage major uses of their water quantity resources. The Charter was developed in response to a concern by Great Lakes states governors that large-scale diversions from the basin could damage the Great Lakes ecosystem.

Wisconsin Act 60 directed the DNR to participate in regional water quantity resources management activities and to develop: 1) a water (both groundwater and surface water) withdrawal registration system; 2) a water loss approval program; and 3) a statewide water quantity resources management plan. Authority to implement these requirements is included in sections. 30.18 and 281.35 (formerly 144.026), Wis. Stats. The PPS (now the Great Lakes and Planning Section) prepared the state's water quantity management plan and promulgated ch. NR 142, Wis. Adm. Code, which contains the water withdrawal registration, water loss approval and Great Lakes basin water loss requirements. The Great Lakes and Planning Section collects withdrawal information from the Public Service Commission.

The water quantity plan required by Act 60 had to: 1) identify water uses in the state; 2) estimate future trends in water use; 3) recommend how to use, manage and protect state waters and 4) describe a system for allocating water during an emergency water shortage. The Water Quantity Resources Plan was prepared by PPS staff and approved by the Natural Resources Board in August, 1988. Although there was some discussion of groundwater, most of the focus of the plan was on surface water. The plan contains 9 reports: Overview, Wisconsin's Water Quantity Resources, Water Use in Wisconsin: 1985, Water Use in Wisconsin: 1990-2010, Economic Overview of Wisconsin's Water Resources, Water Use: Legal and Regulatory Framework, Water Conservation: Summary of Techniques and Impacts, Maintenance of Instream Flow, and Summary.

The Summary document contained a number of recommendations, including maintaining and updating the water quantity data base, updating water use predictions every five years, evaluation of the existing water resource management programs, increased efforts at water conservation, development of a state instream flow policy and adoption of an emergency water allocation program (Prey and Lohr, 1988).

<u>Fisheries Management and Habitat Protection (formerly Water Regulation and Zoning</u>

The Bureau of Water Regulation and Zoning has administered the surface water diversion permit program since the 1950s. This program, now handled by the Rivers and Regulations Section of the Bureau of Fisheries Management and Habitat Protection, enforces chapter 30, Wis. Stats., which limits diversion of surface water by permit including environmental review to protect the public interest in the waterway. Ch. 30 also limits structures (e.g., intake or outfall pipes) on the bed of public water. Discharges are limited under ch. 283 (formerly ch. 147), Wis. Stats. Approximately 390 irrigators in Wisconsin now hold permits for surface water diversion. Permits are issued in the DNRs regional offices. A database is maintained in the DNRs central office of withdrawals from surface water; each entity is required to report withdrawals annually.

<u>Waste Management (formerly Solid and Hazardous Waste Management)</u>

The Bureau of Waste Management regulates metallic mining activities under ch. 293 (formerly ss. 144.80-144.94), Stats. Withdrawals from groundwater or diversions of surface water require high capacity well approval (s. 281.17(1), Wis. Stats., formerly s. 144.025(2)(e), Wis. Stats.), or ch. 30, Stats., approval, respectively, before a mining permit is issued. The DNR may not approve a high capacity approval if the groundwater withdrawal or dewatering of a mine "will result in the unreasonable detriment of public or private water supplies or the unreasonable detriment of public rights in the waters of the state." (s. 293.855(3)(b), Stats.) Water quantity impact from mines and mining waste sites are regulated under chs. NR 132 and NR 182, Wis. Adm. Code. Some of the applicable specific provisions include ss. NR

132.06(4), NR 132.07(3)(f), NR 132.17(9), and NR 182.075(2).

Nonmetallic mining is regulated under ch. 295 (formerly s. 144.9407), Stats. This law requires a mining permit as well as a reclamation permit which would be administered at the county level. This law has not been implemented because administrative rules have not been adopted. Legislation to modify ch. 295 is in the Governor's budget. The amendments would regulate reclamation but not other aspects of mining. Administration would be at the county level. Under draft administrative rules for this program, the reclamation of a site would have to assure that there was not a permanent lowering of the water table that results in adverse effects on surface waters or significant reduction in available groundwaters. Water quantity considerations during mining are regulated under the high capacity well law and under ch. 30, Stats.

Wisconsin Geological and Natural History Survey (WGNHS)

The WGNHS has a number of important responsibilities in assessing and characterizing the state's groundwater resources. These efforts have focused on defining aquifer extent and geologic structure, groundwater quality appraisals and groundwater susceptibility and vulnerability assessments. Groundwater quantity assessments are heavily dependent on geologic mapping and aquifer assessment, which are coordinated by the DNR, WGNHS, USGS, and local governments. WGNHS is in the process of mapping all of the state's aquifers, and has completed mapping the major bedrock aquifers. The mapping depicts the areal extent of the aquifers and includes some geologic cross-sections of the aquifers. Pleistocene-glacial deposits that are a major source of groundwater are currently being characterized and mapped.

The WGNHS performs applied groundwater research and provides technical assistance, maps, and other information and education to aid in the management of groundwater resources. The WGNHS groundwater program is complemented by geology, soils, and climate programs that provide maps and research-based information essential to the understanding of groundwater occurrence, quality, and movement. WGNHS staff have recently prepared groundwater-related maps (e.g., water-table or aquifer maps) at a scale of 1:100,000 for Barron, Buffalo, Burnett, Dane, Eau Claire, Fond du Lac, Kenosha, Lincoln, Milwaukee, Oconto, Ozaukee, Polk, Price, Racine, Trempealeau, Walworth, Washington, and Waukesha counties.

The WGNHS stores and disseminates public information, records, and research results. To strengthen this service, the WGNHS continues to: review, sort and catalog about 18,000 well construction reports per year (in cooperation with the DNR); measure monthly groundwater levels in a monitoring network of 184 wells (in cooperation with the USGS); collect and describe geologic samples from 300 wells per year; and, collect and analyze approximately 600 groundwater samples per year for nitrate, chloride, and several other basic parameters.

WGNHS research projects related to groundwater quantity completed this year or in progress include: groundwater flow and quality in fractured dolomite in Door County; hydrogeologic and engineering properties of glacial materials; age, origin, and movement of groundwater in low-permeability materials; hydrogeology of Dane County; hydrogeology of Southeast Wisconsin; delineation of hydrogeologic units throughout Wisconsin; and hydrogeology, groundwater use, and groundwater quality of the Fox Cities area.

Central Wisconsin Groundwater Center (CWGC)

The mission of the Central Wisconsin Groundwater Center is to provide education and technical assistance to the citizens and government of Wisconsin. The Center was created in 1985 in response to public concern over groundwater issues. The Center's efforts relate to both point and nonpoint source pollution and groundwater management. Some of their activities related to groundwater quantity include: public education efforts, wellhead protection and groundwater management assistance, and research in the Little Plover River basin.

Wisconsin Groundwater Coordinating Council (GCC)

The Wisconsin Groundwater Coordinating Council (GCC) was formed by 1983 Wisconsin Act 410 to improve the management of the state's groundwater. The GCC consists of the secretaries (or their designees) of the Departments of Natural Resources; Commerce; Health and Family Services; Transportation; Agriculture, Trade and Consumer Protection; the President of the University of Wisconsin System; the State Geologist; and a representative of the Governor. According to s. 160.51, Wis. Stats., the GCC is to "advise and assist state agencies in the coordination of nonregulatory programs and the exchange of information related to groundwater, including but not limited to, agency budgets for groundwater programs, groundwater monitoring, data management, public information and education, laboratory analysis and facilities, research activities and the appropriation of allocation of state funds for research."

Although the GCC does not have a regulatory function, it does have a responsibility to promote coordination of groundwater activities. In fact, since 1985, the GCC has served as a model for interagency coordination and cooperation among state government officials, the Governor, local government and federal government. As noted earlier, the GCC asked the GW Section of the DNR to prepare this report based on discussion at one of its meetings. Because of the involvement of its member agencies and participation of federal and local agencies through its subcommittees, the GCC will continue to be involved in the groundwater quantity discussion as it evolves.

Public Service Commission (PSC)

The PSC is responsible for approving expenditures of new public water or electrical utilities and regulating the rate setting of these utilities. Approximately 1,500 public utilities have wells regulated by the PSC and are required to submit total annual pumping data to the PSC. For the past five years the following total groundwater withdrawals for public utility wells were submitted to the PSC: 1990 - 185 billion gallons/year (Bgal/yr), 1991 - 206 Bgal/yr, 1992 - 204 Bgal/yr, 1993 - 197 Bgal/yr, 1994 - 208 Bgal/yr, 1995 - 217 Bgal/yr (Feneht, 1996).

United States Geological Survey (USGS)

The USGS conducts studies to define and increase the understanding of regional groundwater systems. As noted previously, the USGS cooperatively maintains a statewide observation well network and a system of streamflow stations and lake stations. Every five years, the USGS publishes water use data for Wisconsin, which summarizes water use trends (Ellefson, et al., 1993). This publication is part of an ongoing study to

monitor water level trends and determine if changes are natural or manmade and how these changes are affecting groundwater. Examples of work by the USGS are described elsewhere in this report. The USGS, through a cooperative program, shares data from groundwater studies with the DNR, the WGNHS, and many local agencies and units of government.
Besides the USGS, the federal government claims no jurisdiction over the adequacy of water supplies, except where supply problems affect federal laws, activities or international agreements. Federal water rights may be enforced where excessive groundwater withdrawals adversely affect federal legislation such as the Endangered Species Act, Indian Rights, Wild and Scenic Rivers Act or to protect federal land.

Local units of government and local utilities

It is not the intent of this report to identify all the local units of government and utilities and their regulatory authorities with respect to groundwater quantity. However, this report would be incomplete without acknowledging the important role these local agencies have in addressing groundwater quantity concerns. Local communities or water utilities have a responsibility to provide an adequate supply of good quality water to their customers.

As noted earlier, 97% of Wisconsin communities rely on groundwater to meet their water supply needs. This report describes some of the difficulties local communities face in meeting this responsibility.

Where present, regional planning commissions can work to promote coordination of groundwater activities within a specific geographic area. Fortunately, regional planning commissions are present in the areas where groundwater quantity concerns are most evident, i. e., the Lower Fox River Valley, southeast Wisconsin and Dane County, as well as elsewhere in the state.

STATUS OF CURRENT GROUNDWATER QUANTITY ACTIVITIES

What actions have been taken in response to the groundwater quantity impacts identified in this report? As noted earlier, there have been and continue to be a number of studies in the Lower Fox River Valley, Milwaukee and Dane County to increase the understanding of the hydrogeologic framework of these areas and to provide information to allow for best management of groundwater in these important areas. In addition, the BDWG has been working with municipalities and utilities in each of these areas encouraging cooperation among the various parties to promote proper management and protection of groundwater resources in these areas.

Surprisingly, much of the groundwater quantity discussion over the past several years has not focused on the areas of greatest impact. Instead, it has centered on the effect of high cap well withdrawals on groundwater and surface water resources and how the high cap regulatory program could be modified to increase the protection of water resources. In 1989, the BDWG reviewed a permit request to allow the installation of a high-capacity municipal well for the City of Wisconsin Rapids near a Class I trout stream. There were concerns raised by interested parties that the groundwater withdrawal from the proposed well might reduce baseflow to the trout stream; however, the DNR approved the well construction because it did not believe it had the specific legal authority to deny the request (Dawson, 1995).

Generally, the Private Water program denies or grants a limited approval for a high-capacity well only if operation of that system and the proposed withdrawal will adversely affect or reduce the availability of water to any public utility well based on statutory language (s. 281.17(1), formerly 144.025(2)(e), Wis. Stats.). The DNR does have broad authority for protection of the waters of the state. There are, however, no specific provisions in ch. 281 (formerly ch. 144), Stats., or ch. NR 812, Wis. Adm. Code, to consider the potential impacts groundwater withdrawal from high capacity wells may have on private wells or surface waters such as lakes, streams and wetlands.

1985 Wisconsin Act 60 provided additional criteria for consideration in approving high capacity wells, but these criteria apply only to new permit applications for high cap wells and surface water diversions averaging greater than 2 Mgal/d. Act 60 created s. 281.35(5)(d) (formerly s. 144.026(5)(d)), Stats., which requires that the DNR determine that proposed withdrawals and uses, among other criteria, "are consistent with the protection of public health, safety and welfare and will not be detrimental to the public interest ... (and) will not have a significant detrimental effect on the quantity and quality of the waters of the state." There are additional criteria to be considered for interbasin diversion. These criteria are also specified in ss. NR 142.06(3) and (4), Wis. Adm. Code. However, these criteria do not apply to high capacity wells with a capacity less than 2 Mgal/d. High capacity wells are also exempt from complying with the wetland water quality standards in ch. NR 103, Wis. Adm. Code.

Even though the DNR has limited ability to regulate high capacity wells which might have an effect on either groundwater or surface water, the Wisconsin Supreme Court case, *State of Wisconsin v. Michels Pipeline Construction Company*, created a liability for a person withdrawing groundwater which creates interference with the water use of another person. Although an impacted well owner can seek judicial relief, few such cases go to court. When informed of a problem, the high capacity well owner usually pays to lower the pump or deepen the neighbor's well. Increasing the depth of a high capacity well is rarely the chosen option because it is normally more expensive than deepening the neighboring wells. In addition, a deeper high capacity well could still impact nearby wells. BDWG staff provide technical assistance to affected parties in these situations.

Act 60 created s. 281.35(7) (formerly s. 144.026(7)), Stats., which allows the DNR, without prior public hearing, to issue an emergency order to stop a withdrawal if the DNR determines that there is a danger of imminent harm to public health, safety or welfare, to the environment or to the water resources or related land resources of the state.

There have been a number of options considered over the past several years to address potential effects of high capacity wells on groundwater or surface water. Tom Dawson, former Wisconsin Public Intervenor, in a December 13, 1989 letter to Rep. Schneider and Sen. Helbach, suggested statutory amendments to allow consideration of environmental effects in the high capacity well permitting process. His proposal was to make the criteria of s. 281.35(5) (formerly s. 144.026(5)), Stats., applicable to all high capacity wells, not just those with a capacity greater than 2 mgd. Such legislation was not proposed.

In the early 1990s, the DNR and the Public Intervenor discussed how to consider the environmental effects of high capacity wells. The DNRs Water Supply program indicated several concerns with evaluating potential impacts for every high cap well application. Concerns raised by the Water Supply program included the lack of technical data and tools to model or predict groundwater-surface water interactions, the high workload that would be associated with high capacity permit review under such a scenario, the low priority of the problem, the potential for cumulative small effects compared to one large high capacity well and the lack of consensus on how to solve competing water uses. As a result, the DNR proposed restricting high capacity wells within 1000 feet of a trout stream or an outstanding resource water (ORW). However, this proposal was never pursued.

The issue arose again in late 1993 when DNR Water Regulation and Zoning staff from the Southeast District in Milwaukee became concerned about the potential impact of proposed high capacity wells on nearby wetlands. After some discussion, a ch. 30 permit was issued along with the high capacity well approval; the applicant was required to limit pumping in the shallow well in the Silurian dolomite and to drill a well into the sandstone aquifer to supplement the shallow well. Because of legal concerns, the ch. 30 permit was not viewed as a long-term solution to the problem.

Based on the above concerns, Tom Dawson asked the GCC to look into groundwater quantity issues further. The result was a meeting in July 1994 to discuss groundwater quantity issues. Representatives from a number of state and federal agencies attended. There was a consensus that the effect of groundwater withdrawals on water resources is a problem, but it is hard to determine how to address the issue given the complexity of the issue and limited financial resources. Three recommendations came out of the meeting:

1. Identify sensitive areas of the state and prohibit or restrict high capacity wells in those areas unless no impact is shown.

2. Allow the DNR Bureau of Water Supply flexibility in regulation of high capacity wells that may jeopardize water resources. Perhaps permit restrictions could prohibit adverse effects.

3. Bring the groundwater quantity issue to the GCC.

No further action was taken on the first two suggestions. The groundwater quantity issue was brought to the GCC at its August 1994 meeting. At that meeting, the GCC asked the DNR GS to prepare a groundwater quantity report. This document is that report. It was prepared by the DNR GS with the assistance of a multiagency TAC. A list the TAC members is on the inside front cover.

This report provides an overview of groundwater quantity problems and issues in Wisconsin. It is not intended as a comprehensive report on all groundwater quantity issues in the state. This report is the first step in addressing groundwater quantity in Wisconsin. It is hoped that this report will serve as a starting point for discussion and action to address the groundwater quantity concerns highlighted in this report.

CONCLUSIONS

What conclusions can we draw from this discussion of groundwater quantity problems?

1. In general, Wisconsin has abundant groundwater supplies.

2. Despite a general abundance of groundwater in Wisconsin, there is a growing concern in some areas about the availability of good quality groundwater for municipal, industrial, agricultural and domestic use and for adequate baseflow to our lakes, streams and wetlands.

3 Groundwater quantity problems have occurred naturally and from human activities. Natural shortages of groundwater have occurred due to weather conditions (e. g., drought) and geologic setting (e. g., crystalline bedrock aquifer with low yields).

4. Groundwater quantity problems also occur because of human activities such as groundwater withdrawal and land use activities which reduce groundwater recharge. Problems caused by human activity normally result from mismanagement of the groundwater resources, either overpumping or locating wells too close together. In some cases, water is withdrawn from one basin and transferred to another. All of this can result in a decrease in the saturated thickness of an aquifer, increased pumping costs, and reduced baseflow to surface waters.

5. The best documented effects of groundwater withdrawals are seen on a regional scale in the Lower Fox River Valley, southeastern Wisconsin, and Dane County. There are substantial declines in groundwater levels in these three areas. Effects of groundwater withdrawals are also seen at the local scale. In these cases, there is frequently little documentation and the cause is more often suspected rather than confirmed.

6. There have been and will continue to be costs associated with providing an adequate water supply to meet the needs in the Lower Fox River Valley, southeastern Wisconsin and Dane County. However, it is beyond the scope of this report to document those costs.

7. If groundwater withdrawals reduce baseflow to surface waters, there may be a change both in water levels and in water chemistry. The effects may include a loss of wildlife habitat or a decline in the fishery. The habitat of a wetland may change or a wetland may dry up completely. Groundwater withdrawals may reduce baseflow to the point that surface water discharges to groundwater instead. Reductions in surface water quantity may result in a change in possible uses of the surface water, stream classification and/or more stringent discharge requirements for facilities which discharge to the surface water body.

8. In some parts of the state, groundwater contains naturally-occurring substances (e. g. sulfates, iron, chlorides, arsenic, radium) which limit water use. Human caused contamination has also reduced the water quality in several areas throughout the state which limits the supply or accessibility of good quality groundwater.

9. Because of the many factors involved, gathering definitive data on the effects of groundwater

withdrawals on surface waters is complex, time-consuming, and expensive. Programs, such as the statewide observation well network, are being reduced.

10. The examples given in this report are illustrative of the types of groundwater quantity problems found in Wisconsin. The examples are not meant to be inclusive of all groundwater quantity problems in the state.

11. Groundwater use is increasing in the state and is anticipated to continue increasing for the foreseeable future.

12. There is information available on water quantity withdrawals and the sources of those withdrawals, but not a coordinated effort to collect and maintain the information so that it can be easily accessed.

13. There has been research conducted in those areas of the state where the effects of groundwater withdrawals are most noticeable. Additional information is needed to identify the implications of current trends in groundwater use; identify areas where groundwater quantity problems have occurred or are likely to occur; quantify the social, economic and environmental costs associated with groundwater quantity problems; determine the level of information needed to make informed groundwater quantity decisions; and identify appropriate management options for addressing groundwater quantity problems in Wisconsin.

14. There are a number of agencies at the federal, state and local level which play key roles in groundwater quantity issues. Statutory requirements give DNR a primary role.

15. Currently, the DNR has limited authority to regulate withdrawals in areas that may be susceptible to groundwater or surface water impacts.

16. Although groundwater quantity issues have thus far not been a high priority, a continuing increase in water demand suggests they will be of concern in some areas.

17. There will be fewer staff in the near future with which to address groundwater quantity issues.

RECOMMENDATIONS

Where do we go from here? The formation of two committees or workgroups to address the groundwater quantity concerns highlighted in this report is recommended.

First, the DNR Groundwater Monitoring Team or another workgroup should be assigned to evaluate groundwater quantity issues and propose a course of action for the agency. As noted in this report, the DNR has important regulatory responsibility on this issue as the central unit of government for protecting and managing the state's water resources. However, groundwater quantity issues cross agency and jurisdictional lines. It is, therefore, appropriate that other agencies (federal, state and local) and external stakeholders join the Monitoring Team or workgroup, or be participants in the agency deliberations to provide a comprehensive perspective on groundwater quantity issues even though the DNR will make ultimate decisions.

Second, federal, state and local agencies, which have some responsibility or interest in groundwater quantity issues, should meet on a regular basis to address issues of concern. It is important to have broad representation to make sure all interested parties are represented. It is hoped that a partnership can be created to address and resolve groundwater quantity concerns. The responsibility for setting up regular meetings could go to the GCC Local Government Subcommittee or to a separate subcommittee created by the GCC. Membership should include, at a minimum, representation from the DNR, WGNHS, CWGWC, USGS, local units of government and water utilities. One of the responsibilities of the subcommittee would be to report back to the GCC on a regular basis.

Below are some of the important issues which the two committees should address.

1. The DNR Groundwater Monitoring Team or other DNR workgroup needs to evaluate whether the state's regulation of water withdrawals requires modification in order to minimize adverse impacts from water withdrawals. Issues to be evaluated would include the legal framework for the existing regulations; resource needs (both staff and money); resources to be protected; location and extent of groundwater quantity problems; management options (regulatory versus non-regulatory) and environmental, economic and socio-political implications of the possible options.

   That evaluation should include determination of the amount and type of information that would be needed to allow proper review of the potential impact of a groundwater withdrawal on groundwater and surface water resources. This would be helpful to determine the cost and time needed for both the applicant and the DNR to make a decision on impacts. Information would then be available to compare with the current program and assess the merits of additional regulation of groundwater withdrawals.

   If one or more regulatory options is considered, there needs to be consideration of whether additional regulatory authority is needed. For example, one of the recommendations of the inter-agency meeting in July of 1994 was that the DNR Water Supply program be able to restrict high capacity wells that may adversely impact water resources. However, it is likely that additional regulatory authority would be needed to carry out this recommendation.

Part of the discussion also needs to include determining what level of effort should be provided to identify and resolve groundwater quantity problems in the Lower Fox River Valley, Dane County and southeastern Wisconsin. This report has indicated that these are the most critical areas of the state in terms of the impacts of groundwater withdrawals. There are on-going activities to varying degrees in each of the three areas to address water quantity concerns. For each of these areas, an assessment is needed of the present circumstances, long-term trends for development and water use and options for properly managing the groundwater resource in these areas. It is particularly important to assess the economic and political implications of current and possible management options to make sure that the intended outcome will take place. For example, there may be some merit in considering groundwater pumping restrictions in a particular county where development is occurring to minimize aquifer impacts. However, the result is likely to be development in other areas not currently being developed; this may or may not be desirable.

2. Both workgroups or committees should work together to prioritize the information needs identified in this report. Since this is a time of decreasing resources, it is important that the most critical quantity issues be identified and addressed through the GCC joint solicitation process or other means.

   Attention also needs to be given to the reduction of groundwater level monitoring wells and streamflow gaging stations throughout the state. If maintaining and potentially reinstalling monitoring wells or gaging stations is determined to be a high priority, then efforts are needed to prioritize sites and identify funding sources.

   Another important issue is whether sensitive areas of the state should be identified for protection where groundwater withdrawals are having or may have significant effects on groundwater levels, surface water, or ecosystems. This was one of the recommendations of the inter-agency meeting in July 1994 as a first step to protecting these areas. If this option is pursued, the committee or workgroup would have to define sensitive areas, determine who would make the delineations, what the cost would be and what mechanisms might be available for monitoring and/or protecting these areas. For example, might sensitive areas include recharge areas? Are portions of the state particularly vulnerable to groundwater withdrawals where efforts should be focussed?

3. The DNR Monitoring Team should evaluate existing data bases for quantity information and determine what changes, if any are appropriate to keep track of groundwater quantity information. There is currently water withdrawal information in the Bureaus of Drinking Water and Groundwater, Watershed Management, and Fisheries Management and Habitat Protection. It would be useful to examine the data bases and determine whether they should be combined or coordinated to keep track of both groundwater and surface water quantity problems. It may be appropriate, for example, to develop and maintain a groundwater withdrawal database for areas of the state of most concern. If so, cost of development and maintenance will be important. State and federal agencies should work closely with local units of government to meet their data management needs.

4. The two teams should work together to develop an information and education plan to promote recharge and wise use of Wisconsin's groundwater resources. It would be necessary to determine

what audiences are to be targeted and what messages need to be sent. The DNR, for example, may want to work closely with local units of government to promote wellhead protection to minimize groundwater quality impacts, proper well location to minimize quantity impacts and water use conservation plans to reduce water use. A number of agencies, including local utilities may decide to work together for a public information campaign on wise water use. Another option may be to work with teachers to develop and promote a groundwater curriculum that would address both groundwater quantity and quality issues. Some consideration should be given to providing assistance to small communities/water utilities without sufficient resources for water quantity planning.

5. The DNR Monitoring Team should review and update the Water Quantity Resources Management Plan if appropriate. The Management Plan was prepared in 1988 in response to a statutory requirement of s. 281.35 (formerly s. 144.026), Stats., and focused primarily on surface water quantity. The recommendations of the Summary Report included establishing and maintaining a water quantity database, updating water use predictions, evaluating the existing water quantity management programs, increasing efforts at water conservation, developing a state instream flow policy and adopting an emergency water allocation program. The plan has not been updated nor have the recommendations been implemented since 1988.

REFERENCES

Batten, W. G. and Bradbury, K. R., 1996, Regional Groundwater Flow System Between the Wolf and Fox Rivers Near Green Bay, Wisconsin. Wis. Geological and Natural History Survey Information Circular 75, 28 p.

Bochert, L., 1991, The Framework for Groundwater Management in Wisconsin: An Historical Perspective, in Working Together to Manage Wisconsin's Groundwater - Next Steps? Conference Proceedings, p. 3-11.

Clite, N., 1992, Three-dimensional simulation of groundwater impacts resulting from expansion of rock aquifers in the town of Lisbon, Waukesha County, Wisconsin. University of Wisconsin-Milwaukee; Master's Thesis.

Cherkauer, D. S., 1995, Impact of tunnel dewatering on surface water bodies in Milwaukee: Determination of hydrogeological controls and the efficiency of monitoring arrays. Groundwater Research/Monitoring Project, Water Resources Center, University of Wisconsin - Madison.

Consoer, Townsend and Assoc., Inc., 1992, Engineering Report on the Green Bay Metropolitan Water Supply and Quality Study: Project Number 12-3520.

Czarkowski, C., 1995, Wisconsin Department of Natural Resources (DNR), personal communication

Dawson, T., 1995, Wisconsin Department of Justice, personal communication

Drescher, W. J., 1953, Ground-water Conditions in Artesian Aquifers in Brown County, Wisconsin: U. S. Geological Survey Paper 1190, 49 p.

Ellefson, B. R., K. S. Rury, J. T. Krohelski, 1988, Water Use in Wisconsin, 1985, U. S. G. S. Open -file Report 87-699.

Ellefson, B. R., T. J. Sabin and J. T. Krohelski, 1993, Water Use in Wisconsin, 1990, U. S. G. S. Open-file Report 93-118.

Ellefson, B., 1997, U. S. G. S., personal communication.

Falkowski, G., 1996, Wisconsin DNR, personal communication.

Feneht, P., 1996, Wisconsin Public Service Commission, personal communication.

Furbish, W., 1996, Wisconsin DNR, personal communication.

Gebert, W., 1994, U. S. Geological Survey, personal communication.

Hahn, N., 1984, Radium in Wisconsin Groundwater and Removal Methods for Community Water Systems, Wisconsin DNR, 17 p.

Hennings, R., 1996, Wisconsin Geological and Natural History Survey, personal communication.

Hennings, R., 1994, Wisconsin Geological and Natural History Survey, personal communication.

Kammerer, P. A., Jr. 1981, Groundwater Quality Atlas of Wisconsin, WGNHS Information Circular 39, 39 p.

Kammerer, P. A., Jr., 1995, Ground-Water Flow and Quality in Wisconsin's Shallow Aquifer System, USGS Water-Resources Investigations Report 90-4171, 42 p.

Kennedy, D., 1994, Integrating Drought Management with Western Water Policy: Challenges for the Future, in Proceedings of the Conference Drought Management in a Changing West: New Directions for Water Policy, edited by Donald A. Wilhite and Deborah A. Wood, p. 39-43, International Drought Information Center, University of Nebraska-Lincoln, ITIC Technical Report Series 94-1.

Kline, J., 1995, Wisconsin DNR, personal communication

Kraft, G., 1995, Central Wisconsin Groundwater Center, personal communication

Kraft, G., 1996, Central Wisconsin Groundwater Center, personal communication

Krohelski, J., 1986, Hydrology and Ground-water Use and Quality, Brown County, Wisconsin, Wisconsin Geological and Natural History Survey Information Circular No. 57, 42 p.

Krohelski, J., 1994, U. S. Geological Survey, personal communication

Krohelski, J., 1995, U. S. Geological Survey, personal communication

Maertz, D. E., 1995, Water-Resources Investigations in Wisconsin, USGS Open-File Report 95-328, 84 p.

McLeod, R. S., 1978, Water level declines in the Madison area, Dane County, Wisconsin, U. S. G. S. in cooperation with Madison Water Utility, Open-File Report 78-936, 15 p.

Mechenich, D. and G. Kraft, 1996, Contaminant source assessment and management using groundwater flow and contaminant models in the Stevens Point-Whiting-Plover wellhead protection area, Central Wisconsin Groundwater Center, University of Wisconsin - Stevens Point.

Mudrey, M. G. and K. R. Bradbury, 1993, Distribution of Radionuclides in Wisconsin Groundwater, WGNHS Open-File Report 93-9, 20 p.

Patterson, G. L. and A. Zaporozec, 1986, Ground-Water Fluctuations in Wisconsin, WGNHS and USGS, 15p.

Potter, K., 1993, Estimating the spatial distribution of groundwater recharge rates using hydrologic, hydrogeologic and geochemical methods. Groundwater Research/Monitoring Project, Water Resources Center. University of Wisconsin - Madison.

Potter, K., and K. Bradbury, 1995, Groundwater Hydrogeology of an Agricultural Watershed, Groundwater Research/Monitoring Project, Water Resources Center, University of Wisconsin - Madison.

Rheineck, B. D., 1995, River-Groundwater Interactions and Implications for Wellhead Protection at Black River Falls, Wisconsin, UW-Madison Master's Thesis.

Schaver, S., 1995, Wisconsin DNR, personal communication

Southeastern Wisconsin Regional Planning Commission (SEWRPC), 1995, A Regional Water Quality Management Plan for Southeastern Wisconsin: an Update and Status Report, Memorandum Report Number 93.

Stoll, R., Burkel, R., LaPlant, N., 1994, Naturally-occurring Arsenic in Sandstone Aquifer Water Supply Wells of Northeastern Wisconsin, Groundwater Research/Monitoring Project, Water Resources Center, University of Wisconsin - Madison, also available as "Arsenic as a Naturally Elevated Parameter in Water Wells in Winnebago and Outagamie Counties, Wisconsin" by Rebecca S. Burkel Master of Science Thesis, Univ. of Wis. Green Bay (unpublished), August 1993

Telleman, B. 1994. My Well v. Your Surface Water Rights: How Western States Manage Interconnected Groundwater and Surface Water, Water Resources Research Center, University of Arizona, Issue paper no. 15.

Uelman, D., 1953, "The Law of Underground Water," Wis. Law Review. Vol:1953, No. 3, p. 493.

Weeks, E. P. and H. G. Stangland, 1971, Effects of Irrigation on Stream flow in the Central Sand Plain of Wisconsin, USGS Open-file report, 113 p.

Weeks, E. P., Ericson, D. W., and Holt, C. L. R., Jr., 1965, Hydrology of the Little Plover River basin, Portage County, Wisconsin, and the effects of water resource development, U. S. Geological Survey Water-Supply Paper 1811, 78 p.

Wisconsin Department of Natural Resources (DNR), 1988, Report No. 9, Summary, The Wisconsin Water Quantity Resources Management Plan, 22 p., June, Jeff Prey and Terry Lohr, PUBL-WR-186-88.

Wisconsin DNR, 1987, Groundwater Contamination Susceptibility Map and Evaluation, Wisconsin Groundwater Management Plan Report No. 5, 27 p.

Wisconsin DNR, 1983, Groundwater - Wisconsin's Buried Treasure. Supplement to Wisconsin Natural Resources Magazine. 31p.

Wisconsin Groundwater Coordinating Council (GCC), 1994, Report to the Legislature, p.35.

Wisconsin Groundwater Coordinating Council (GCC), 1995, Report to the Legislature, 110 p.

Zaporozec, A., 1982, Groundwater Level Monitoring Program in Wisconsin, WGNHS 10 p.

Zaporozec, A., 1995, Groundwater Levels in Wisconsin, Annual Summary 1994,
WGNHS Education Series 15, 6 p.

GROUNDWATER GLOSSARY

Aquifer: A body of rock or soil layer capable of yielding groundwater to wells and springs.

Artesian: Term which refers to groundwater in an aquifer being under sufficient pressure to rise above the top of the aquifer containing it.

Artesian well: A well in which groundwater rises above the top of the aquifer, whether or not it flows out at the land surface. A *flowing artesian well* commonly describes a well that naturally flows out at the land surface.

Baseflow: Groundwater which discharges to a surface water (e.g. lake, stream, or wetland).

Cambrian: Geologic time period between 570 and 500 million years ago.

Dolomite: A rock composed primarily of calcium magnesium carbonate minerals ($CaMg(CO_3)_2$. Many rocks in WI referred to as limestone are actually dolomite or dolomitic limestone.

Driftless area: The southwest portion of the state that was not covered by glaciers.

Evaporation: The process by which water as a liquid or ice changes to water vapor. Heat and wind accelerate this process.

Evapotranspiration: The combined loss of water to the atmosphere from evaporation and water loss from living plants by transpiration.

Geology: The science dealing with the origin, history, materials and structure of the earth, and the forces and processes which produce change within the earth and its surface.

Groundwater: Water beneath the ground surface in a saturated zone.

High-capacity well system: Where the capacity and rate of withdrawal of all wells on one property have a pumping capacity of 100,000 gallons a day or 70 gallons or more per minute.

Hydrogeology: The science dealing with groundwater and its relation to geology.

Hydrologic cycle: The perpetual movement of water from the atmosphere to the earth's surface, subsurface, ocean and back again. Primarily solar energy, wind, and gravity drive this cycle.

Impermeable: Term describing a rock, sediment, or soil that allows very little or no water to pass through it.

Infiltration: The movement of water into and through a soil.

Limestone: A sedimentary rock composed primarily of calcite minerals (calcium carbonate, $CaCO_3$).

Ordovician: Geologic time period between 500 and 440 million years ago.

Permeability: The ability and ease with which water (i.e. groundwater) can move or flow through rock or soil.

Pleistocene: The geologic time period from about 2 to 3 million years ago to 10,000 years ago, also known as the "ice age."

Potable: Safe to drink.

Potentiometric surface: Represents the non-pumping level to which water will rise in a well cased in an aquifer.

Precambrian: Geologic time period before 570 million years ago.

Recharge area: Land surface areas where rain and snowmelt infiltrate through soil and rock and to the groundwater in the saturated zone.

Saturated zone: A subsurface area of rock or soil in which all the spaces and voids, large and small, are filled with groundwater. The top of this zone is called the *water table.*

Silurian: Geologic time period between 440 and 400 million years ago.

Spring: Natural discharge of groundwater at the surface.

Transmissivity: A measure of the amount of water that can pass through a given thickness of an aquifer.

Water table surface: The top of the saturated zone in an unconfined aquifer in which the pore water pressure is equal to the atmospheric pressure.

APPENDIX A

WATER RIGHTS - WHAT DO OTHER STATES DO?
Eastern States

Generally, English common law serves as the foundation for groundwater withdrawal regulations in many of the states located east of the 100th Meridian. Statutes or case law which apply to any particular groundwater conflict will vary from jurisdiction to jurisdiction; however, when you examine the various state regulatory programs closely you will find that the majority of the existing regulations have evolved from the following common law tenets: (1) the rule of absolute ownership; (2) the rule of reasonable use; or (3) the rule of correlative rights.

A description of these key legal principles, coupled with a few examples of how the rules have been applied in the past, and a brief explanation of the main points of law which differentiate one doctrine from the next, should help illustrate the various ways in which a conflict between two or more users of groundwater may be managed in the Eastern United States:

Absolute Ownership Doctrine

The absolute ownership doctrine, also known as the "English Rule," asserts that the individual who holds title to a tract of land has ownership of all of the groundwater found beneath the surface of their land, just as they have a similar right of ownership for the soil and all other minerals located on the property. The doctrine is best summed up by the maxim: "To whomsoever the soil belongs, he also owns the sky and to the depths." (Uelman, 1953)

The doctrine of absolute ownership was first applied in an era when the science of hydrogeology was not yet recognized. The courts of that time considered the movement of groundwater to be too mysterious and unpredictable to enable the development of any reliable rules which could equitably deal with competing uses of groundwater other than as a property right. The doctrine of absolute ownership provides that a landowner may withdraw and use all of the groundwater that he or she might capture because it is property and, as a basic right of property ownership, an individual is entitled to freely use any property under their control.

Also as part of this doctrine, the landowner is relieved of all legal liability for any adverse effects that might be the result of groundwater pumpage since it was believed that the effects of such pumpage could not be anticipated in advance.

Reasonable Use Doctrine

The reasonable use doctrine, or "American Rule," provides that a landowner has a right to withdraw any available subsurface water as long as it is to be used for some beneficial activity on the overlying land. The withdrawal of groundwater may continue even when the reasonable use of this water will result in a significant interference with the use of the groundwater resource by an adjacent landowner. There is no real practical distinction between a landowner's property right to use groundwater under the reasonable use doctrine and the right of groundwater ownership under the absolute ownership doctrine other than that the reasonable use doctrine imposes a limit on groundwater use that is dependent on the reasonableness of the intended use. Traditional uses of groundwater are usually considered by the courts to be a reasonable use of the resource.

The concept of "reasonable use" is defined in groundwater common law somewhat differently than it is in the riparian rights doctrine of surface water common law. Under the riparian doctrine, the concept of reasonableness is a relative one in which an individual's right to use any surface water is limited in its extent by the impact of the proposed water use on the other riparian users. No similar limitation of a groundwater user's withdrawal rights applies except in those instances when the water is to be used at a location that is separated from the overlying land. When required to provide a legal interpretation of "reasonableness" as it relates to groundwater use conflicts, the courts have generally affirmed that a landowner retains a right to reasonably use groundwater for normal land use activities, even when the withdrawal interferes with another's use of the groundwater supply, as long as it can be demonstrated that the interference is not the result of waste, negligence or malicious intent.

Correlative Rights Doctrine

The correlative rights doctrine provides that the owner of a property has a right to use the groundwater that is available in any underlying aquifer as long as the neighbor's water rights are not damaged or altered. At the same time, the doctrine also recognizes that a balancing of individual water use needs may become necessary whenever the demand for groundwater exceeds the available supply.

Groundwater is considered a common resource which extends beyond individual property boundaries. No absolute right of resource ownership may be claimed by any individual holding the deed to one of the overlying properties. Land ownership simply confers to the individual a legal right of access to a resource that is currently managed by the majority of states as part of the public trust. Actual use of a groundwater resource by any individual will be limited by the volume of water that is available in the aquifer and the reasonable needs of other users, regardless of the time at which other competing uses are developed.

The rule of correlative rights gives preference to local uses of water over remote use in a way that is similar to the preference for local use provided under the rule of reasonable use. The two doctrines are dissimilar in that an individual's use of the groundwater under the correlative rights doctrine is tempered by the needs of other users of the aquifer and that all users may have to reduce their exploitation of the resource whenever water scarcity occurs.

If asked to examine allocation issues related to the correlative rights doctrine, the courts will usually weigh the needs of all landowners and the impact on the public trust before determining what is considered to be a reasonable allocation. This judicial consideration and balancing of the needs of groundwater users is equivalent to the review and balancing of riparian interests which occurs under the doctrine of reasonable use for surface water.

Regional interpretation of the common law principles described above, combined with varying degrees of local competition for available groundwater and a lack of federal interest regarding the regulation of groundwater withdrawals, has resulted in the development of a variety of state strategies for managing competition among groundwater users. These strategies lie along a continuum which ranges from: a total reliance upon common law tort actions that require the individual groundwater user to seek relief from other competing groundwater users through the use of injunctions or awards for damages; through limited regulation of resource access by means of a registration process; and by strict allocation of the resource through a permit process.

Restatement of Torts

Reform of the various groundwater allocation laws has been proposed by several legal scholars. Suggested reform measures would directly address problems posed by well interference and water shortages.

In Section 858 of the *Restatement (second) of Torts* liability for the use of groundwater would be limited as follows:

> A landowner or grantee who withdraws groundwater from the land and uses it for a beneficial purpose would not be subject to liability for interference with the use of water by another, unless
>
> a) the withdrawal unreasonably causes harm to the proprietor of neighboring land by a lowering of the water table or a reduction in artesian pressure,
> b) the withdrawal exceeds the landowner's reasonable share of the annual supply or total available supply of groundwater, or
> c) the withdrawal has a direct and substantial effect on a watercourse or lake and unreasonably causes harm to a person entitled to the use of water in the affected surface water body.

The Restatement is basically a blending of the correlative rights doctrine for groundwater and the doctrine of riparian rights for surface water. Under the rules of the Restatement, a landowner's right to withdraw groundwater would only be limited when the use unreasonably interferes with a neighboring use. The three basic kinds of unreasonable interference which would be prohibited are well interference, monopolization of the resource, and diversion from surface water.

The test of liability for well interference is whether or not the pumping of the groundwater has caused an unreasonable lowering of the water table or an unreasonable lowering of artesian pressure. It is recognized that any use of groundwater will have some effect upon an aquifer and that a reasonable drawdown must be allowed as a right; however, when a groundwater user withdraws an amount which is disproportionate to the amount withdrawn by other users and other wells begin to fail, then the disproportionately larger withdrawal may be deemed unreasonable.

When interference occurs and there is not an unreasonably large withdrawal, the Restatement suggests that courts use as a test for evaluating reasonableness the same factors used to assess the reasonableness of a riparian use of surface water:

a) purpose of the use,
b) suitability of the use to the water body (or aquifer),
c) economic value of the use,

d) social value of the use,
e) extent and amount of harm caused by the use,
f) practicality of avoiding harm by adjusting the use or method of use by one proprietor or the other,
g) practicality of adjusting the quantity of water used by each proprietor,
h) protection of existing values of water uses, land, investments, and enterprises, and
i) the justice of requiring the user causing harm to bear the loss.

Western States

Generally, water appropriation and management in the western United States fall under the prior-appropriation doctrine in which the first person (i.e., senior right) to withdraw and use the water holds rights over later persons (i.e., junior rights) who want to use that water. The water-right holder actually owns the right to use that water and if someone else wants to use that water they must purchase that right or pay to use the water held by the owner of the water right. Generally if a dispute arises over the use of water in an area, senior water-right holders have precedence over junior water rights; this is also known as "first in time, first in right." The prior-appropriation system originally applied to rights to surface water; however, it has also been applied to groundwater rights. Often disputes over groundwater and surface water appropriations are economic with little regard for protecting stream flow or dewatering an aquifer.

In most western states a permit and a water right must be acquired to withdraw groundwater; except private domestic and livestock use. In general, granting or denying a permit and groundwater right are based on the following criteria: 1) there must be no effect on prior appropriations of surface water and groundwater, 2) the water must be put to beneficial use, 3) the applicant must have the means to withdrawal and actually use the water, 4) use of the water must be in the public's interest, and, in some cases, 5) there must be no adverse impact on fish, game, recreation, and the aquifer itself. Generally, these criteria will establish what quantity or volume of water is allowed in the permit.

Western states manage and regulate groundwater in a variety of ways. Some western states manage groundwater and surface water under one unified system without legal distinction between the two; some protect senior groundwater withdrawal rights over junior rights; others only regulate and manage groundwater withdrawals in special districts where water supplies are critical; and other western states manage groundwater and surface water under separate systems but have provisions to integrate their management (Telleman, 1994).

A number of western states experienced extended drought conditions in the late 1980s and early 1990s. This prompted western states to examine western water and natural resources management strategies to address water quantity concerns. There is also growing recognition that existing policies need to be evaluated regarding the growing urban population with its water demands and decreasing support for irrigation agriculture (Kennedy, 1994).

Groundwater Susceptibility Map