Cost of Nitrate Contamination of Public Water Supplies

A Report of Interviews with Water Suppliers

July 2007

By the University of Minnesota Department of Soil Water and Climate, in cooperation with the Minnesota Department of Health and the Minnesota Rural Water Association. Special thanks go to the city water managers and other city officials who provided information for this study.

Funding for this project was provided by The Environment and Natural Resources Trust Fund as recommended by the Legislative Commission on Minnesota Resources (LCMR) (MN Laws 2005 First Special Session, Chapter 1, Article 2, Section 11, Subd. 07i).

Table of Contents

Summary

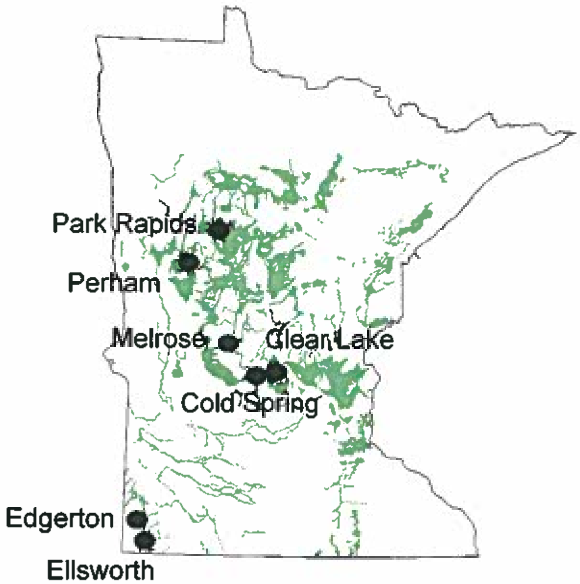
Responding to groundwater nitrate contamination is costly and can be a significant burden on the budgets of small towns. For this study, managers from seven Minnesota cities were interviewed to learn how much they spent in response to nitrate contamination. The purpose was to help other towns anticipate potential expenses and justify wellhead protection activities that prevent contamination.

Municipal nitrate removal systems increase the cost of water delivery by fourfold or more. This translates into $100 to $200 more per customer per year. Even before a treatment system is installed, cities pay for elevated groundwater nitrate concentrations through increased costs of siting a new well, more frequent nitrate testing, and time spent blending water from multiple wells.

Cities with rising nitrate concentrations may be able to avoid spending the $400,000 – or much more – needed to install a treatment system by working now to protect their aquifer from nitrate contamination. Their challenge is to motivate numerous stakeholders to take actions that will have an uncertain result and may not pay off for years. Because well capture areas (wellhead protection areas) are generally outside of city limits, cities have few tools to influence land use and to permanently protect the well capture area. Existing conservation programs were generally designed to protect surface water and are poorly suited to protecting groundwater.

Treatment systems are only temporary solutions to drinking water quality. Wellhead protection can prevent the need for a treatment system or reduce the cost of treatment if a system is in use. In addition, wellhead protection prevents other types of contamination and protects an irreplaceable and essential natural resource.

Figure 1: Sandy glacial outwash regions of Minnesota and study cities



Map shows areas with the attribute "Outwash – Undivided as to Moraine Association" from Hobbs and Goebel (1982).

Table 1: A sample of community water suppliers with elevated nitrate concentrations

	Population served	Million gallons supplied annually	1000 gallons /person/year	Nitrate management	Size of DWSMA [a]
Adrian	1200	50	42	Anion exchange system	3 sq mi.
Clear Lake	414 (2006)	15.6 (2005)	32	Anion exchange system, well blending	½ sq mi
Cold Spring	3,693 (2005)	202	55	High nitrate wells go nearly unused	7 sq mi
Edgerton	1030 (2006)	45 (2005)	44	Anion exchange system	1 sq mi
Ellsworth	540	17	30	Anion exchange system	5 sq. mi.
Lincoln-Pipestone Rural Water -- Holland Well Field	1062 (2004)			Reverse osmosis system	37 sq. mi.
Melrose	3091 (2003)	697 (2005) (85% goes to agr. industries)	225	Well blending	2.9 sq mi
Park Rapids	3275	215	65	Well blending	4 sq. mi.
Perham	2726 (2006)	326 (2005) (50% goes to industries)	120	Well blending	18 sq mi

Costs of Responding to Contaminated Groundwater

Once a drinking water source is contaminated with excessive nitrate, a community water supplier must either treat the water or find another source. The following is a list of potential expenses and examples of costs incurred by Minnesota communities.

Short term management

If nitrate-N in the drinking water supply rises above 10 ppm, the water supplier must notify all residents and provide an alternative water supply, such as bottled water.

$360	**Clear Lake, notifications**
$250	**Edgerton, postings and media announcements**
$4,000	**Melrose, notifications and education**

Other potential costs include remediation of a contaminated site, litigation or legal opinions, consulting and engineering fees, increased insurance costs, and decreased property values. None of the cities in this study reported any of these costs.

New well

When an aquifer is contaminated with nitrate, siting a new well becomes more expensive because multiple test wells must be dug to locate a clean aquifer.

Deep aquifers are often a preferred water supply because they are less susceptible to nitrate contamination. However, water from deep aquifers is more likely to require treatment to remove higher concentrations of iron, manganese, sulfate or naturally occurring contaminants such as arsenic or radium. Removal systems for naturally occurring ions or contaminants may initially cost about the same as nitrate removal systems, but their life expectancy is generally longer and operating and maintenance costs are lower.

Examples of expenses associated with a new well:

- Test wells to identify a site without excess nitrate.
  - **$5,500** **Park Rapids, two test wells (2005)**
  - **$16,000 to $19,000 each** **Clear Lake, three test wells (2003 and 2004)**
  - **$3,000** **Edgerton, test wells (2001)**
- Land purchase
- Drilling, pump installation, well housing
  - **$162,000** **Park Rapids, to drill a pair of wells (2005 estimate)**
  - **$246,300** **Clear Lake (2004)**
- Treatment systems to remove iron, sulfur, or radon
  - **$2,010,000** **Park Rapids, Fe and Mn removal plant, including building (2005 estimate)**
  - **$5,000,000 to $6,000,000** **Melrose, Fe and Mn removal plant, not associated with drilling a new well (2006 estimate)**
- Sealing an old well
  - **$3,000** **Melrose**

Background

Nitrate Contamination in Minnesota

One of Minnesota's most valuable resources are the aquifers that supply drinking water to over 70% of the state's residents. Nearly all of the state's 954 community water supply systems use groundwater[1], and many have elevated nitrate concentrations in their drinking water source. Between 1999 and 2004, nitrate-N concentrations were elevated (>3 mg/L or ppm) in 64 communities serving 226,000 people and 24 non-municipal suppliers (e.g. mobile home parks)[2]. Unless groundwater protection is undertaken, these communities may face rising nitrate concentrations in the future. In the same time period, nitrate-N concentrations exceeded health standards (>10 mg/L) in 12 communities and 4 non-community suppliers delivering water to 47,000 customers.

Nitrate (NO_3^-) moves readily through the soil and is odorless and tasteless in water. The primary health concern of elevated nitrate in drinking water is "Blue Baby Syndrome" (methemoglobinemia) caused when nitrate-contaminated water is consumed by infants under 6 months of age. In the infants stomach, nitrate is converted to nitrite which binds to hemoglobin, preventing the blood from carrying oxygen. (In rare cases, adults have been poisoned by nitrate, but not by the amounts in drinking water.) In addition, some research has suggested that long-term consumption of nitrate is associated with certain cancers, but evidence is unclear (Fewtrell, 2004; Rademacher, 1992). Nitrate is relatively easy to measure and can serve as an indicator that other components of agricultural or human waste is leaching through the soil and into groundwater.

Nitrate Sources

In Minnesota, natural background concentrations of nitrate-N in groundwater are very low (<1mg/L or ppm). Higher concentrations generally occur when nitrate from commercial fertilizer, manure, or human waste (sewage or septage) leach from the surface through the soil and into groundwater. Contamination is more likely in areas of deep sandy glacial outwash deposits, sometimes found over loamy glacial till or lake sediments, such as those in central Minnesota, or in the river channel aquifers in southwestern Minnesota. Wells in these vulnerable areas often draw drinking water from surficial aquifers, i.e., aquifers above bedrock with no clay or rock confining layer protecting them from contaminants in surface recharge water.

Estimating Costs of Nitrate Contamination

Costs of contamination include the costs of using the contaminated water (e.g., effects on health, crops, or industrial activities), and the costs of responding to the contamination, including restoring the aquifer quality (generally not feasible), containing a plume of contamination, or avoiding the contaminated water through treatment or an alternative water source (Raucher, 1983). These costs can be estimated by calculating either the "avoidance cost", that is, costs incurred to monitor, treat, or find an alternative water source; or the

---

[1] Surface water is the drinking water source for 18% of the state's population, including Minneapolis and St. Paul.

[2] Data from the Minnesota Department of Health.

"contingent value" based on asking people what they are willing to pay for an uncontaminated aquifer. Contingent value studies of the value of groundwater protection are discussed in Phillips et al. (1999) and Poe et al. (2000), but the results are not readily translated into an estimate of costs in Minnesota. The avoidance cost method does not incorporate all ecological damages or nonuse values of water quality, so it can be considered a low-end estimate of people's willingness to pay or of the total costs of contamination (Abdalla, 1994). Intrinsic or non-use benefits of groundwater include retaining the option to have a clean aquifer at some time in the future. The value of non-use benefits is not trivial, given the irreversible nature of groundwater contamination (Raucher, 1983).

Estimating health costs is controversial because the nitrate standard is not based on a cost-benefit calculus, but by choosing a level substantially below clinically observable human health impacts. Thus, small or occasional exceedances of the standard will likely have little observable impact on health costs (Giraldez and Fox, 1995; Addiscott and Benjamin, 2004).

The Freshwater Foundation (1989) studied the costs of groundwater contamination to Minnesota companies and cities. The study was limited to industrial waste or hazardous materials, but the categories of potential costs identified are also relevant to nitrate contamination. They include:

- New equipment, treatment, and direct cleanup
- Increased monitoring
- Increased energy usage
- Increased operation and maintenance costs
- Staff time
- Consulting and legal fees
- Increased water rates
- Devalued real estate
- Diminished home or commercial real estate sales
- Relocation of commercial development and lost jobs
- Loss to tax base

No one has attempted to summarize these costs in relation to groundwater nitrate contamination in Minnesota.

Study Methods

The purpose of the study was to help communities anticipate the costs they may face as groundwater nitrate concentrations rise, and thus to quantify the value of groundwater protection. The study only considered direct economic costs and did not consider health or environmental effects of nitrate contamination.

In the summer of 2006, water supply managers in seven Minnesota communities (Fig. 1) were interviewed about the costs associated with monitoring, treating, or avoiding groundwater contaminated with nitrate. The communities were selected from among those in central Minnesota with elevated nitrate concentrations. Only five communities in central Minnesota were identified as currently incurring costs associated with nitrate contamination, so two additional communities were interviewed where geologically sensitive aquifers are used in southwestern Minnesota. Additional data was used from a previous study of nitrate treatment systems (MDA and MDH) and from other interviews (Diego Bonta, personal communication). Characteristics of the communities are summarized in Table 1. To help other communities assess the potential costs of their unique situation, costs are presented as examples rather than averages.

Reverse osmosis (RO) treatment system

In an RO system, water is forced through a semi-permeable membrane leaving behind a large proportion of high-nitrate waste water. Costs of running an RO system increase if mineral concentrations are high. Only one municipal RO system is operating in Minnesota.

Expenses for Lincoln-Pipestone Rural Water (LPRW) include:

- Initial construction. RO systems are expected to last about 20 years.
  $1,706,650 (1999)
- Operating and maintenance costs including electrical power for the pumps and replacement membranes
  $31,000 (maintenance including membranes)
  $36,000 (energy)
- Waste water disposal
  LPRW disposes of 1 gallon of waste water for every 5 gallons used.

Anion exchange treatment system

Anion exchange (AE) systems remove nitrate by replacing the negative nitrate ion (NO_3^-) with the negative chloride ion (Cl^-) from salt. Water softeners do not remove nitrate because they replace positive ions (e.g. Fe^{+++}) with the positive sodium (Na^+) ion from salt. Costs of AE systems are shown in **Error! Reference source not found.**. The initial construction costs depend partly on the amount of water to be treated, whereas operating and maintenance costs depend on the amount of nitrate removed which determines the amount of salt required. Costs can be reduced by increasing the nitrate concentration in the final treated water, or by lowering the nitrate concentration in untreated water through wellhead protection activities. For example, the City of Edgerton estimates that salt usage could double if nitrate-N concentrations in their untreated water rose from the current value of 7-9 ppm up to 10-12 ppm, which was the

Table 2: Examples of annual costs for anion exchange treatment systems

	Clear Lake	Edgerton	Ellsworth	Adrian
Population served	414 (2006)	1,030 (2006)	540	1,200
Million gallons supplied	15.6 (2005)	45 (2005)	17	50
Initial construction[a]	$412,390 (1995)	$352,000 (2003)	$362,000 (1994)	$601,000 (1998)
NaCl purchases	$9,200 to $1,600 (2004 to 2006)[b]	$6,150 (2006)	$3,000 (2006)	$12,000
Energy	$4,867, $7,924, $2,576 (2004, 2005, 2006)	$2,600 (2005)	$4,200 (2006)	$4800 to $9600
Regular nitrate testing	$900	$450	$500	
Additional labor	$16,000 (2005). Manager estimates 60% to 65% of his time is spent on the treatment system.		$13,000	
Other operation and maintenance costs	$5,400 (for general upkeep)			$600 (maintenance parts)
Total extra costs of treatment (w/o labor)	$1.82 to $2.25 per 1000 gal.	$0.82 per 1000 gal.	$1.68 per 1000 gal.	$1.52 per 1000 gal.

[a] Anion exchange systems are expected to last 20 to 25 years.
[b] Salt usage has gone down since a new well came on line in 2005.

nitrate-N concentration before land in the well recharge area was enrolled in agricultural set-aside programs. Salt usage in Clear Lake dropped after a new low-nitrate well came on line in 2005.

Distillation treatment system

Water is boiled and steam is condensed to yield water with very few dissolved substances. No Minnesota municipalities use distillation systems.

Well blending

Some Minnesota cities blend water from low and high nitrate wells to produce safe drinking water. At its simplest, blending is a matter of using low nitrate wells first and running the high nitrate wells last and only as needed. This involves minimal costs except putting additional wear on the pumps in the wells being used most often. In some cities, blending has costs associated with managing pumps and testing water to ensure the final water is safe. Blending is only an option if a city has wells with different nitrate concentrations that are pumped into a common area where the water can mix before going into the distribution system.

Annual costs of well blending include:

- Time associated with monitoring nitrate concentrations and switching pumps.
  $3,000 Melrose
- Frequent lab tests to monitor nitrate concentrations
  $1,000 Melrose
  $900 Clear Lake

Wellhead Protection

Wellhead protection is the process of managing potential sources of contamination within the capture area (wellhead protection area) for the well in an effort to reduce the risk of contamination at concentrations that present a human health concern. Wellhead protection plans consider nitrate, industrial contaminants, and other potential contaminants. More information is available at the Minnesota Department of Health web site (see Resources). Wellhead protection is the only cost-effective and long-term solution to aquifer contamination.

Wellhead protection plans (WHPPs)

Wellhead protection plans are required for 930 community water systems and about 700 noncommunity (schools, factories, etc.) public water systems in Minnesota. About 130 of these systems have approved WHPPs and another 180 are preparing them. WHPPs describe the aquifer, capture zones (recharge zones for a well), current and future threats to groundwater quality, and detailed activities that will be undertaken to reduce or prevent contamination. They must be updated after ten years.

Costs of wellhead protection

Labor. The development of a wellhead protection plan is a joint effort between the city (or its contractor) and staff from the Minnesota Department of Health and the Minnesota Rural Water Association. After development of the WHPP, maintenance and implementation of the plan generally requires 5% to 10% of the time of a community water manager.

Some cities have hired people dedicated to WHP implementation. For example, the cities of Rockville, Richmond, and Cold Spring, and several Cold Spring private businesses have joined together to hire a non-staff member to implement their wellhead protection plans. In southwest Minnesota a proposal is underway to hire a person to work within five counties to implement wellhead protection activities.

Implementation includes maintaining good communication with county officials and other local government units to ensure that decisions about zoning, licensing, and rules consider the effect on the wellhead protection area. Time is also spent on promoting best management practices by land owners and encouraging key owners to take advantage of cost share programs to take land out of agricultural production. Other time is spent implementing educational efforts.

Land purchases. Considering the cost of a water treatment plant and other approaches to wellhead protection, the city of Perham decided the most effective use of resources would be to purchase irrigated agricultural land within their wellhead protection zone. They began by buying land adjacent to the city, reselling some of it for residential development. They plan to gradually buy other land within the 10-year recharge zone and put it into conservation easements.

Cost share. Cities often encourage land owners to participate in federal and state programs that pay per acre support to remove land from agricultural production. Some cities have provided additional financial incentives to land owners. Statewide in 2006, 20,283 of the acres in CRP, CREP2, and RIM were in wellhead protection areas. If land is enrolled in CRP for the purpose of wellhead protection, it must be within 2000 feet of the well. This has restricted the use of CRP. CREP2, on the other hand, does not have a radius limit.

Cities have also funded incentive programs to encourage upgrading of septic systems and sealing of unused wells.

Technical assistance is important to help landowners implement best management practices related to nutrient management, irrigation, manure management, turf management, and private well and septic system maintenance. This assistance is usually one-on-one work provided by partners including Soil and Water Conservation Districts, Watershed Districts, Minnesota Extension Service, Natural Resources Conservation Service, County Environmental Services Departments, Minnesota Department of Agriculture, and crop consultants.

Education. All wellhead protection plans include some education components to build awareness and knowledge. Activities include posting road signs to mark the boundaries of the wellhead protection area, exhibits at county fairs and similar events, pamphlets, public service announcements, and direct mailings to people within the wellhead protection area.

Monitoring. Some cities have installed monitoring wells or organized a network of private wells to be tested regularly to monitor nitrate concentrations in the aquifer. The MDH spends $1500 to $2000 per year for mandatory quarterly testing of water supplies over 5.0 mg/L nitrate-N.

Expenses associated with wellhead protection planning and implementation:

$15,000 to $40,000	Melrose, WHP delineation by MDH
$100,620	Cold Spring, WHP plan development funded by the MPCA Clean Water Partnership Grant
$18,000	Park Rapids, WHP plan development by the Hubbard County Water Plan
$250/well	Cold Spring, cost share to seal wells
$300	Cold Spring, education about well maintenance
$250	Cold Spring, education about septic systems
$1,000	Cold Spring, public education through various media, festivals and promotional items
$800/yr	Park Rapids, itemized annual costs
$1,250	Park Rapids, itemized one-time costs
$4,000/yr	Melrose, education
$2,500/yr	Melrose, consultant
$6,000/yr	Melrose, staff time

Barriers to wellhead protection

City water managers identified the following barriers to effective wellhead protection, as it relates to nitrate contamination.

- **Uncertainty**. Planners can predict the source of nitrate contamination and the path and timing of water movement from the surface to the aquifer, but they are rarely certain. Furthermore, in many places aquifer recharge occurs over decades. If it took years for nitrate concentrations to rise, it will likely take years for concentrations to decline in response to management changes. Expenditures can be difficult to justify when the benefit may not expected for years and the magnitude of the benefit is uncertain.
- **Competing priorities**. Effective wellhead protection depends on long-term commitment from all decision-makers within the public water supplier, including water managers, city administrators, and city council members. Additionally, local and state officials, landowners, and the general public must be committed. All these stakeholders have competing concerns ranging from short-term budgetary issues to other natural resource concerns such as surface water programs. Attention will be turned to where funding is available.
- **Lack of authority**. The wellhead protection area for a well is usually outside city boundaries. Often, public water suppliers have no authority to control land use beyond their jurisdictional boundaries. They depend on local zoning authority to manage proposed land-use changes and on state and county enforcement of rules governing septic systems, feedlots, and other nitrate sources. Most importantly, they often rely on voluntary cooperation from farmers and homeowners who apply fertilizer or manure.
- **Ineffective policies for administering conservation programs**. In some places, the best way to reduce nitrate contamination is to take a small amount of land in the wellhead protection area out of agricultural production. Federal cost share programs such as the Conservation Reserve Program (CRP) are designed primarily to protect soil and surface water and may not be as effective for wellhead protection. For example, the CRP provides per-acre incentives to take key land out of row crop production. Land within a 2,000-foot radius of a community well and within a wellhead protection area can be automatically enrolled in CRP. However, this reduces the number of possible acres because much of the land within 2,000 feet of the well may not actually be within its capture area. Using a fixed radius or other simple method to delineate a well water protection area can result in substantial over protection of land down gradient from the well and under protection of up-gradient land (Hodgson et al., 2006; Raymond et al. 2006). Another limitation of existing conservation programs is that incentive payments may not be adequate to allow farmers to take highly productive farmland out of production, especially as prices of corn and other commodities rise. Given the value of drinking water to human health, it may be appropriate to provide higher incentive payments to set aside land in wellhead protection areas that will protect aquifers from long term contamination.
- **Diverse and unequal stakeholders**. The costs and benefits of wellhead protection, and the power to influence land use and management are held unevenly by the city, township, county, state, residential water users, industrial water users, developers,

farmers, homeowners, and other land owners. A successful solution requires communication and cooperation among all the parties and acknowledgment of the unevenness of costs and benefits. Out of fairness and expedience, planners may try to spread costs among many stakeholders by choosing wellhead protection activities that apply to everyone, such as promoting nutrient best management practices. Getting all players to contribute to the solution is essential, but may be inadequate where it is necessary to take a few key acres, owned by one or two producers, completely out of agricultural production. Working with producers to implement such "unfair" solutions is made more difficult by the uncertainty of the results.

- **Inertia**. Water suppliers may be hesitant to begin WHP planning and implementation – a task with an unknown time commitment. However, with the support of the Minnesota Department of Health (MDH) and the Minnesota Rural Water Association (MRWA), most have found the process to be manageable and successful.
- **Technical support is not a barrier**. All cities interviewed agreed they received good technical support from the MDH and MRWA. Every wellhead protection plan depended on extensive staff time from MDH and MRWA. Conservation Districts and the Minnesota Department of Agriculture have provided technical assistance with nutrient management planning.

How much does water cost?

The cost to supply water to a community varies greatly (Table 3). Costs for municipalities with treatment systems are several times higher than those without. Timely and effective wellhead protection can reduce or completely prevent nitrate treatment costs, as well as reduce the threat of other types of contamination.

Table 3: Cost to supply water

City	Cost ($/1000 gal.)	Calculation
Anion exchange system		
Clear Lake	$7.23	Total water supply cost
Ellsworth	$4.55	Total water supply cost
No nitrate removal system		
Cold Spring	$1.40	User fee
Melrose	$1.15[a]	User fee
Park Rapids	$1.50	User fee, including sewer
Perham	$1 to $2	User fee

[a] Proposed iron treatment plant in Melrose would raise cost to $2.50 or $3.

Who pays?

The costs of groundwater nitrate contamination and wellhead protection are spread unevenly across many parties including the following.

- Public water suppliers and their fee-paying customers who pay for treatment systems, new wells, or other responses to groundwater contamination.
- Consumers who may suffer health effects.
- Land owners who implement measures to prevent nitrate leaching, such as taking land out of agricultural production or improving nutrient management. Their costs may be offset by cost share payments or reduced fertilizer expenses.
- Taxpayer-supported entities including Watershed Districts, Soil and Water Conservation Districts, the Minnesota Department of Agriculture, the University of Minnesota Extension Service, and others that provide technical assistance to land managers.
- The Minnesota Pollution Control Agency (MPCA) Clean Water Partnership Program which provides grants and loans to address surface and groundwater pollution problems.
- The Minnesota Rural Water Association (MRWA) which supports wellhead protection planning. Their work is supported by rural water suppliers and taxpayers.
- The Minnesota Department of Health (MDH) which supports wellhead protection planning and pays for quarterly monitoring of water suppliers who have elevated nitrate concentrations.
- Federal conservation programs including the Environmental Quality Incentives Program (EQIP), the Conservation Security Program (CSP), and the Conservation Reserve Program (CRP), along with state programs such as the Conservation Reserve Enhancement Program (CREP) and Reinvest in Minnesota (RIM).

Resources and References

Abdalla, C.W. 1994. Groundwater values from avoidance cost studies: Implications for policy and future research. American Journal of Agricultural Economics 76:1062-1067.

Addiscott, T.M. and N. Benjamin. 2004. Nitrate and human health. Soil Use and Management 20:98-104.

Fewtrell, L. 2004. Drinking-water nitrate, methemoglobinemia, and global burden of disease: A discussion. Environmental Health Perspectives 12(14):1371-1374.

Freshwater Foundation. 1989. Economic Implications of Groundwater Contamination to Companies and Cities. Wayzata MN: Freshwater Foundation.

Giraldez, C. and G. Fox. 1995. An economic analysis of groundwater contamination from agricultural nitrate emissions in southern Ontario. Canadian Journal of Agricultural Economics 43:387-402.

Hobbs, H.C. and J.E. Goebel. 1982. Geologic Map of Minnesota: Quaternary Geology. 1:500,000. Minnesota Geological Survey State Map Series Map S-1. Digital compilation by B.A. Lusardi, published by the Land Management Information Center. Metadata at: http://www.lmic.state.mn.us/chouse/metadata/quatgeo.html.

Hodgson, J.Y.S., J.R. Stoll, and R.C. Stoll. 2006. Evaluating the effectiveness of a fixed wellhead delineation: regional case study. Journal of the American Water Resources Association 42:409-423.

Minnesota Department of Agriculture (MDA) and the Minnesota Department of Health (MDH). 2004. Nitrate Contamination: What is the Cost? Drinking water protection series fact sheet. http://www.mda.state.mn.us/protecting/waterprotection/drinkingwater.htm

Minnesota Department of Health
Source Water Protection page
http://www.health.state.mn.us/divs/eh/water/swp/index.htm,

Minnesota Pollution Control Agency (MPCA)
Ground Water in Minnesota
http://www.pca.state.mn.us/water/groundwater/
Clean Water Partnership Program
http://www.pca.state.mn.us/water/cwp-319.html

Minnesota Rural Water Association source water protection page
http://www.mrwa.com/sourcewater.htm

Poe, G.L., K.J. Boyle, J.C. Bergstrom. 2000. A meta analysis of contingent values for groundwater quality in the United States [2144]. Selected Paper, American Agricultural Economics Association.

Rademacher J.J., T.B. Young, and M.S. Kanarek. 1992. Gastric cancer mortality and nitrate levels in Wisconsin drinking water. Archives of Environmental Health 47:292-294

Raucher, R.L. 1983. A conceptual framework for measuring the benefits of groundwater protection. Water Resources Research 19:320-326.

Raymond, H.A., M. Bondoc, J. McGinnis, K. Metropulos, P. Heider, A. Reed, and S. Saines. 2006. Using analytic element models to delineate drinking water source protection areas. Groundwater 44:16-23.

Rinaudo JD, C. Arnal, R. Blanchin, P. Elsass, A. Meilhac, and S. Loubier. 2005. Assessing the cost of groundwater pollution: the case of diffuse agricultural pollution in the Upper Rhine valley aquifer. Water Science and Technology 52:153-162.

Glossary

Capture area – the surface and subsurface area that provides water to a public water supply well.

Conservation Reserve Program (CRP) – a federally funded program in which farmers are paid to take land out of agricultural production for 10 to 15 years. Payments generally match local rental rates. Contact your local Soil and Water Conservation District for more information.

Conservation Reserve Enhancement Program (CREP2) – a state-funded program similar to CRP. Contact your local Soil and Water Conservation District for more information.

Drinking water supply management area (DWSMA) – the MDH-approved surface and subsurface area surrounding a public water supply well that completely contains the scientifically calculated wellhead protection area and is managed by the entity identified in a wellhead protection plan. The boundaries of a DWSMA generally follow property and political boundaries, whereas the boundaries of the WHP area follow the estimated capture area for the well(s).

MDA – Minnesota Department of Agriculture (www.mda.state.mn.us)

MDH – Minnesota Department of Health (www.health.state.mn.us)

MPCA – Minnesota Pollution Control Agency (www.pca.state.mn.us)

MRWA – Minnesota Rural Water Association (www.mrwa.com)

ppm – parts per million. With regard to nitrate-N concentrations, ppm is equal to milligrams per liter (mg/L)

Recharge area – the surface and subsurface area that provides water to an aquifer (although sometimes the term is used to refer to the area that supplies a well).

Reinvest in Minnesota (RIM) – a state-funded program that builds on CREP2 by adding a conservation easement that is either permanent or adds 30 years beyond the CREP2 contract.

Wellhead protection area (WHP area) – the designated area around a public water supply well(s) that is to be protected from contaminants that may adversely affect human health. It includes the surface and subsurface area through which contaminants are reasonably likely to move toward and reach the well(s). Regulation of WHP areas was established under the federal Safe Drinking Water Act, and is implemented through state governments.