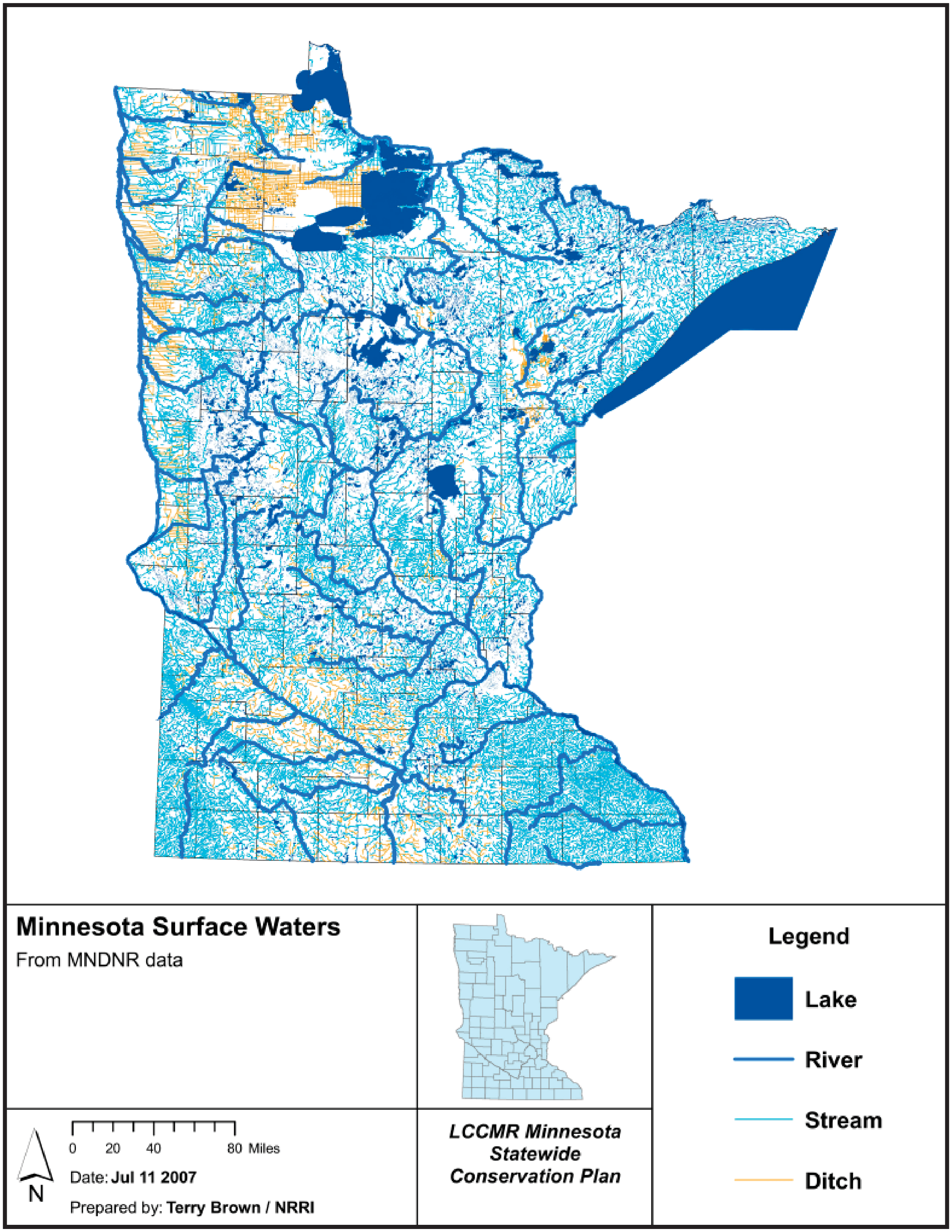

Figure 1: Surface waters in Minnesota. Credit: Terry Brown, University of Minnesota.

"The frog does not drink up the pond in which he lives."

—American Indian Saying

History

Water is one of Minnesota's most important and most visible natural resources. Water underpins much of the state's economy and provides its citizens and visitors with a wide variety of recreational options. Compared to many parts of the United States, Minnesota contains a high diversity of water resource types, ranging from large rivers to small streams, cold water to warm water lakes, many different wetland types, and groundwater. This is due to Minnesota's glacial history and diversity of landforms. This aquatic diversity, across seven aquatic ecoregions supports an impressive range of plant and animal species.

Prior to European settlement and the subsequent population expansion a wide range of natural or baseline water resource conditions could be documented in the state. Water bodies ranged from naturally oligotrophic waters with low nutrients, low productivity and high water clarity to naturally eutrophic waters with high nutrient concentrations, high productivity and low water clarity. Lake Superior is one of the most oligotrophic systems in world. Minnesota's shallow lakes are naturally eutrophic. Not all pre-settlement water conditions were pristine. Many water bodies were not clear due to naturally occurring concentrations of arsenic, salt, methane, radon, radium and dissolved solids. As efforts move forward to conserve and improve the quality and quantity of Minnesota's water resources, it will be important to distinguish these natural variations from those caused by human activities.

The current condition of Minnesota's water resources is quite different from the pre-settlement era. The clearing of the land, conversion of the land to agricultural systems and urban/suburban development have all had a direct impact on water resources. Figure 2 shows the result of these stressors on the north shore region of Lake Superior.

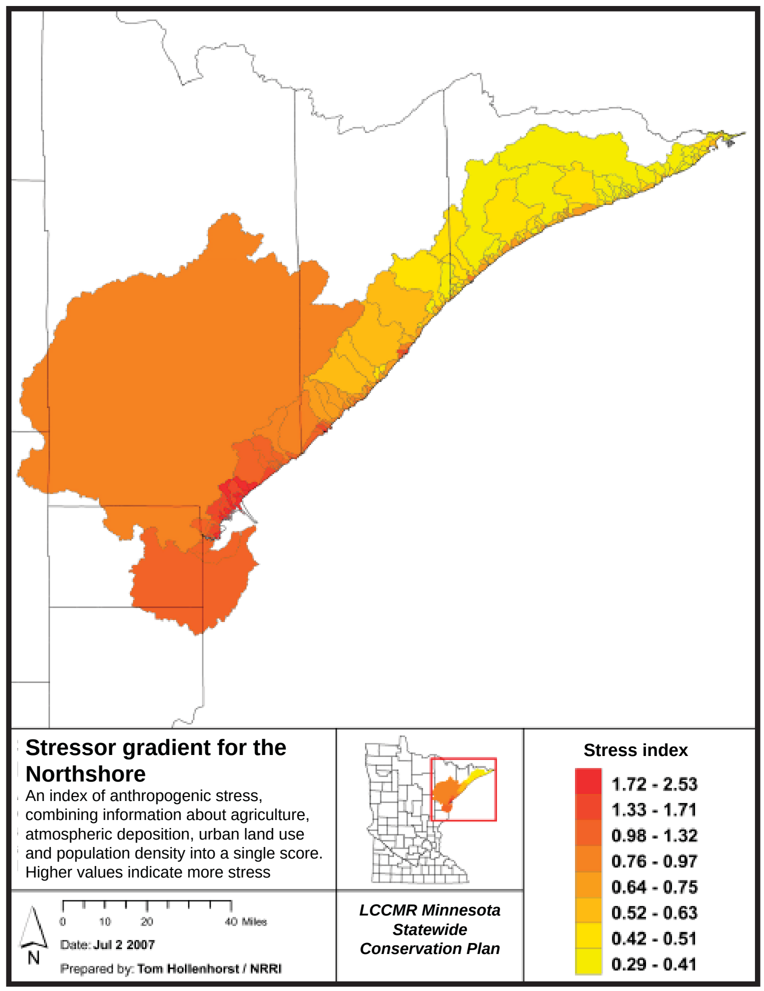

Figure 2: Northshore stressor gradient. The stressor index is a means of integrating a series of environmental stress factors into a single number. The factors include road density, population density, percent agriculture and residential development, and numbers of point sources of pollution (including discharge permits, presence of mines, power plants and dams). This index has been used to identify 'reference areas' (those that represent the best ecosystems, which have high conservation value) as well as 'at-risk' ecosystems. Credit: Niemi et al., University of Minnesota.

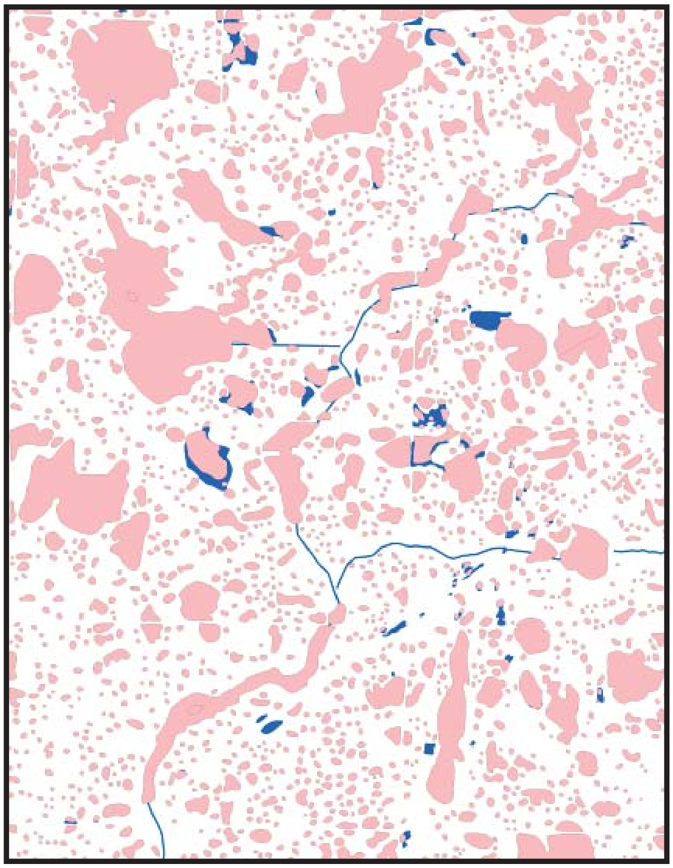

Figure 3: Wetlands of Kandiyohi County. Blue indicates existing wetlands. Salmon indicates drained (and therefore theoretcially restorable) wetlands. Credit: Rex Johnson, US Fish and Wildlife Service.

It is currently estimated by the Minnesota Pollution Control Agency (MPCA) that approximately 40% of Minnesota's rivers, lakes, and streams are considered "impaired" under the Clean Water Act, and do not meet water quality standards.

The hydrologic cycle and the natural balance between surface water and groundwater has been disturbed. It is estimated that nearly 95% of the wetlands in the state have been drained. An example of this is found in Figure 3, which shows the number of former wetlands that could be restored in Kandyohi County.

Surface Water and Ground Water Connectedness

The quantity of both surface water and ground water varies naturally across the state due to variations in climate and geology. These two systems are highly interconnected with significant changes to one reflected in the other. Baseflow in rivers, the flow that occurs after runoff and drainage from rainstorms or snowmelt have ceased, is in reality ground water that drains to surface channels. Current recharge rates for Minnesota's groundwater are depicted in Figure 4, facing page.

Nonsustainable withdrawal of groundwater can have significant impacts on surface waters. Over-pumping of groundwater in the Twin Cities metro area has caused decreased baseflow in trout streams, forcing the relocation of groundwater wells. In many parts of the state, groundwater pumping has threatened calcareous fens. In north central Minnesota water use permits were not renewed after wetlands were impacted by groundwater pumping for irrigation.

Surface water is typically managed on a watershed basis, recognizing that surface water does not cross watershed boundaries. Managing ground water and aquifers will require that we recognize the boundaries of the aquifer, and the land area that contributes water to the aquifer. Those boundaries are determined by the arrangement of water-bearing and water-confining geologic materials (see Figure 5, facing page). Most aquifers and confining units in Minnesota have not been mapped. This deficiency precludes understanding of aquifer capacity, recharge rates, and land areas contributing water to aquifers that is required to manage these resources.

Although these two systems are interconnected, most of the drivers of change to the overall resource act primarily on one or the other and they are discussed separately in this report. Where a driver impacts both systems, it is discussed within the system where it has the larger impact.

Drivers of Change: Surface Water

- Solids Loading
- Nutrient Loading
- Aquatic Habitat Loss
- Contaminants
- Hydrologic Modification

Minnesota has an abundance of surface water (see Figure 1, page 58): 93,000 miles of rivers, streams and ditches; approximately 870,000 wetlands covering 10 million acres; and 3 million acres of lakes larger than 10 acres, about 13,000 in all.

Minnesota's rivers, streams and ditches are fed by surface runoff, as well as by springs and baseflow from shallow and deep aquifers. Annual runoff varies from one inch in parts of western Minnesota to 9 inches in southeastern Minnesota and up to 16 inches along portions of Lake Superior. Runoff is highly variable, largely in response to snowmelt, rainfall and evaporation patterns.

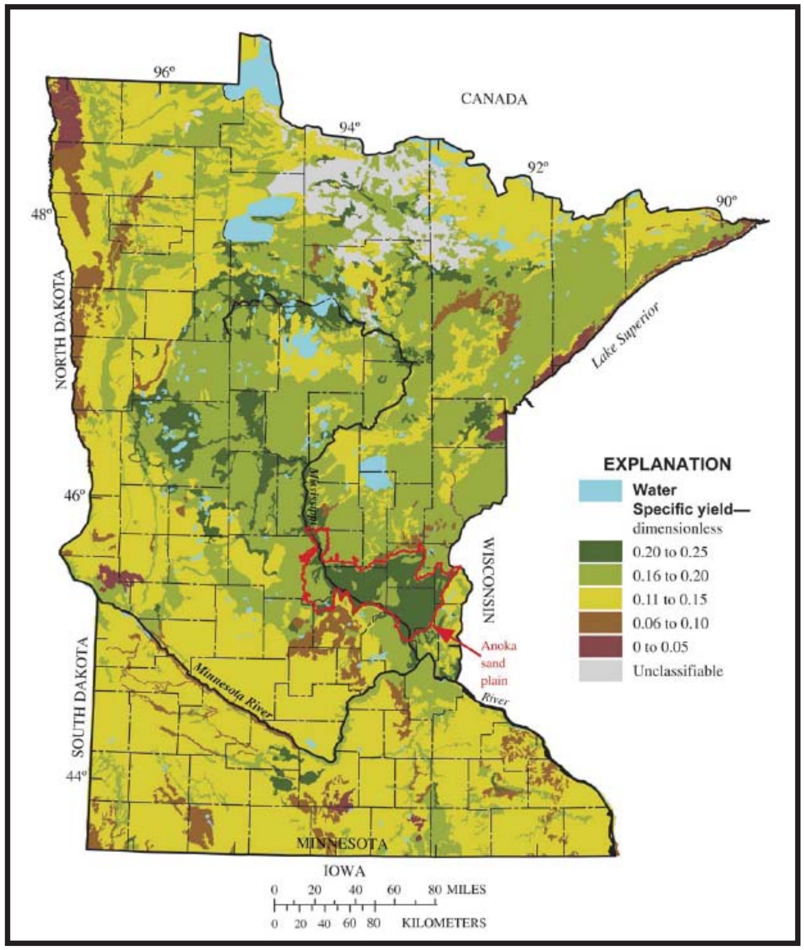

Figure 4: Average annual recharge to surficial materials in Minnesota (1971 - 2000) estimated based on RRR model. Credit: Lorenz and Delin (2007).

Solids Loading

Solids loading results from activities such as agriculture, shoreland development, urbanization, construction activities and stormwater drainage. Erosion of sediment from bluffs and streambanks is also important and can be influenced by runoff variability.

Solids delivered from the watershed can cause cloudy or turbid water which negatively impacts fish and aquatic communities (Note: The impacts of sedimentation on fish and aquatic communities are addressed in the Fish Natural Resource Profile). Turbid waters absorb more solar radiation and become warmer than those water bodies with clear water and can result in associated changes in plant and animal communities. Sediment particles themselves may contain significant amounts of organic matter, nutrients, and toxic pollutants such as heavy metals and pesticides, and thus they become sources of secondary pollutants. Sediments that are not associated with secondary contaminants are known as "clean" sediments.

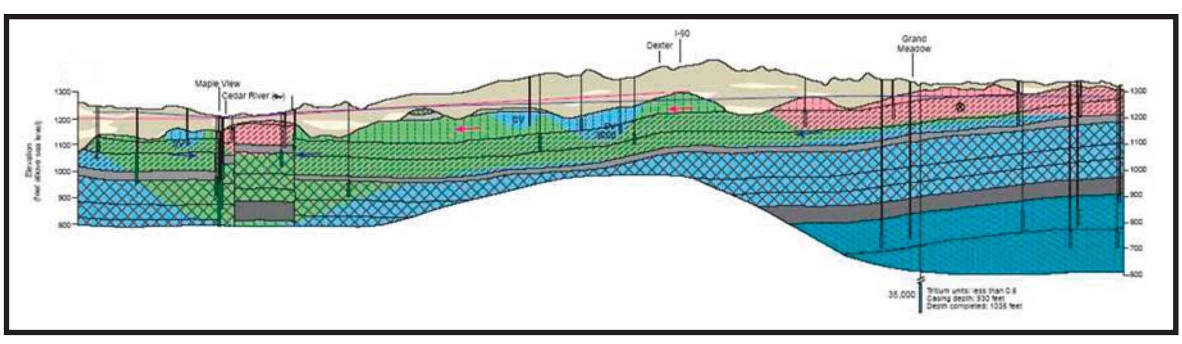

Figure 5: Bedrock hydrogeology cross-section from Mower County Geologic Atlas, Part B. Here, colors represent the age of the ground water. The pink water has entered the ground in the last 50 years, the green water is of intermediate age, and the blue water is as old as 35,000 years. Credit: Minnesota DNR.

Moving water generally has the capability of becoming more turbid than standing water. One prediction of climate change is an increase in the number and intensity of extreme storm events. As climate tempurature increases there is a greater potential for introduction of fine and coarse sediments to all surface water bodies. In conjunction with high flows and lower bank erosion causing further increases in concentrations of fine and coarse sediments.

Better data for sediment loads and sediment sources are needed. Monitoring can be difficult and expensive. Stormwater sediment concentrations and secondary pollutant concentrations and loads are extremely variable in space and time and are event-based. The higher levels of pollutants which occur as a result of rainstorms, high winds on lakes, and during snowmelt runoff are difficult to sample. This is particularly true for smaller, flashier streams, because higher flows and higher loads of sediments occur during unpredictable, short-duration rainstorms and during spring snow-melt runoff which is highly variable from year-to-year. Reliable methods to differentiate ("fingerprint") in-stream versus external sources of sediment to a river would assist in the development of TMDLs for sediment impairment. While the MPCA has had some support for research in this area, the state is encouraged to continue to invest in this needed research.

A better understanding of the critical landscape areas is also needed. These are small areas that contribute disproportionately large amounts of sediment to surface waters. Also needed is a better understanding of streambank and bluff erosion processes, and the influence of them on hydrologic management. Additional data are needed to develop models that link climate to landscape

Water: Shared Resource Implications

Within the State: North Central Lakes Collaborative

The North Central Lakes Collaborative is an affiliation of citizens, organizations, local governments, and state agencies working together to identify and promote strategies for sustainable healthy lakes in central Minnesota. The five county area encompassing Aitkin, Cass, Crow Wing, Hubbard, and Itasca counties is a rapidly growing region of the state with 30-year growth projections expected to exceed 60%, far exceeding statewide average growth projections. The Brainerd Lakes area is among the country's fastest growing "micropolitan" areas, ranking 27th in the nation with a 24.5% increase in population during the previous decade. These population growth statistics do not consider the popularity of central Minnesota for seasonal housing such as lakeshore homes. With this rapid-paced growth comes a number of challenges to the long-term sustainability of the region's water resources, which include over a fifth of the state's lakes and 11% of the state's river miles (42% of the Mississippi River miles within Minnesota). Local planners are faced with a dilemma: how to accommodate growth while still maintaining natural systems that contribute to a high quality of life for all residents, particularly in a tourism-driven economy.

Initially organized in 2003 as one of five pilot project areas under Governor Pawlenty's Clean Water Initiative, the North Central Lakes Collaborative has since made important contributions to sustainable healthy lakes in the region and statewide. Among these accomplishments are the development of Alternative Shoreland Development Standards, a suite of regulatory tools that are available for local governments to adopt into their zoning ordinances; delivery of information and technical assistance to over 30 landowners interested in conservation easements as a means of protecting their land and lakeshore for future generations; implementation of a regional wastewater treatment strategy to promote the regular maintenance and inspection of dispersed on-site sewage treatment systems (septic tanks) common in rural Minnesota; and production of a number of radio spots and newspaper articles under the popular Lake Waves communication series that informs lake users and residents about lake-friendly actions they can take to protect lake water quality and aquatic habitats.

The strength of the North Central Lakes Collaborative lies in the diversity of individuals, organizations, and government contributing time and creativity to seek balanced solutions for the complex challenges facing central Minnesota lakes.

to surface/groundwater runoff to water quality, fish and wildlife, and infrastructure. More data are needed to evaluate the effectiveness and cost-benefit of planning, Best Management Practices (BMPs) strategies and engineering solutions being used to address the issue.

Nutrient Loading

Phosphorus is the nutrient of most concern in surface waters in Minnesota (see Figure 6). It is a naturally-occurring nutrient that is required for plant growth but in excess amounts it promotes a proliferation of algae that results in reduced dissolved oxygen content as algae die and decay. Reduced oxygen concentrations stress fish and other aquatic species. The increased productivity also leads to increased turbidity, and to taste and odor impairments in drinking water (Note: The impact of excess nutrients on fish and aquatic communities is addressed in the Fish Natural Resource Profile).

Excessive phosphorus is usually delivered from non-point sources (such as agriculture, shoreland development and urbanization) to waterbodies via surface runoff. Phosphorus also enters Minnesota surface waters from point sources such as the discharge of treated wastewater and stormwater drainage.

More data on the prevalence and trends of phosphorus loading in the state's surface waters are urgently needed. Currently only 10% of the state's surface waters have been assessed.

Best management practices for phosphorus include preventing surface runoff, manure management, stormwater management and other strategies that reduce surface runoff from urban areas.

Aquatic Habitat Loss

Habitat for aquatic organisms is defined as the physical and chemical environment that provides the resources for daily living, including food, protection, nesting and rearing. The most productive and vulnerable zones of rivers and lakes occur at the margin of the land and water (Note: habitat features of importance to fish communities and other aquatic organisms are also addressed in the Fish Natural Resource Profile).

Habitat quality is most susceptible to degradation resulting from human activities occurring near the shoreline and within the watershed of a river, lake, or wetland. Many of these activities result in decreased watershed and riparian vegetation which can result in runoff with elevated water temperatures and increased sediment and nutrient loads.

Human activities that influence habitat quality in streams, wetlands and lakes include:

- residential, commercial or industrial activities,
- logging,
- agriculture,
- mining,
- shoreline or stream channel modifications,
- groundwater and surface water extraction.

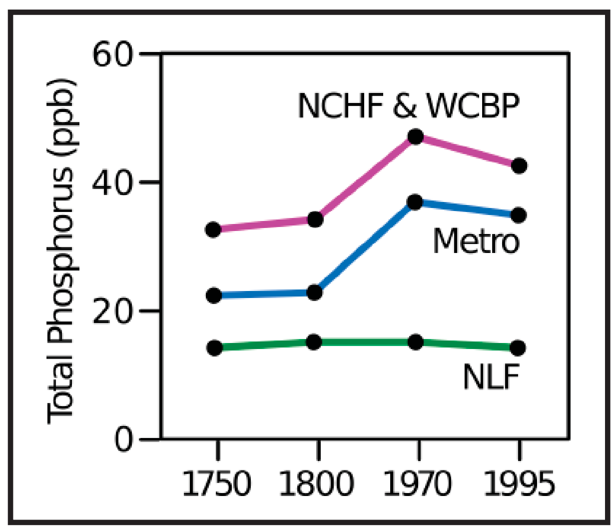

Figure 6: Increases in total phosphorus (TP) over time in 55 representative Minnesota lakes (the dates of the measurements are on the horizontal axis). Phosphorus is a major pollutant, and it has increased significantly in the Metro region lakes and in the center of the state (which is labeled NCHF and WCBP) over the past 200 years. Lakes in forested northeastern Minneosta (labeled 'NLF') have not seen an increase in phosphorus. Maximum and minimum values may range widely around the points shown, which are averages. Credit: Ramstack et al. 2004. Graphic byTerry Brown, University of Minnesota. This work was funded by LCCMR.

Under changing climatic regimes, wetlands, and the areas as the intersection of the land and water will become even more sensitive as water levels fluctuate and plant communities adapt to changing conditions. Under warmer climates, shading from riparian vegetation will be increasingly important to buffer daily temperature swings in cool and cold water streams.

At a gross scale preliminary tools are available to quantify potential stressors influencing in-stream and in-lake habitats and ecosystems. The water/land margin areas as well as aquatic vegetation beds and shallow areas are poorly mapped, and therefore poorly protected. Riparian and shoreland protection rules should be considered to protect these valuable and vulnerable areas. Further research on the potential impacts of changing climate, including increasing temperatures as well as the increasing number of intense storms is needed to identify vulnerable ecosystems and habitats. Such efforts will allow us to prioritize protection and restoration activities.

Contaminants

There are a number of chemical, physical, and microbiological contaminants that can impact water quality. The focus of this section is on specific toxic chemical contaminants that have the greatest impact on the state's water resources. We recognize that there are "legacy" contaminants in our lake and river sediments such as PCBs; "emerging" contaminants that are just now being detected in the environment, such as pharmaceuticals, brominated flame retardants, and perfluorinated compounds; and metals, such as mercury. We will highlight the important contaminant drivers of change below.

Mercury

Mercury is the contaminant of primary concern in surface waters in Minnesota. It is a naturally occurring but toxic metal. It is mobilized into the environment from coal-fired power plants (certain kinds of coal contain mercury), mining, and some manufacturing processes. Mercury is emitted into the atmosphere, but then enters lakes and rivers with precipitation. It is be transformed by bacteria into methylmercury, which bioaccumulates in fish. Current levels of mercury in the environment are considerably greater than preindustrial levels, as recorded in lake sediments (see Figure 7).

Methylmercury is a potent neurotoxin, and poses particular risk to children and fetuses when exposed.

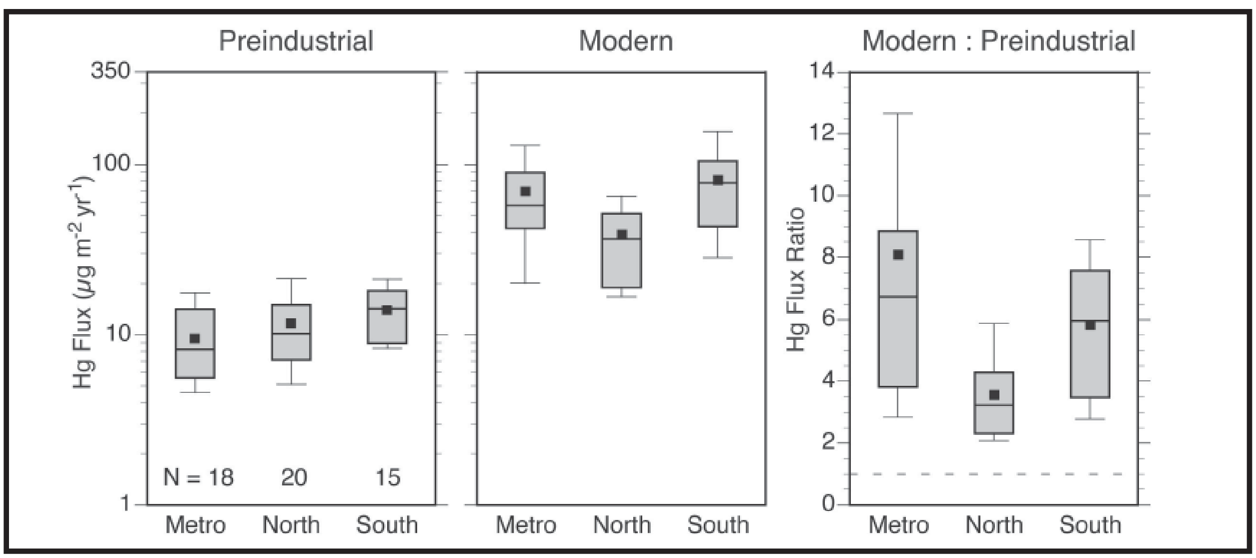

Figure 7: Box plots of sediment - Mercury (Hg) fluxes and flux ratios for the study lakes by region. Preindustrial is the mean Hg accumulation rate prior to 1860 and Modern is the mean rate post-1994. Metro = Minneapolis-St. Paul metropolitan area, North = northeastern Minnesota, South = south central Minnesota (rural). Boxes represent interquartile ranges, bars delineate upper and lower 10%, and the center line is the median; means are shown by closed squares. Credit: Engstrom, Balogh and Swain (2006). This work was funded by LCCMR.

These potential risks from methylmercury exposure has led the Minnesota Department of Health to issue fish consumption advisories for all of our lakes and streams. Because the primary source of this contaminant is the atmosphere, it is discussed more fully in the Air Natural Resource Profile (see page 18).

Pesticides

Pesticides affect both surface and groundwater. Generally, they are of more concern in groundwater than in surface waters (see Groundwater section, page 68). In a limited set of surface water samples collected in agricultural production regions of the state between May and July 2005, 98% exhibited the presence of atrazine and deethylatrazine, and 76% exhibited the presence of metolachlor. In no cases, however, did concentrations of these pesticides exceed federal or state health guidelines or maximum contaminant levels for drinking water.

Pharmaceuticals/Endocrine Disruptors

Many consumer goods and products contain chemicals that can mimic the behavior of hormones and other chemical signals of the endocrine system in animals, known as endocrine disrupting compounds (EDCs). These chemicals include common additives to detergents, food packaging, and plastic containers, as well as naturally excreted estradiol, and the synthetic estrogens in birth control pills and menopausal medications. Consequently, they are very widespread in our environment. They end up in wastewater, but since wastewater plants are not designed to remove these kinds of compounds, they are discharged to natural waters. Agriculture practices are also a source, due to the extensive use of animal hormones, and the use of certain hormonally active pesticides. Landfill leachate is another source. The occurrence of EDCs is directly related to population, and cultural behavior.

Studies of their impacts on wild populations of fish in the Mississippi River, and the results of laboratory studies on fish done by researchers at the USGS, University of Minnesota, and St. Cloud State University, have clearly demonstrated the potential for these estrogens and estrogen-mimicking compounds to affect the reproduction capability of male fish. Their impacts on other wildlife in the state, or on humans, are much less understood.

Pharmaceuticals in the environment are primarily a result of the use of antibiotics and other drugs in

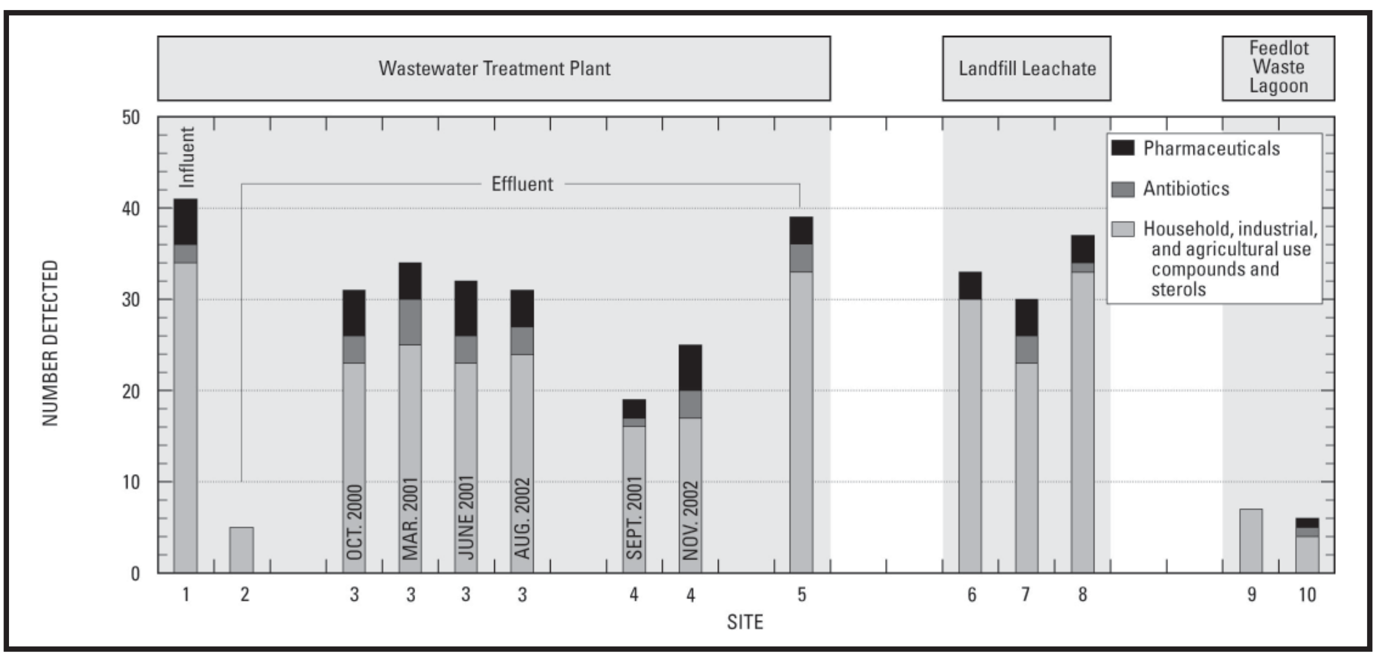

Figure 8: Organic wastewater compounds detected in wastewater treatment plant, landfill leachate, and feedlot waste lagoon samples, Minnesota, 2000-02. (site identification numbers can be found in table 1 and figures 1 and 2 of the report.). Credit: Lee et al. (2004), USGS.

commercial animal operations, and in the disposal of consumer drugs in waste water by the general population. The USGS has documented the widespread occurrence of a wide range of over-the-counter and prescription drugs in our surface and groundwater both nationally and locally.

A state-wide study of organic wastewater compounds in 2000 to 2002 by the USGS demonstrated that 74 of 91 potential compounds were detected at least once. The most commonly detected compounds were metalochlor, cholesterol, caffeine, DEET, bromoform, several plasticizers, a synthetic musk, a plant sterol, and cotinine (see Figure 8, page 65). The fate and impacts of these drugs in our surface waters is largely unknown.

The risks to humans posed by the presence of EDCs and pharmaceuticals in our water is unknown at this time; there are limited data on the impacts to wildlife populations. Critical information that is needed includes:

- Persistence and reactivity of compounds once released to the environment.
- Exposure of compounds to people and animals – concentrations in surface, ground, and drinking water supplies.
- Impact of exposure to individual species.
- Risk assessment for populations (as opposed to individuals).
- Human toxicity data.

Hydrologic Modification

There are three primary types of hydrologic modification in Minnesota. These include:

- Impervious surfaces in urban settings.
- Surface ditching in all 10 major river basins.
- Subsurface tile drainage in the Minnesota River Basin.

Dams are also a type of hydrologic modification, but have been typically less important than the other types of hydrologic modification for impairing water quality. Where they exist they have huge impacts; changing lotic habitats to lentic, preventing fish passage, and, as a result, causing the extinction of other organisims such as freshwater mussels (see Fish Natural Resource Profile).

Hydrologic modification is a stressor to water bodies because it changes the volume, rates, and timing and duration of water runoff from the landscape. Hydrologic modifications impact most stages of the water cycle.

Hydrologic modifications affect surface waters through the following mechanisms:

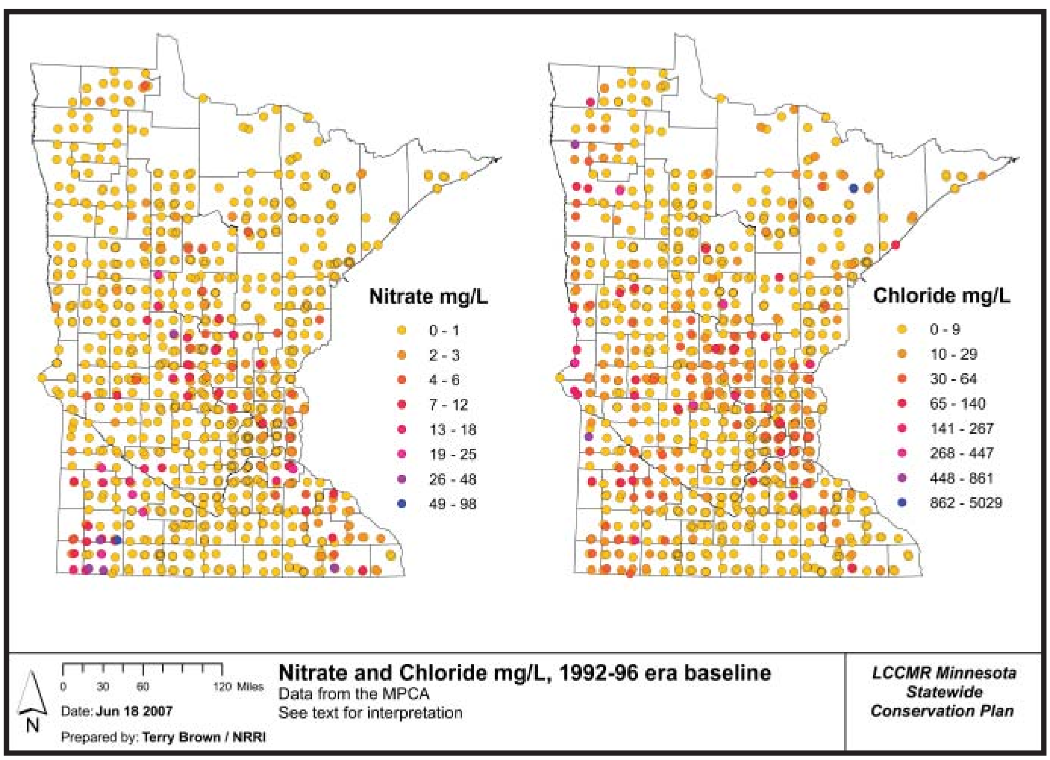

Figure 9: Nitrates and chlorides in Minnesota surface waters. Credit: Terry Brown, University of Minnesota.

- Surface ditching, artificially straightened natural streams, and impervious surfaces increase total runoff of sediment, phosphorus and contaminants to surface waters.
- Subsurface tile drainage increases the delivery of nitrate(N) and pesticides to surface waters (see Figure 9, facing page).
- Impervious surfaces coupled with surface ditching and straightening of natural streams increase peak flows, which results in flooding, channel scouring (erosion) and alteration (see Figure 10).
- Impervious surfaces cause flow velocities and amounts to increase and then decrease more rapidly in response to a given rain event (a "flash flood effect").
- Impervious surfaces cause lower base flows which exacerbate drought impacts, especially temperature and oxygen extremes.
- Surface ditching and subsurface tile drainage lower the shallow water table, and caused the loss of nearly 90% of the natural wetlands in southern Minnesota over the last century. Impervious surfaces produce lower base flows which impacts seasonal wetland persistence.

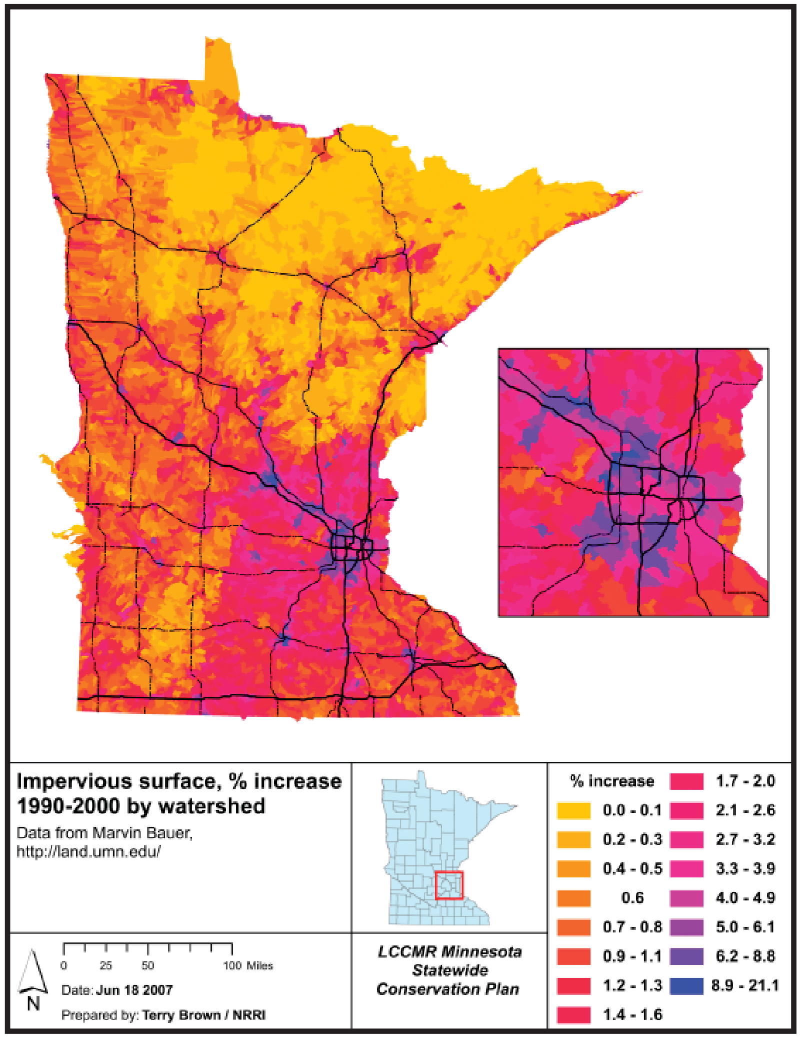

Figure 10: Impervious surface increase by watershed 1990-2000. Credit: Marvin Bauer, University of Minnesota. Funded by LCMR. Figure prepared by Terry Brown, University of Minnesota.

Because of these effects, hydrologic modification is a major consideration in managing stormwater runoff to minimize water pollution.

Changing demographics, in the form of increased population, and land use, in the form of urbanization, have resulted in large increases in urban growth and rapid expansion in the extent of impervious surfaces. Energy (ethanol) and agricultural policies and practices have encouraged a shift toward annual cropping systems, which has brought about increased surface and subsurface drainage. Historical ditches, tile drains, and channelized stream reaches persist and continue to be associated with many water quality problems.

An increasingly wetter climate in the Minnesota River basin caused a large increase in the extent of subsurface tile drainage over the last two decades. Potential changes in climate will further amplify the effects of poor societal land use management decisions. Most dramatically, projected increases in the frequency of severe storms may exponentially increase channel and shoreland erosion, flooding, and soil loss.

There are regional patterns in the impacts of these major drivers of water resource degradation. Minnesota's diverse climate and landforms are associated with regional differences in human activities on the landscape, and therefore, types of stressors.

- In agricultural regions channelization and tile drainage have disrupted flow regimes. Impacts from these activities include sediment, nutrient, and pesticide loading, decreased oxygen, and increased temperature.
- Urban resources are degraded most often by the effects of increased impervious surface area.
- Forested areas are also threatened by impervious surface increases caused second home development along lake shores and streams. Runoff-related changes from increased stream crossings by roads, and the amount of logging have also degraded water in forested areas. Some of the more sensitive forest areas are affected by forest practices such as in wetland areas, riparian zones and where the terrain is steep and has thin or poorly drained soils.
- In the far north, boreal ecosystems are especially vulnerable to changing climatic conditions since hydrologic regimes are forecast to have a greater degree of change than to the south. These areas contain most of the State's cold-water biological communities.

See the Groundwater section below for further discussion on the impacts of hydrologic modification and existing data gaps.

Drivers of Change: Groundwater

- Hydrologic Modification
- Consumptive Use
- Contaminant Loading (pesticides)
- Nutrient Loading

Minnesota hosts a variety of geologic materials in a complex, three-dimensional arrangement. These include glacial drift, glacial outwash and bedrock aquifers. On a regional scale, differences in the water-bearing characteristics of these materials and their arrangement results in extremely uneven distribution of groundwater resources. For example, the western border region has fewer and smaller aquifers than southeastern Minnesota or the Twin Cities area. On a more local scale these differences greatly affect how long it takes precipitation, the origin of groundwater, to travel from the land surface to the aquifers supplying our wells. In many places wells provide water that entered the ground hundreds or thousands of years ago (see Figure 5, page 61). That water was never exposed to human activity and therefore its quality has not been degraded by either natural or human means. In other places, the available aquifers are shallower or are recharged over a much shorter time frame. The water in these aquifers commonly contains contaminants from our industrial, agricultural, or waste management practices.

Not so water rich

"The label of Minnesota as water rich does not fit as well as once believed. The growth corridor stretching through the Twin Cities to St. Cloud already makes significant demands on its renewable water resources, making water supply management a special concern. In the remainder of the state, even today, care also must be taken by local and state officials in planning to meet the demand for and allocation of water."

Use of Minnesota's Renewable Water Resources: Moving toward Sustainability, Environmental Quality Board and Department of Natural Resources, April 2007

Hydrologic Modification

See the discussion of hydrologic modification in the Surface Water section on page 60 for a complete description.

Hydrologic modifications affect groundwater in the following ways:

- When precipitation reaches the land surface, impervious surfaces may prevent their infiltration. These surfaces typically divert the water to stormwater systems that affect both the destination of that water, and the rate at which it travels.

Agricultural drainage systems similarly intercept precipitation and move it to surface water bodies. This can significantly reduce groundwater recharge in that this precipitation may not infiltrate the surface and become groundwater depending on where it is routed.

- Groundwater withdrawal (see Figure 11) by pumping wells, is another form of hydrologic modification. Pumping may induce an increase in the rate of recharge, or change the path of recharge, to groundwater aquifers. In addition, hydrologic modification occurs because the location of discharge may not be hydrologically connected to the aquifer from which the water was taken.
- Sinkholes: In some geologic settings the impoundment of water at the land surface can cause sinkholes to develop which catastrophically drain the impoundment. In the case of wastewater treatment ponds or stormwater ponds this can introduce a large slug of poor quality water into the groundwater system.

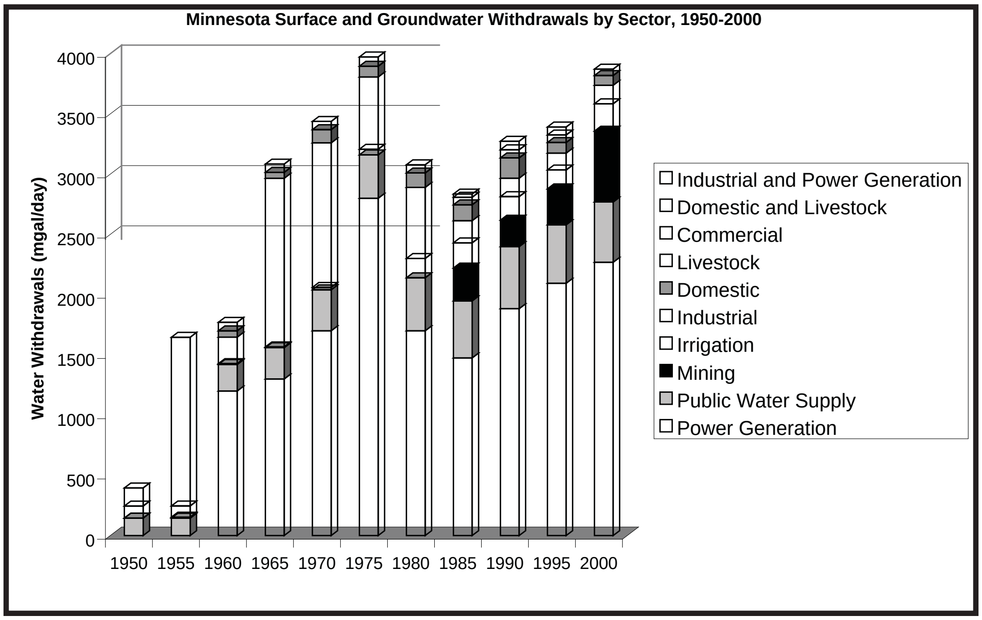

Figure 11: Surface and groundwater withdrawal rates by sector. Notes: For 1950 and 1955, domestic withdrawals were reported together with livestock withdrawals, and industrial and power generation withdrawals were reported together. Commercial withdrawals were not recorded in 2000 or before 1985. Mining withdrawals were combined with industrial withdrawals before 1985. 'Pubic Water Supply' category includes public water going to domestic, commercial, industrial and power generation sectors. Credit: Laura Schmitt, University of Minnesota.

The impact of subsurface tile drainage on streambank erosion or groundwater recharge is not known, nor is the impact of impervious surfaces on groundwater recharge.

Consumptive Use

Water consumption is the use of water withdrawn from a water body, watercourse or aquifer that is not directly returned to its original source.

Water consumption reduces the volume of water available for other purposes within a water body, watercourse or aquifer. Because groundwater and surface waters are interconnected – they are one system – consumption of groundwater from an aquifer may reduce the amount of surface water in a stream, lake or wetland, and vice versa. Consumption alters the quantity and flow regime of water resources provided by a natural system and can adversely affect the unique natural features and ecosystem functions that depend upon them. In some cases, water consumption can alter water chemistry. In Wisconsin, for example, ground water withdrawal pumping has been shown to increase arsenic concentrations in groundwater.

Withdrawal of groundwater may lower the water level in an aquifer either temporarily or permanently depending on available recharge. Much of the ground water pumped is discharged at or near the land surface via irrigation systems, on-site waste treatment systems (septic tank systems) or municipal wastewater treatment systems. Large scale systems tend to move the water farther from its source laterally, potentially having greater effect on the water resource and the people and ecosystems that depend on it.

The primary drivers of water consumption are the people and businesses (see Figure 11, page 69) that require water for drinking, energy production, food production and commercial/industrial use. Minnesota's population, demographic characteristics and weather, as well as its land use, energy use, transportation and water use habits profoundly influence the amount and location of consumed water. In addition, climate change may exacerbate the problem in some areas by increasing water demand and reducing water storage.

Regional and global population also can be important drivers of water consumption. As regional and world populations increase, new demands for food and energy will increase water consumption in Minnesota. The water needed to grow crops is in effect transferred out of basin and state as virtual water in the form of food or energy.

Water consumption may affect and be affected by other drivers, such as hydrologic modifications, which change the amount and timing of flows or available supplies, and contaminants, which alter the suitability of water resources for human and ecosystem uses. Nutrient loading, in particular that of nitrates to groundwater, may also make water unsafe to drink. Erosion leads to sedimentation that may diminish the capacity of surface water reservoirs to store water. Finally, consumption of water supplies may degrade habitat by reducing low flows in streams and groundwater discharges important to fens and other wetlands.

Minnesota withdraws roughly 200 billion gallons of groundwater every year for domestic supply, industrial processing and irrigation. In addition, ethanol plants use a substantial amount of water for processing, and a large number of ethanol plants are located in areas where groundwater is scarce. The burgeoning ethanol industry in Minnesota currently uses roughly 2.4 billion gallons of water, mostly from groundwater supplies. Lack of adequate groundwater supplies has forced at least one ethanol plant in western Minnesota to close, and another was forced to curtail plans for expansion. Overpumping of groundwater in Dilworth, located in northwestern Minnesota, forced the town to seek other more expensive sources of water.

Because the location and characteristics of water resources vary across the state, as do the people and ecosystems that depend upon them, the effects of water consumption likewise vary. A 2007 Environmental

Water: Shared Resource Implications

National Obligations

The Mighty Mississippi begins in Minnesota, and rolls down through the heartland of the nation, emptying into the Gulf of Mexico. This vast river system contains the 16th longest river in the world. Its watershed is the second largest in the world, and drains 1.2 million square miles including parts of 32 states, and serves as a major artery for movement of commercial goods from the Twin Cities to New Orleans, as well as goods brought from far and wide to its many ports by train and truck. It is one of three major flyways for migratory birds traveling between South and Central America and North America. It is a defining icon of American history and heritage. In Minnesota, it drains 40% of the state of Minnesota, and ¾ of our population live in its watershed. Stewardship of the Mississippi River not only affects most Minnesotans, it affects the lives of many Americans, as well as providing a vast set of ecosystem services. What we discharge to the River in Minnesota can affect human health in New Orleans, and the half-billion dollar shrimp fishery in the Gulf of Mexico. We not only have an obligation to protect this river, we have an obligation to be a model for the rest of the country in providing stewardship for this great River who claims our state as its birthplace.

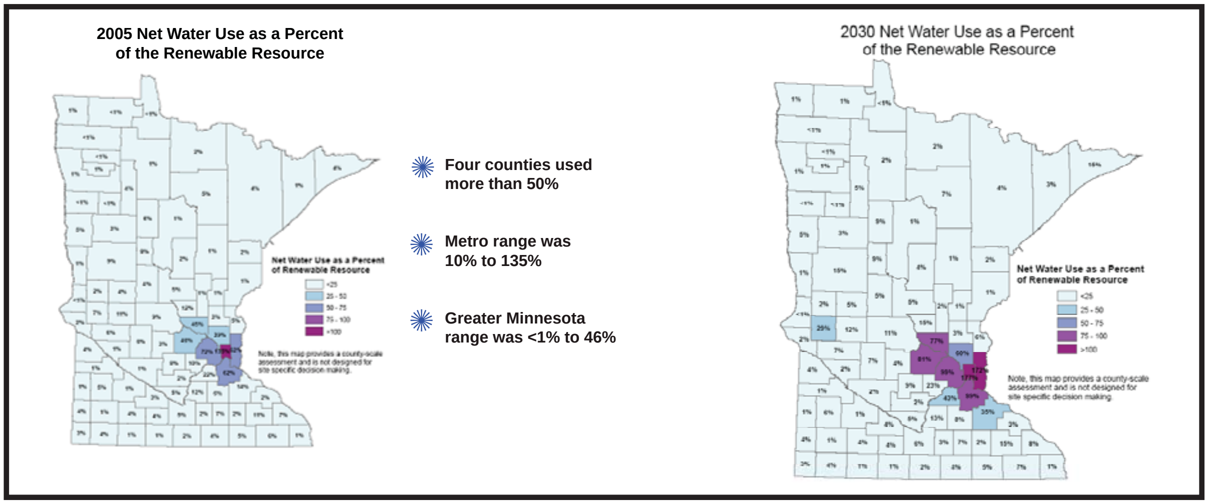

Figure 12: The assessment shown in these images worked with published methods describing recharge to the water table system (and, with one method, discharge from ground water systems). It used these as surrogates for sustainable supply values, developing five sets of renewable resource estimates. The analysis used the median volume of renewable water resources estimated for each county in making comparisons with demand for that county. The comparisons were made for reported and permitted use in 2005, and estimated use in 2030. In addition, the analysis adjusted appropriations from surface waters coming into a county, since resource estimates did not include such waters. It also removed non-consumptive water uses from the tally. The 2005 water use values were calculated by averaging each county's per capita demand for the years 1995 to 2005 in order to provide a baseline not artificially affected by a single year's climate. These same use rates were applied in estimating demand in 2030. Credit: Environmental Quality Board.

Quality Board-Department of Natural Resources assessment evaluated current and future water demand, as well as renewable water resources available at the county scale. While the analysis did not take into account those waters flowing into a county, the results signal that water allocation has already become a serious issue in some locations. The results indicate that water consumption in 2005 may exceed renewable supply levels in one county and take more than half of such supplies in three other counties, all in the metropolitan region. By 2030, the same four metro counties are expected to be at or above renewable resource levels and another three in the northwest quadrant of the growth corridor well above the 50 percent consumption level (see Figure 12). While the issue has obvious regional distinctions, most localities throughout the state encounter water supply and use conflicts. This is evidenced by the Department of Natural Resources suspension of surface water appropriations in 2006 to protect at risk aquatic communities and by the increasing concern with water use by ethanol production facilities.

The life history of many aquatic organisms is dependent on the variability of water across the landscape and through time. *Minnesota Statutes*, Section 103G.265 recognizes this in its call for the state to ensure an adequate supply to meet "long-range seasonal requirements" for various human and ecosystem uses. Yet to do this, water managers need to understand the timing, frequency and magnitude of supplies, the varying demands placed on them and potential use conflicts. For example, surface water appropriations can be expected to increase during the hottest and driest seasons and years when supply is the lowest and aquatic organisms are under greatest stress.

At present, the state has limited ability to:

- Quantify water consumption.
- Define the location and characteristics of ground water resources.
- Measure aquifer recharge rates and understand the impact of the redistribution of water.
- Understand what volume of water is renewable; that is, how much can be taken for use on a long-term, sustainable basis, seasonally and annually, without mining groundwater or harming ecosystems.
- Understand the impacts of drainage or other land use practices on rates of recharge, and

means to quantify these impacts.
- Understand the impacts of global warming on climate, rates of recharge and water demand.
- Characterize the interactions of surface and groundwaters, including both water quality and quantity implications.
- Quantify the seasonal and inter-annual variability of stream flow and quality of water needed to support basic ecosystem functions.

Future work should:

- Focus on geographic areas with supply and demand conflicts and evaluate resource management options, including how best to integrate use of surface and groundwaters.
- Evaluate how public water suppliers are integrating sustainability into the second generation of water emergency and conservation plans.
- Analyze water demand and availability on a seasonal or monthly basis; conduct analyses on watershed and sub-county, as well as county levels; and evaluate the current effects and future risk of water quality degradation on water supplies.
- Investigate new means to quantify sustainable supply or ways to build upon existing supply methods.
- Investigate the seasonally variable protected flow requirements needed to preserve aquatic communities
- Assess the results of historic mass water level measurements in the Twin City metro area and those planned for 2008.
- Evaluate Minnesota's "safe yield" concept for protection of ground water resources.
- Develop the comprehensive water management framework needed to manage water on a long-term, sustainable basis as required by law, including the routine water resource monitoring and assessment activities required to support the framework.

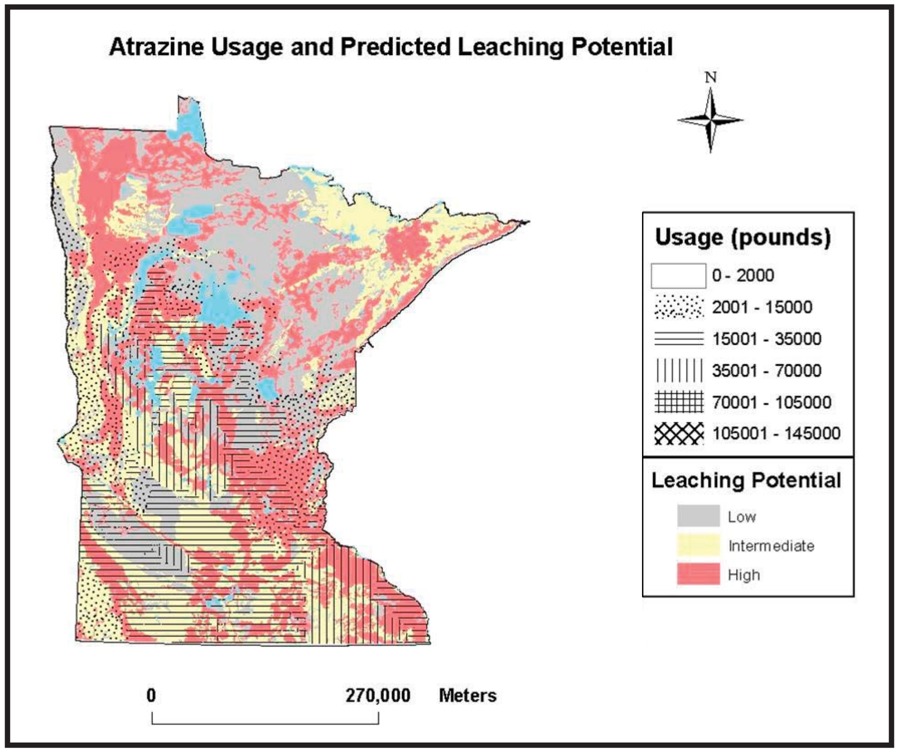

Figure 13: Atrazine usage and predicted leaching potential. Credit: David Mulla, University of Minnesota.

Contaminant Loading (pesticides)

Pesticide contamination results from the loading to surface or groundwater of chemical herbicides, insecticides, and fungicides. In a limited set of groundwater well samples taken in 2004 and 2005, 6 out of 19 wells and 14 out of 46 samples exhibited the presence of alachlor. Five out of 19 wells and 11 out of 46 samples exhibited the presence of metolachlor. In no cases, however, did concentrations of these pesticides in groundwater exceed federal or state health guidelines for drinking water.

Pesticide contamination leads to the degradation of surface and ground water, in some cases limiting the ability to use water. It can also result in negative impacts on aquatic ecosystems, wildlife, humans and pets. Degradation of water quality to a point that it can no longer be allocated to its designated use effectively limits the quantity of water available.

The primary driver of pesticide contamination is targeted land use, driven by the industries that use pesticides (such as industrial agriculture), turf management, road side vegetation maintenance, and private or residential consumption. Pesticide contamination may affect and be affected by other drivers including land use change, increased agricultural production, hydrologic modification and climate change, all of which may lead to increased pesticide use or more direct transport of the contaminant to the local water body.

The impact of pesticide loading to water bodies in Minnesota is broad, but largely limited to the zones of agricultural production from northwestern Minnesota to southeastern Minnesota. Minnesota's geology and hydrology, which vary across the state, determine the vulnerability of water resources to pesticide loading. For example, Figure 13 shows likely areas of potential concern for atrazine loading, overlaying use of the chemical with leaching potential to illustrate how sensitivity varies across the state.

Existing data gaps limit the state's ability to:

- Quantify pesticide loading to surface and ground water.
- Better define the location and characteristics of water quality degradation due to pesticides.
- Characterize seasonal fluctuations in pesticide loading rates.
- Describe short-term and long-term impacts to aquatic ecosystems, wildlife and humans.
- Understand the impacts of global warming on storm patterns and their resulting impact on loading rates.
- Characterize the interactions of surface and ground waters, including both water quality and quantity implications as they relate to pesticide loading.

Future work should:

- Develop a long-term water quality and quantity monitoring plan that brings together all state agencies involved in monitoring quality and quantity, so that there is consistency and overlap in spatial and temporal sampling.
- Support and expand upon the work of the Environmental Quality Board to evaluate long-term water quality trends in Minnesota.
- Evaluate whether additional sampling at specific locations would advance the work of other agencies with minimal extra effort or expenditure.
- Research the chronic and acute impacts of pesticides on aquatic ecosystems when coupled with the stressors of other pollutant loading (much research focuses on the impacts of single contaminants versus the impacts of multiple exposure).
- Increase the temporal resolution of pesticide

Water: Shared Resource Implications

International Obligations

Minnesota shares its northern border with Canada, and has three major watersheds that span that boundary. Lake Superior, the largest of the Great Lakes and the largest lake by area in the world, is shared by Minnesota, Wisconsin, Michigan, and Ontario. It contains 10% of the world's surface freshwater, supports a multibillion dollar recreational and commercial fishery, and is home to the largest commercial shipping port in the Great Lakes (Duluth-Superior). The Rainy River is the defining international boundary for much of Minnesota and Manitoba. The Boundary Waters National Canoe Area and the Quetico Provincial Park in Manitoba are two parts of the same vast stretch of connected lakes that knows no political boundary. The Red River flows north along the Minnesota-Dakotas border up to Lake Winnipeg and beyond, and ultimately empties into Hudson Bay. These are all immensely valuable bodies of water, providing economic, cultural, and spiritual benefits of priceless magnitude. We not only have an obligation to care for these waters for future Minnesotans, we have an obligation to protect and conserve these waters for the nation, the continent, and the world.

water sampling.

- Increase the number of sampling locations.
- Continue investigations of alternative means of pest and weed control.
- Continue research into more varieties of resistant crops needing lesser quantities of pesticide application.

Figure 14: Deer Lake, Itasca County. Credit: Jean Coleman, CR Planning

Nutrient Loading

Nitrate(N) loading is the most widespread and common type of ground water contamination in Minnesota. Excess nitrate in groundwater used as drinking water is a health hazard for infants and young children. Concentrations greater than the drinking water standard can cause methemoglobanemia, or "blue baby" syndrome.

Groundwater nitrate loading is affected by several factors:

- Geology - karst, shallow aquifers in southwest MN
- Soils - alluvial soils very prone to contamination
- Well head and well casing construction - dug wells in southwest MN are very prone to contamination
- Land management, including the nutrient input rate.

Less permeable soils and geologic materials cause the nitrate to linger in the biologically active soil zone where they may be taken up by plants or denitrified by microorganisms.

Nitrate pollution in the environment is derived primarily from agricultural practices, wastewater treatment systems including septic systems, urbanization, and from energy production in the form of compounds released into the atmosphere from the combustion of fossil fuels.

Nitrogen undergoes many transformations and is transported within the environment by many processes. Quantifying the spatial and temporal variability of processes such as uptake, removal, drainage, leaching, mineralization, nitrification, denitrification, volatilization, and ammonification is challenging. Developing watershed scale nitrogen budgets under alternative management scenarios is needed to help identify the best approaches for reducing nitrate losses to surface and groundwaters, and for balancing these reductions with the simultaneous need to reduce greenhouse gas emissions.

More effective best management practices are needed to reduce nitrogen inputs resulting from fertilizer applications. The effectiveness of riparian buffer strips, one of the primary Best Management Practices available for reducing sediment and nutrients to streams and rivers is not well quantified, especially in areas with extensive tile drainage.

"Here's a goal: Protect 75% of currently undeveloped shoreline and restore 50% of existing shoreline to provide better buffer."

—Campaign for Conservation survey participant