

Sustainable Management of Water Quality in Southeastern Minnesota, USA: History, Citizen Attitudes, and Future Implications

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Abstract The water resources of southeastern Minnesota, USA, have been exploited by humans for the past two centuries. The region's sedimentary (karst) geology holds vast underground aquifers with high-quality drinking water. Springs and seeps percolate from these aquifers in valleys to produce hundreds of kilometers of coldwater trout streams. Citizens in the region place high values on these surface and groundwater resources, protecting them from potential harm by becoming informed about threats and organizing in protest over resource contamination and perceived overuse. Agriculture, ethanol production, silica sand mining and processing, and urban development have all threatened the area's water resources and prompted citizen action. Recent regional studies have examined

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long-term trends in water quality, surveyed citizen attitudes and values, and made recommendations for monitoring and protecting both surface and groundwaters in southeastern Minnesota. A culture of water stewardship will continue to grow in this region, serving as a good model to follow wherever sustainable water management practices are being developed.

Keywords Sustainable water management • Karst geology • Driftless area • Citizen engagement

1 Introduction

The multi-use water resources of the Driftless Area of the United States' Upper Midwest (Fig. 1), and specifically those in southeastern Minnesota, have been under siege since the first European settlers arrived in the early 1800s (Thorn et al. 1997), and the region's citizens have been actively engaged in protecting these waters. This riverine landscape, missed by the most recent continental glaciers, is underlain by karst geology. Surface waters can quickly enter both shallow and deep, underground aquifers via cracks, fissures, and sinkholes in the intervening layers of limestone, sandstone, and shale (Schwartz and Thiel 1963).

The groundwater aquifers of the region currently provide water for >400,000 people and the industrial and agricultural activities that support the area's economy (Fig. 2). Shallow aquifers were impacted by contaminants from surface activities decades ago, forcing reliance on deeper, more protected aquifers (Lindgren 2001; Lee 2008). These deeper aquifers eventually emerge via springs from wooded valleys to form hundreds of kilometers of coldwater trout streams, which have been restored and rehabilitated (Thorn et al. 1997) with tax-generated public funding (via amendment to the state constitution) to support multi-million dollar trout fisheries and their associated tourism (Gartner et al. 2002; Hart 2008).

Intensive agriculture and livestock grazing through the early 1900s produced heavy soil erosion, filling waterways, and extirpating native fishes, but farmers successfully adapted numerous soil conservation practices to keep the soil in place (Thorn et al. 1997; Trimble 2013). Later, chemicals and fertilizers associated with industrialized agriculture drained into aquifers, contaminating drinking waters with herbicides, pesticides, and nitrates (Fig. 2). Applications have become more efficient and better timed to reduce the likelihood of these chemicals migrating into groundwater (Randall 2003).

Urban development and growth have increased the demand for drinking water, while negatively affecting shallow groundwater supplies (via poor septic systems) and surface waters (Lee 2008; Fillmore County SWCD 2010; Fig. 2). Mandated water-conserving fixtures and appliances, rain gardens, sanitary sewer extensions, and drought-resistant landscaping have counteracted many of these problems.

Ethanol production from corn and mining activities for silica sand (needed by the oil and gas industry for hydraulic fracturing) are expanding and threatening

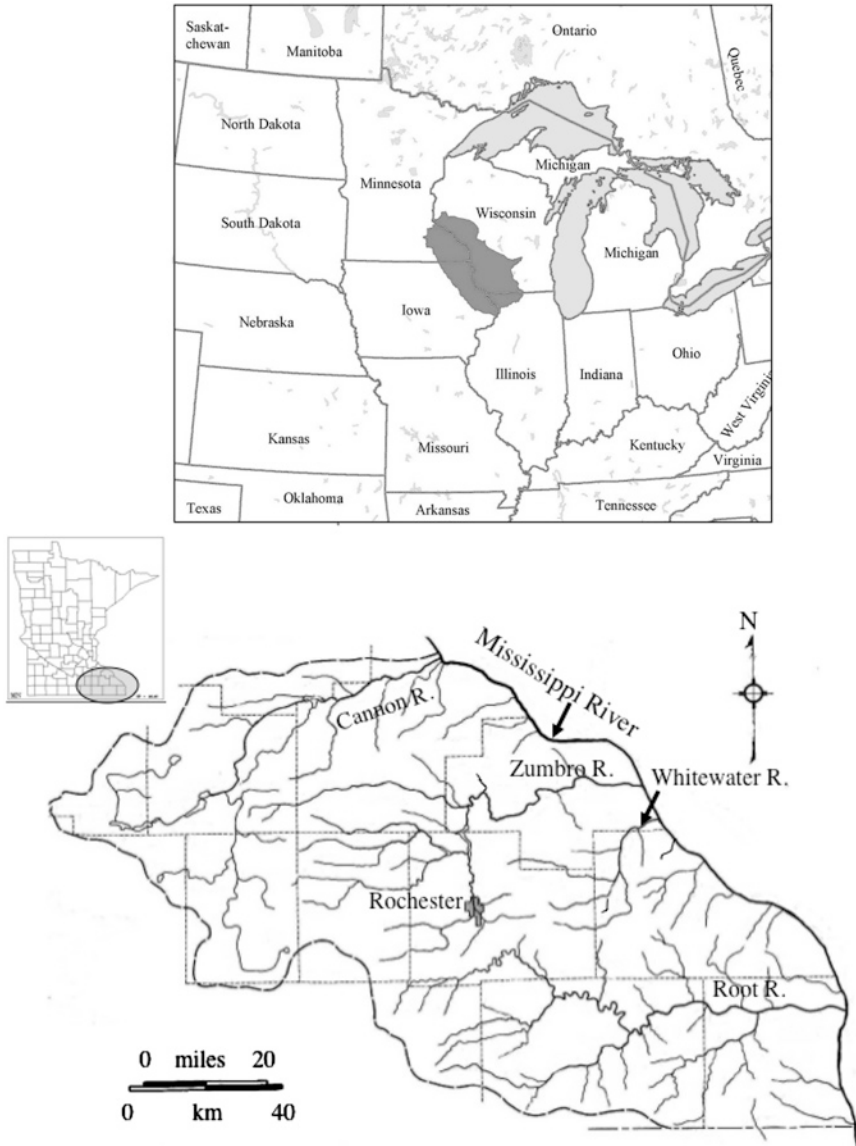


Fig. 1 Maps depicting the Driftless area (*dark shaded area*) covering portions of Minnesota, Wisconsin, Iowa, and Illinois, USA (*top map*) and the rivers and streams in southeastern Minnesota that are tributary to the Mississippi River (*lower map*). *Dashed lines* represent county borders, major rivers are labeled, and the city of Rochester is highlighted. Most of the region's designated coldwater trout streams lie within the watersheds of the Whitewater River and the Root River

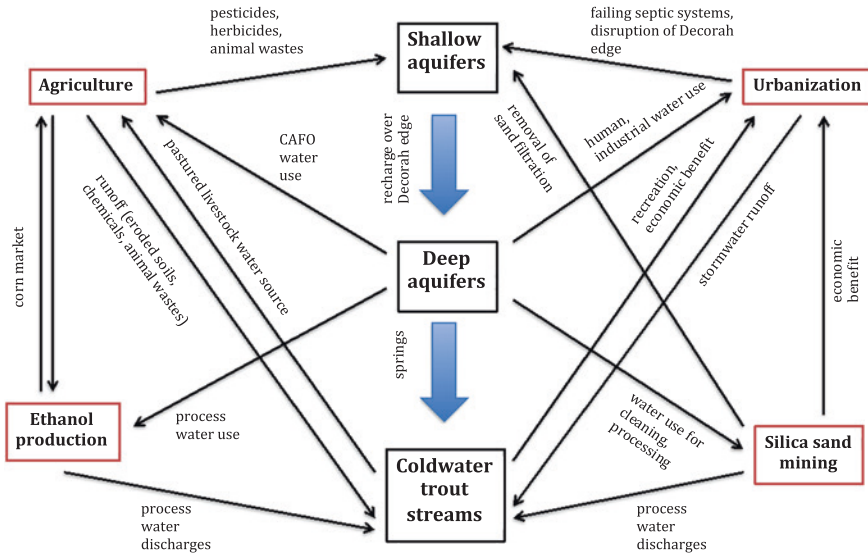


Fig. 2 Schematic depicting the interaction of groundwater and surface water in southeastern Minnesota and the influences of human activities on these water resources

water supplies (Schnoor et al. 2007; Richards 2012; Fig. 2). Consequently, citizens have entered the political arena calling for increased oversight and regulation of these industries to protect aquifers.

The region’s citizens have formed many watershed groups to protect their surface and groundwater resources, participating in watershed summits, learning from demonstration projects, and collaborating with state and federal agencies to monitor the physical, chemical, and biological quality of their water supplies. Threats to water resources will continue to emerge within this region, but an actively engaged citizenry is prepared and ready to meet these new challenges.

2 The Southeastern Minnesota Region

The southeastern portion of the State of Minnesota, USA (44°N, 92°W) encompasses an area of 14,777 km² bounded on the east by the upper Mississippi River. It is part of a larger region (southeastern Minnesota, southwestern Wisconsin, northeastern Iowa, and northwestern Illinois) called the Driftless Area (Fig. 1) that was missed by the last continental glacier (Wisconsin glaciation) 15,000 years ago, but carved by its meltwaters (Fremling 2004). For 400 km within the Driftless Area, the Mississippi River flows through a gorge up to 200 m deep, carved downward through the ancient Paleozoic Plateau of sedimentary rock (limestone, sandstone, shale). Tributary streams further dissect the plateau, creating a complex of ridges, valleys, and precipitous bluffs.

The Minnesota portion of the Driftless Area spans portions of nine counties (Rice, Steele, Goodhue, Wabasha, Dodge, Olmsted, Winona, Fillmore, and Houston) encompassing four major watersheds: Cannon River, Zumbro River, Whitewater River, and Root River (Fig. 1). These systems all flow directly to the Mississippi River, carrying the runoff from urban areas, agricultural lands, and forests. Streams and rivers in this region often exhibit flashy hydrographs, rising rapidly in response to periodic heavy rainfall events and spring snowmelt to flood cities, villages, and farmlands within their valleys (Waters 1977).

Southeastern Minnesota is underlain by several hundred meters of sedimentary rocks formed under ancient seas during the Paleozoic Era 440–570 million years ago (Schwartz and Thiel 1963). Among these layers are various limestones and dolomites (Maquoketa, Dubuque, Galena, Platteville, Prairie Du Chien, St. Lawrence) with cracks and fissures that allow for rapid, vertical water movements, porous sandstones (St. Peter, Jordan, Mt. Simon) that serve as vast underground aquifers, and impervious shales (Decorah, Glenwood, Eau Claire) that restrict water movement. The region is categorized as a karst landscape, characterized by sinkholes, caves, subterranean rivers, springs, and disappearing streams (Fremling 2004). Groundwater flowing from the hundreds of springs and cave mouths gives rise to the coldwater trout streams that typify this region (Fig. 2).

The climate of southeastern Minnesota is the warmest and wettest of the entire state. Annual average temperature is 9.4 °C, with annual precipitation averaging 86.9 cm. The majority (75 %) of precipitation falls as rain from April to September. This climate results in an annual growing season of 155 days, with 890 growing degree-days (above baseline of 12.8 °C).

Agriculture is the dominant land use in southeastern Minnesota. Numbers of farms are declining, yet farms are becoming larger, with increasing field size, more soybean acreage, and decreasing acreages of small grains, forage crops, and pasture (Randall 2003). Potential impacts of these trends to water quality may include increased runoff, reduced base flows, thermal pulses, and increased nutrient, chemical, and fine sediment inputs (MN DNR 2003).

In 2010, the total human population for the nine-county region of southeastern Minnesota was 413,852. With over 106,000 people, Rochester is the area's largest city (and the third largest city in Minnesota; Fig. 1), increasing 38 % in 20 years. Four other cities (Faribault, Northfield, Owatonna, Winona) have populations between 20,000 and 30,000 people. Populations in three of the nine counties are expected to increase by >30 % by 2040 (Robertson 2012).

3 Trout Streams

Southeastern Minnesota currently has 181 designated trout streams, encompassing >1,265 km of stream length (Fig. 1). These streams support naturally reproducing populations of native brook trout and introduced brown trout, as well as put-and-take fisheries for introduced rainbow trout. The cold, clear water needed to support these trout is the result of the region's karst geology and abundant aquifers.

Trout management officially began in southeastern Minnesota in 1874 because promiscuous and largely unregulated fishing had reduced brook trout populations to low levels, requiring restricted harvest to sustain recreational fishing (Thorn et al. 1997). Brook trout were first stocked in 1878, and within the following 10 years, brown trout and rainbow trout both had been widely stocked. Despite these efforts, trout abundance plummeted in response to degrading habitat, warming waters, and greatly diminished spring flows (Thorn et al. 1997). These poor conditions and poor fisheries persisted through 1930.

A slow, gradual recovery of trout streams and their fisheries began in southeastern Minnesota in the 1930s and 1940s. After soil conservation practices were implemented to reduce erosion and flooding, stream habitat at first stabilized and then began to improve (Trimble 2013). The Minnesota Department of Conservation began to actively rehabilitate in-stream habitats in the late 1940s, completing 151 such projects involving >200 km of stream over 50 years (MN DNR 2003). Although widespread trout stocking was still necessary during the 1970s to maintain most fisheries, the need for stocking diminished during the 1980s and continues to decline as natural reproduction expands (Thorn et al. 1997). Currently, most trout populations in the region are continuing a >30-year trend of expanding abundances, with management efforts focusing on rehabilitating habitat and increasing stream access by acquiring public easements on private lands (MN DNR 2003).

Trout stream management in southeastern Minnesota is supported by three funding sources. State fishing license and trout and salmon stamp sales are a direct source of funding from within the state. The Federal Aid in Sport Fish Restoration Program provides federal money collected by taxing fishing equipment and motorboat fuel. Finally, a state constitutional amendment that dedicates a small portion of state sales taxes to within-state conservation and arts projects (Clean Water, Land, and Legacy Amendment) has provided millions of US dollars to protect drinking water sources and to protect, enhance, and restore wetlands, lakes, rivers, streams, and groundwater. The amendment required statewide voter approval in 2008, with 33 % of funds generated going specifically to the Clean Water Fund. Approximately, \$7 million US from this fund has been used specifically to rehabilitate trout stream habitats in southeastern Minnesota.

These trout streams and the fishing opportunities they provide are major contributors to the economy of southeastern Minnesota. Trout anglers were estimated to use >520,000 angler-days fishing in these streams during a single year (Vlaming and Fulton 2002), spending at least \$48 million US within the region to support their fishing activities (Gartner et al. 2002). Trout angler surveys suggest that region residents spend >\$200 US/fishing trip and >\$4,800 US/year, whereas non-region residents spend nearly \$400 US/trip and >\$3,700 US/year in their trout fishing pursuits (Hart 2008).

When examined in a broader context, trout fishing has an even greater economic impact on the region. For the entire Driftless Area of Minnesota, Wisconsin, Iowa, and Illinois, spending by trout anglers was estimated at \$1.1 billion US/year (Hart 2008). In addition, state natural resources agencies have spent approximately \$45 million US for stream restoration (725 km of stream improved, \$62,000 US/km

improvement cost) during the past 25 years to provide the fisheries that attract these trout anglers. Every \$1 US spent on stream restoration returns \$24.50 US to the regional economy and that return on investment occurs every year for the lifetime of the restoration projects (Hart 2008). Consequently, trout fishing is a significant economic driver within the Driftless Area, and protecting and enhancing these cold-water resources benefits all area residents.

4 Challenges to Maintaining Water Resources in Southeastern Minnesota

Surface waters and groundwater in southeastern Minnesota are abundant and accessible, but past human activities in the region have impaired water quality (Lee 2008; Minnesota Department of Agriculture 2012). In addition, a growing human population and greater water demands from expanding agricultural and industrial ventures threaten to consume water in volumes that may be unsustainable (Randall 2003; O'Dell 2007). The following sections summarize four ongoing challenges to sustainable water use in southeastern Minnesota (agriculture, ethanol production, silica sand mining and processing, and urban development) and describe how the region's citizens are addressing each challenge.

4.1 Agriculture

Southeastern Minnesota was the first region of the state settled by European immigrants during the mid-1800s. These early settlers removed the native vegetation (mixed hardwood forests, savannahs, and tallgrass prairies) for agriculture, lumber, and fuel (Waters 1977), creating small, subsistence-level, diversified farms dependent on oxen, horses, and humans for power (Granger and Kelly 2005). Croplands were located mostly on uplands and valley bottoms, with forested steep side slopes and livestock pastures in rolling terrain. By 1870, 80 % of Minnesota's population lived on the small farms in the southeast, and a shift to wheat monoculture had exhausted soils and forced a return to diversified farming (mixed livestock, poultry, corn, small grains, and hay). However, expanding farms and intensive livestock grazing on marginal lands through the 1920s led to severe soil erosion. Trout streams, already warmed after removal of riparian trees, became filled with mud and contaminated with livestock wastes, eliminating native brook trout and sculpin from many streams (Waters 1977).

Beginning in the 1930s and continuing to today, conservation practices such as contour farming, strip cropping, reduced tillage, improved forest management, rotational grazing, and terracing have greatly reduced soil erosion and agricultural runoff (Thorn et al. 1997). Streams have recovered and now support self-sustaining populations of brook and brown trout (Waters 1977). Despite these improvements, changing agricultural practices continue to affect the water resources of this region.

For the past half-century, agriculture in southeastern Minnesota has shifted steadily from small, diversified farms to large, row-crop (corn, soybeans) cash farming operations. Concurrently, concentrated animal feeding operations (CAFOs) expanded dramatically, especially for dairy cattle, beef cattle, and hogs. Watersheds in the region today vary from 40–70 % agriculture and 20–40 % forest, with dairy (59 %) and beef (24 %) cattle dominating livestock production and hogs and poultry (17 % combined) less common (Randall 2003). These changes in agriculture have had significant impacts on both surface and groundwaters within the karst region of southeastern Minnesota. Nutrients, pesticides, and herbicides have infiltrated streams and aquifers throughout the region, posing health hazards and economic hardships to citizens of both rural and urban areas (Fig. 2).

Nitrate concentrations have increased dramatically in groundwater aquifers in southeastern Minnesota during the past several decades (O'Dell 2007). This region is highly susceptible to groundwater contamination due to its geology (Minnesota Department of Agriculture 2012). These nitrates have been linked to inorganic fertilizers applied to corn, leakage from waste storage lagoons associated with CAFOs, and failure of residential septic systems. Since the 1980s, nitrates have been detected in nearly 100 % of well water samples tested within southeastern Minnesota, with typically 30–35 % of these samples having concentrations exceeding the Environmental Protection Agency's health risk limit for drinking water of 10 mg/L (Minnesota Department of Agriculture 2012). The widespread nature of nitrate contamination of well water has prompted health departments to issue consumption advisories, especially for infants.

The geology of the Driftless Area also makes its groundwater susceptible to contamination from fecal coliform bacteria and diseases associated with animal wastes. Manure storage and application and leaking septic systems all are potential sources of this contamination (Fig. 2). The risk of groundwater contamination is amplified by applications of manure from CAFOs to farm fields, especially those in sensitive areas near wells and sinkholes. Minnesota state laws are in place to regulate manure storage and application, although additional voluntary restrictions are required to adequately protect most aquifers from becoming contaminated (Minnesota Pollution Control Agency 2005). In addition, unexpected situations have occurred, such as sudden drainage of manure lagoons into previously unknown sinkholes, highlighting the sensitive and unpredictable nature of the region.

CAFOs within southeastern Minnesota place high demands on groundwater resources. For example, each dairy cow can consume 140–200 L/day of water (Thomas 2011). In Winona County alone there are 29,000 dairy cattle (US Department of Agriculture, 2012 Minnesota Agriculture Statistics), consuming >5 million liters per day of water, mostly from underground aquifers (Fig. 2). Additional large volumes of water are needed daily to support the necessary animal and barn cleaning operations of an operating dairy operation. A large (>1,000 animals) dairy CAFO can easily use as much water as a small community.

Surface waters in southeastern Minnesota continue to be challenged by polluted runoff (e.g., eroded soils, fertilizers and other chemicals, and animal wastes), despite long-term attempts to manage it via numerous conservation practices

(Fig. 2). State and federal agencies, working in conjunction with landowners and concerned citizens, have designed and installed water control structures, grassed waterways, buffer strips, and a myriad of other structures and practices intended to slow runoff and increase water infiltration. While individually effective, they collectively have produced only fair results. Recent modeling in a single watershed indicates that efforts to date have been effective in eliminating only 61 % of polluted runoff (Emmons and Olivier Resources, Inc., unpublished soil and water assessment tool (SWAT) model for Whitewater River watershed). Consequently, drainage from southeastern Minnesota and other farmlands throughout the United States' Upper Midwest often are implicated as the cause of the Gulf of Mexico's dead zone, the largest hypoxic zone in the United States. High-nutrient runoff from this region of intensive agriculture may be responsible for up to 70 % of the nutrient loading that reaches the Gulf of Mexico via the Mississippi River (NOAA 2009).

During the past 10–15 years, state agencies and local watershed groups have worked together to study problems in various drainages within southeastern Minnesota, with a goal of more accurately defining the problem and devising solutions that are realistic and achievable over the short term. Ultimately, this study and planning will culminate in surface waters that meet the water quality standards as set forth in the United States Clean Water Act, as enforced by the US Environmental Protection Agency. To date, both watershed-specific and region-wide total maximum daily load (TMDL) plans have been developed and approved for such pollutants as turbidity (and/or total suspended solids), fecal coliform bacteria, nutrients (nitrates, phosphates), and others. The Minnesota Pollution Control Agency is the lead agency in charge of developing such plans for surface waters in Minnesota.

In June 2013, Minnesota and US government officials announced that four Minnesota watersheds dominated by intensive agriculture had been chosen to participate in a new program, the Minnesota Agriculture Water Quality Certification Program. Using \$9.5 million US from federal and state sources, the 3-year program will seek out farmers in each watershed willing to voluntarily adopt and implement precise, site-specific methods to protect surface and groundwaters from agricultural pollutants. Funds will help pay farmers to implement strategies to help mitigate their pollutant-causing activities, with participating farmers then being exempt for 10 years from new water quality regulations. The Whitewater River watershed (Fig. 1), extending across portions of three counties in southeastern Minnesota, was one of the watersheds selected for this pilot program.

4.2 Ethanol Production

There are 21 ethanol production facilities located in Minnesota, mostly using a dry mill process to produce 4.2 billion liters of ethanol/year from corn. Most of this production is used as an additive to gasoline to meet a state mandate that all gasoline sold in the state must contain at least 10 % ethanol. Minnesota was the first state in the USA to require ethanol in gasoline and will raise the minimum

requirement for ethanol in gasoline to 20 % beginning in 2015. Minnesota also has the most E85 (85 % ethanol content) gasoline stations in the country, providing fuel for vehicles designed to burn this high ethanol-content fuel.

Through 2011, farmers in the United States received \$6 billion US/year in federal subsidies to grow corn for ethanol production. Ethanol producers also received \$0.12 US/L in tax credits to encourage ethanol production. Subsidies and tax credits both ended beginning in 2012, but ethanol production has continued to increase, largely because market demand for ethanol remains high to meet the government mandates for blended fuels.

Southeastern Minnesota has two ethanol production plants, located in Claremont and Preston. To maximize cost effectiveness, plants are sited to obtain corn from within an 80 km radius, to be near inexpensive railroad transportation and to gain access to an abundant water source. Typically, three liters of water are needed to produce each liter of ethanol. Some of this water is used once and discharged, although most water can be (but is not always) reused within the plant. A typical ethanol plant in Minnesota that can produce 150–350 million liters of ethanol/year could use up to 1.25 million liters of water/day (Fig. 2), the equivalent volume used by a city of 5,000 people (Schnoor et al. 2007).

During 2008 to 2011, a regional corporation planning to build a new ethanol production plant near the city of Eyota became embroiled in a controversy with area citizens regarding the plant's projected water use. The plant was designed to process >53,000 bushels of corn/day to produce >200 million liters of ethanol/year, while requiring >4 million liters of water/day. Citizens felt that this water demand would place the municipal water supply at risk in the long term, and discharges of warmed process waters would threaten local trout streams (Fig. 2). After state agencies determined that the plant's water needs would not harm local water resources (groundwater and surface), area citizens organized (Olmsted County Concerned Citizens) and filed a lawsuit against the state agencies. Years of legal proceedings ultimately determined that local water resources would not be harmed by the plant's water use, but plant investors were unable to raise sufficient capital to proceed with construction and the project was suspended.

4.3 Silica Sand Mining and Processing

Operations for the mining and processing of silica sands are expanding in southeastern Minnesota. Although used in many applications (e.g., water filtration, glass manufacture, industrial casting, sand blasting, and producing concrete), the current boom in the silica sand market is being driven by its use as a proppant in hydraulic fracturing for oil and gas production. Although no hydraulic fracturing occurs in Wisconsin or Minnesota, these states have the largest deposits of silica sand in the United States. Wisconsin has 60 mines and 30 processing facilities (WI DNR 2012), whereas Minnesota has only eight operating mines and a similar number of processing sites (Richards 2012).

Eight of the nine counties in southeastern Minnesota have significant deposits of silica sands near the surface, but only three mines are operational (Richards 2012). In 2012 and 2013, five of these counties imposed silica sand mining moratoria (temporary bans on the development of new mines and processing facilities) after concerns arose regarding environmental issues associated with mining and processing activities. In particular, area citizens were concerned about the potential for mining and processing activities to cause groundwater depletion, water and air pollution, increased truck traffic resulting in rapid deterioration of roads, and ultimately damage to the region's scenic beauty.

Silica sand mines and processing facilities may use hundreds of thousands to millions of liters of water/day, mostly from groundwater. Mines may use water to control dust, whereas processing facilities use water to wet sort the sand into different sizes classes for various applications. This high rate of water use concerns nearby citizens, who worry about dewatering of their own water wells, or even aquifer depletion in areas with slow groundwater recharge (Fig. 2).

Area residents also are concerned about potential water pollution problems from flocculating agents added to the water used in silica sand processing. Wash water additives such as polyacrylamides help in removing unwanted minerals and fines from the sand. Wash water containing acrylamides may infiltrate into the groundwaters when washed sands are placed in surge piles to dry (WI DNR 2012). Acrylamides will biodegrade in aerated soils, but soils beneath surge piles will be waterlogged, not aerated. The US Environmental Protection Agency has a Maximum Contaminant Level Goal of zero for acrylamides in public drinking waters, since long-term consumption of acrylamide-contaminated water can lead to blood and nervous system disorders and increased chance of developing cancer (WI DNR 2012).

After a contentious debate on silica sand mining in southeastern Minnesota, the Minnesota state legislature passed laws in 2013 regulating mining and processing activities and establishing a state-level commission to help local units of government with permitting and regulatory oversight. At the request of Trout Unlimited (a private organization with a mission to keep the United States' coldwater fisheries and their watersheds safe from environmental threats), state legislators considered setback regulations for mining to protect trout streams. Consequently, proposed silica mines within 1.6 km of designated trout streams now require additional permitting and complete hydrogeological evaluations to identify potential threats to those streams (Minnesota Statutes, section 103G.217). The state governor has stated that, if recommended by the state legislature, he would support a total ban on silica mining in southeastern Minnesota to protect sensitive water resources in this region.

4.4 Urban Development

Rochester is the largest and fastest growing city in southeastern Minnesota. The city and outlying towns that surround it comprise a metropolitan area with a population of >200,000 people. A rapidly growing city of this size has had several

significant impacts on the region's water resources, ranging from increasing demands on groundwater, to constraining and controlling streams and rivers within its jurisdictional boundaries, to managing storm water runoff from hundreds of kilometers of city streets and other impervious areas (Fig. 2).

Rochester obtains its drinking water from wells tapping into deep groundwater aquifers known as the St. Peter and Prairie du Chien aquifers, or collectively as the Lower Carbonate aquifer. These aquifers contain sufficient water resources to support the continuing growth of the city (and several other communities within the region) well into the current century and beyond. The city currently uses >20 billion liters of water/year from these aquifers. The deep aquifers contain high-quality water supplies because they are protected from potentially polluting surface activities by overlying impervious layers of shale. The clay-rich Decorah shale formation is the most important of these protective layers (Schwartz and Thiel 1963), with a maximum thickness of approximately 12 m.

Because Rochester is located within a river valley surrounded by rolling hills, the Decorah shale formation often is exposed on hillsides throughout the city. Areas where the edges of the Decorah shale are exposed have been found to be important recharge zones for the deep aquifers that provide Rochester and 15 other communities (across six counties) with their drinking water (Lindgren 2001; Fillmore County SWCD 2010). Rainfall percolates down through soil and porous sedimentary rock formations of the Galena or Upper Carbonate aquifer until it reaches the Decorah shale, which prevents it from further downward movement. However, at the Decorah edge, these waters can spill out over the Decorah shale through a thin soil covering before sinking into deeper, porous sedimentary rock layers that connect to the Lower Carbonate aquifer used by Rochester. Estimates credit the Decorah edge as the site of 50–60 % of the recharge waters entering the Lower Carbonate aquifer (Lee 2008; Fig. 2).

Although the shallow-lying Upper Carbonate or Galena aquifer often contain high levels of nitrate (15–20 mg/L, higher than the current drinking water standard of 10 mg/L; Rochester abandoned use of this aquifer for drinking water in 1950 because of this contamination), nitrate concentrations of waters flowing over the Decorah edge can decrease by >90 % (Lee 2008). This denitrification is produced by a diverse community of wetland plants that exists in the saturated soils at the Decorah edge, a community with some of the highest diversity of any wetland type in the state of Minnesota. Nitrate removal by these wetland communities within Rochester alone has been valued at \$5 million US/year, based on current treatment costs for removing nitrate from drinking water supplies (Lee 2008). These wetlands also remove nitrate pollutants discharging from springs and seeps to form the headwaters of the Cannon, Zumbro, Whitewater, and Root rivers, a filtering and denitrification significant enough to impact water quality in the nearby Mississippi River (Fillmore County SWCD 2010).

Prior to understanding the importance of the Decorah edge in protecting, sustaining, and purifying the drinking waters of Rochester and its neighboring communities, residential and commercial development were allowed to proceed along the Decorah edge as long as they met existing zoning and wetland ordinances. Many

of these developments encountered on-site water management issues, with the many seeps and springs causing a multitude of drainage issues. Construction equipment became mired literally in muddy soils that refused to dry out, the basements of homes had continual water infiltration problems, and Rochester absorbed costs of nearly \$1,000 US/household/year when basement drainage from homes built on the Decorah edge was directed into the city's sanitary sewer system (Lee 2008).

Following the lead of neighboring counties and municipalities, Rochester and Olmsted County amended their zoning and wetlands ordinances to protect the Decorah edge (Lee 2008). Restrictions were placed on development on sites with specific hydric soil types, sites near springs, seeps, streams, or waterways, sites with high water tables, and sites adjoining steep slopes. These and similar restrictions are now in place throughout the region wherever the Decorah edge is present, stretching from Rice County southeasterly for >320 km into northeastern Iowa (Fillmore County SWCD 2010).

Rochester developed in a river valley, occupying the floodplain and hillsides adjacent to the South Fork of the Zumbro River. Several tributaries of the Zumbro also join the river within the city, including Salem, Cascade, Silver, Bear, and Willow creeks. Dams were constructed on the river and creeks early in the city's history, providing power, water, and recreation. Today, the city lies along 14 km of the Zumbro River and >160 km of its tributary creeks.

Because of its location and the extreme flashy nature of the region's streams and rivers in response to sudden, heavy rain events and snowmelt (Waters 1977), Rochester has been prone to flooding since it was established in 1854. The city has a history of severe flooding, causing both loss of life and severe economic hardship. The city has fought back against this flooding by constructing (and reconstructing) various flood-control dams, levees, ditches, and storm sewers to control and redirect floodwaters around and through the city. These activities escalated after especially severe flooding in 1978. However, the vast amount of impervious surface area within the city (buildings, streets, sidewalks, parking lots) prevents infiltration of rainfall (79 cm/year average) and snowmelt (112 cm/year average), forcing it into waterways and increasing the potential for flooding.

Rochester has an annual budget of \$3.1 million US for storm water management. This budget covers maintenance of 145 storm water retention ponds (and coordination on 216 retention ponds owned by other entities), 675 km of storm sewers, 15,700 storm sewer catch basins, 528 km of open roadside ditches, and 1,755 outfalls to receiving waters (Rochester Public Works Department 2013). The municipal storm water permit issued to Rochester by the state mandates the city to minimize impacts of storm water on receiving waters.

Rochester has several zoning ordinances in effect to retain storm waters on the land for later infiltration, to manage storm water flows, and to prevent flows from carrying pollutants to streams and rivers. Construction permits mandate that new commercial and residential developments retain significant proportions of their storm waters on-site in retention basins and/or rain gardens, reducing flows to surface waters during rain events and allowing time for waters to infiltrate into soils that can filter and eliminate potential pollutants (Rochester Public Works 2013).

In 2009, Rochester launched a cost-share grant program, Realize Raingardens Rochester, to promote the installation of rain gardens within the city on residential property or parcels owned by nonprofit organizations. The program provides up to 50 % of costs to design and install rain gardens to help demonstrate to the public how rain gardens can retain and treat storm water while beautifying neighborhoods and creating wildlife habitat (Realize Raingardens Rochester 2013). A private nature center partnered with the city to develop and conduct educational, how-to, rain garden classes and grant-writing workshops to help citizens with their rain garden project applications. To date, this program has been successful in establishing many highly visible rain gardens within the city, encouraging many other residents and groups to establish their own rain gardens on their own properties.

5 Trends in Surface Water Quality

Water resources within the southeastern Minnesota region, and specifically the Mississippi River-Winona watershed (which includes the Whitewater River watershed and several nearby, smaller watersheds that drain directly to the Mississippi River), have been the focus of hundreds of different projects and programs during the last century (Crawford et al. 2012). Both groundwaters and surface waters have been studied, but the greatest volume of information and the majority of investigations have been directed toward streams and rivers. Projects and programs have gathered data on nutrients, metals, nonmetals, physical variables, radiochemicals, pesticides, bacteria, invertebrates, and fish (Crawford et al. 2012).

The Mississippi River-Winona watershed covers 170,000 ha of mostly agricultural (row crops and livestock grazing) and forested lands, with some urban development. Farmers own 88 % of watershed lands, but non-farmers comprise 97 % of the area's electorate. Surface waters in the watershed are on the State of Minnesota impaired waters list for bacteria (*Escherichia coli*), nitrates, turbidity, and mercury, and some aquifers contain elevated levels of bacteria and nitrates.

A grant from Minnesota's Clean Water Fund was used to compile all existing water quality data gathered within the watershed, analyze these data for trends and other significant features, identify limitations and/or data gaps, and provide recommendations for future water quality monitoring. Historic water quality data for the watershed's surface waters were compiled from 225 different programs and analyzed. Nearly 296,000 data points from 20,000 sampling events at 136 unique monitoring sites were used to examine trends during the past 40 (for water quality data) to 80 (for water discharge data) years. Only 12 unique sites on seven stream reaches (one on Garvin Brook, six in the Whitewater River drainage) had adequate data and periods of record for long-term trend analysis (Crawford et al. 2012).

Long-term trend analysis was conducted on 10 variables across the seven stream reaches within the Mississippi River-Winona watershed: annual discharge,

suspended sediment, total suspended solids (TSS), total phosphorus, ammonia, biological oxygen demand (BOD), nitrate, chloride, sodium, and sulfate. All 10 variables were not monitored at all stream reaches for durations sufficient for long-term trend analyses, but 90 % of variables were examined at two to six stream reaches each.

Within the watershed, stream discharge has remained steady or increased during the period of record. This has coincided with an increase in yearly precipitation within the region since the 1950s, although yearly precipitation was only weakly correlated with discharge at any of the stream sites (Crawford et al. 2012). Because many streams within the watershed are influenced more by groundwater discharge than by surface runoff (Schwartz and Thiel 1963), long-term increases in stream discharge may be the result of changing aquifer dynamics.

Levels of TSS, total phosphorus, ammonia, BOD, sulfate, and atrazine have declined in streams within the watershed where data are sufficient to analyze long-term trends. Several of these variables are correlated with one another (TSS, total phosphorus, ammonia, BOD), suggesting related sources. High levels of these variables were associated with past time periods characterized by severe soil erosion and runoff from livestock pastures (Trimble 2013). Improved soil conservation practices apparently have been successful in reducing concentrations of these pollutants in surface waters, even in the face of increasing precipitation. Sulfate concentrations have declined since peaking in the mid-1980s, illustrating the impact of acid rain control measures in the Clean Air Act (Crawford et al. 2012). Recent downward trends in concentrations of the herbicide atrazine and its breakdown products, even as atrazine use increases, may indicate that better application procedures have been developed and put into practice within the watershed.

In contrast to declines in some pollutants, nitrate and chloride levels have more than tripled in the watershed's rivers and streams since 1970 and sodium levels have risen significantly. Nitrate concentrations have increased from 1 mg/L prior to 1970 to >6 mg/L in 2010, with highest levels occurring during summer base flow periods (Crawford et al. 2012). Based on 2009 data, base flow nitrate levels are significantly correlated ($r^2 = 0.68$) with percent row crop agriculture upstream from sampling locations. Because base flows of these coldwater streams depend largely on spring discharges from aquifers (Waters 1977), high stream nitrate values highlight the increasing problem of contamination of aquifers by agricultural fertilizers, especially in shallow aquifers in the upper reaches of the watershed (Crawford et al. 2012).

Chloride and sodium concentrations in streams and rivers in the Mississippi River-Winona watershed have been increasing since the 1970s due to expanding use of water softener salt (NaCl), road deicing salt (NaCl), and potassium chloride (KCl) fertilizer (Crawford et al. 2012). The karst geology of the region allows salts to infiltrate aquifers from residential septic fields, roadside ditches, and agricultural lands. Average chloride concentrations appear to be stabilizing at 15–20 mg/L (Crawford et al. 2012).

Long-term water quality trends within the Mississippi River-Winona watershed indicate that several water pollutants are declining, whereas others continue to worsen. Land conservation measures within the watershed appear to have controlled significant amounts of soil erosion, reducing delivery of eroded soils and associated water pollutants via surface runoff. However, the underlying karst geology continues to allow many pollutants rapid entry into shallow aquifers that discharge directly into streams and rivers. More consistent water quality monitoring of streams and rivers is needed within the watershed to track future trends in water pollutants as additional efforts are made to further reduce surface runoff and to better manage infiltration of fertilizers and salts into shallow aquifers.

6 Citizens' Attitudes and Opinions

The citizens of southeastern Minnesota have become increasingly more concerned with the quality and availability of their water resources during the past several decades. They have taken advantage of opportunities to learn more about these resources and threats to them and have become active and engaged in protecting them. A variety of watershed-based studies, projects, and initiatives have heightened the public's awareness of water resources and potential threats, and citizens are requesting greater involvement in decision-making related to surface and groundwaters. The Minnesota Pollution Control Agency encourages citizens to become more active in water quality decision-making and maintains a Web site to help with civic engagement for watershed projects (<http://www.pca.state.mn.us/index.php/water/water-types-and-programs/minnesotas-impaired-waters-and-tmdls/project-resources/civic-engagement-in-watershed-projects.html>).

Watershed projects in southeastern Minnesota have become commonplace during the last 25 years, combining citizen energy, attitudes, and values with agency expertise to address water resources issues. Many citizens volunteer their time to collect basic water quality information on their neighborhood stream or river, helping to build databases that allow agency personnel to target problem areas for maximum benefit (<http://www.pca.state.mn.us/index.php/water/water-types-and-programs/surface-water/streams-and-rivers/citizen-stream-monitoring-program/index.html>). Minnesota has 400 volunteers monitoring >500 stream and river sites across the state's 10 major river basins.

In recent years, citizen water forums or summits have been convened to allow for direct communication between southeastern Minnesota citizens and the agency personnel charged with protecting the region's water resources. These water summits provide a face-to-face approach for informing the public about agency studies and conclusions, while providing citizens with an opportunity to speak directly with agency staff about their concerns and problems related to water issues.

As a specific example, the Mississippi River-Winona Watershed held two watershed citizen summits, spaced eight months apart, during 2012 and 2013. Attendees listened to presentations about long-term water quality trends within the watershed and the results of water opinion surveys given to watershed landowners. They also participated in a series of round table discussions involving farmers, urban residents, educators, students, local politicians, and agency staff. This diverse group of stakeholders with varying perspectives on water quality issues shared dinner together and discussed their concerns and ideas about how best to achieve their common goal of clean water. Ultimately, these and future water summits will serve to develop a vision and strategy for protecting and/or restoring the water resources within the watershed.

A second approach to engage area citizens in water issues and decision-making has involved the use of surveys given to various groups of residents in southeastern Minnesota. While lacking the face-to-face nature of the citizen summit described above, surveys, if developed and administered appropriately, can produce statistically valid data that can be used to direct and focus actions on water resource protection and management. Two surveys administered to Mississippi River-Winona Watershed residents in 2011 and 2013 will be used to illustrate this approach.

During either 2011 or 2013, 3,374 residents (from a potential pool of 18,722 households) of the Mississippi River-Winona Watershed in southeastern Minnesota were sent a six-page questionnaire via US mail to evaluate the water quality knowledge, attitudes, needs, and expectations of a diverse group of watershed residents (Wheeler 2013). Only residents in a small, select sub-watershed received surveys in 2011, whereas residents in the remainder of the watershed received them in 2013. Valid responses were received from 1,042 residents, a response rate of 30.8 %. The high rate of response and the small sample population produced a maximum response confidence interval (95 %) of ± 4.3 %. For analysis, respondents were categorized as city residents, non-farm rural residents, small-farm (4–50 ha) residents, or large-farm (>50 ha) residents.

The surveys revealed six key findings about water and the residents of the watershed (Wheeler 2013):

1. An overwhelming majority (>78 %) of residents from all categories of residence want clean drinking water, streams as clean as their natural condition, and fish from local streams that are safe to eat.
2. A high proportion of private well users are uninformed about the source of their water, the safety of their well, or a source of information about well water quality.
3. Relatively high proportions of residents consider themselves somewhat or very uninformed about specific water issues within the watershed.
4. Rural residents consider the county extension services and the soil and water conservation districts as their significant information sources on water issues, preferring information in the form of printed fact sheets.

5. Residents favored local government actions, neighbor interaction, grassroots actions, and education as ways to protect water quality.
6. Despite widespread consensus on water quality issues, there were several significant differences in opinion and attitude between large-farm residents and all other respondent groups. For example, large-farm residents were much more likely to rate current stream water quality as good to excellent, whereas city residents most often rated stream water quality as fair or poor. In addition, the majority of large-farm residents listed urban runoff as the chief cause of water quality problems, whereas city dwellers listed agriculture (cropland, livestock) as the largest water quality problem.

It is apparent that both citizen summits and surveys are useful methods for obtaining information on the concerns and attitudes of watershed residents regarding water quality. Surveys can provide a wealth of useful information that can be helpful when establishing goals and objectives for protecting or restoring water quality within a watershed, while at the same time highlighting disparities that may exist among various citizen groups. Bringing these various citizen groups together in citizen summits and allowing them to present and discuss their perceptions and ideas in an informal, nonthreatening environment can be beneficial and enlightening to all citizen groups. Combining the use of both tools is the logical way for natural resource agencies to communicate with the public and to develop the citizen buy-in often required for water quality issues to be addressed successfully.

7 Conclusion

Citizens of southeastern Minnesota have been prompted to action whenever threats to their region's water resources have occurred. They value clean drinking water and high-quality streams for fishing, and they are willing to educate themselves about new activities that may threaten the quality and future availability of these resources. They are not out to squelch all projects and activities that threaten their water. Rather, they are willing to seek out solutions that allow farming, development, and other activities to continue while still protecting the valuable water resources needed by all residents.

Efforts in this watershed and this region continue toward improving and strengthening a culture of water stewardship. Citizens will continue to protect their water resources against potential threats, by staying informed on the quality of the resources and staying connected and engaged with governmental agencies charged with protecting regional waters. This engagement and partnering between the public and agencies is one of the key components leading to public buy-in and ultimately to success of projects. Successful approaches in water management within our region can be used as models when developing sustainable water management practices elsewhere.

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