Groundwater nitrate contamination costs: A survey of private well owners

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Abstract: Groundwater is an important source of drinking water in Minnesota and nationwide. In Minnesota, 5% to 10% of drinking water wells have nitrate (NO_3) concentrations that exceed health standards. Well owners incur direct costs associated with the presence of NO_3, including costs related to treatment systems, well replacement, and purchasing of bottled water. The objective of this study was to quantify actual amounts spent by private well owners when NO_3 levels are elevated, regardless of whether the owners are aware of the contamination. Survey questionnaires asking about well characteristics, NO_3 testing, and costs of actions taken in response to elevated NO_3 were mailed to 800 private well owners in the central sand plains of Minnesota. Sixty percent of recipients returned surveys and then were sent water sampling bottles, of which 77% were returned. Nitrate was determined in the returned water samples. About 6% of wells tested greater than the US Environmental Protection Agency health standard maximum of 10 mg L^{-1} (10 ppm) nitrate-nitrogen. Less than one-third of respondents had tested their water for NO_3 within the past three years. Average remediation costs were \$190 y^{-1} to buy bottled water, \$800 to buy a NO_3 removal system plus \$100 y^{-1} for maintenance, and \$7,200 to install a new well. Of well owners with nitrate-nitrogen over 10 mg L^{-1}, 24% bought bottled water, 21% installed treatment systems, 24% installed new wells, and 31% were unaware of the contamination and took no actions. Water resource planners can compare the costs described in this study to the costs of preventing aquifer contamination through education and technical and financial support. This study also demonstrates a method for representative sampling of private wells without on-site visits, and the continued need for educational programs related to routine testing.

Key words: bottled water—drinking water—groundwater quality—nitrate test kit—sand plains—sandy outwash

About 70% of Minnesotans get their drinking water from groundwater, including more than one million people (23%) who rely on private wells. Nationwide, 44 million Americans—15% of the population—get their water from private drinking water wells (Hutson et al. 2004).

Elevated nitrate (NO_3) concentrations in drinking water can cause methemoglobinemia (blue baby syndrome) in infants. In addition, some research has suggested that long-term consumption of NO_3 is associated with certain cancers, but evidence is unclear (Fewtrell 2004; Rademacher et al. 1992). The US Environmental Protection Agency set a maximum contaminant level for nitrate-nitrogen (NO_3-N) of 10 mg L^{-1} (or 10 ppm) as a safe concentration for infants (US Environmental Protection Agency 2002).

In Minnesota, natural background concentrations of NO_3-N in groundwater are less than 1 mg L^{-1} (Minnesota Pollution Control Agency [MPCA] 2001). Sources of NO_3 contamination include fertilizer, animal manure, human waste (sewage or septage), and atmospheric deposition (e.g., nitrous oxides from combustion). 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. 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. Sand point wells are common in these areas. Sand points, also known as driven-point, well points, or slam wells, are constructed by driving a pipe into relatively loose soils. They are generally less than 7-m (25-ft) deep because of pumping limits. Sand points can be susceptible to contamination because of their lack of grouting, shallowness, and lack of a confining layer.

An estimated 7% of all public and private wells in Minnesota exceed the maximum contaminant level for NO_3-N (MPCA 2006). This estimate is based on several databases that are biased toward newer wells that probably have lower NO_3 concentrations. An MPCA study of vulnerable aquifers measured >10 mg L^{-1} NO_3-N in 3.3% of wells sampled; however, this was a study of aquifers (not wells), so only deep wells in nonagricultural areas were sampled and the upper parts of aquifers were not represented (MPCA 1998). Higher contamination rates would be expected in agricultural areas and surficial aquifers. Of the samples brought to voluntary well water testing clinics sponsored by the Minnesota Department of Agriculture, nearly 8% were over 10 mg L^{-1} NO_3-N (Minnesota Department of Agriculture 2006). The clinics are targeted to areas most vulnerable to NO_3 contamination, and participation may be biased towards people who suspect they are at increased risk for NO_3 contamination.

Some areas of Minnesota have much higher-than-average rates of contamination, but statewide NO_3-N concentrations reported in Minnesota wells are lower than those of neighboring states. In Iowa, representative sampling of rural wells from 1988 to 1991 measured 18% to 20% of wells over 10 mg L^{-1} (Libra et al. 1993). A recent Wisconsin aggregation of several water quality databases found that 12% of wells statewide exceeded 10 mg L^{-1} NO_3-N, and rates in a few counties exceeded 20% (Wisconsin Groundwater Coordinating Council 2006).

Costs of preventing groundwater contamination commonly relate to providing education, technical support, and financial incentives to encourage desired practices. Water resource researchers and planners (including state, county, and city officials, and private consultants) need an understand-

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ing of the costs of NO_3 contamination to be able to justify and allocate the costs of groundwater protection. Once an aquifer is contaminated, every well owner tapped into that aquifer may bear costs of treating the water or finding another source. These costs have not been well analyzed. Most studies reviewed by Phillips et al. (1999) used the contingent valuation method which asks people to assess their willingness to pay for drinking water quality. Other studies estimated the effect of erosion on surface water treatment, morbidity and mortality costs, or costs of avoiding groundwater pollution. None of the studies summarized the actual amount spent to remediate contaminated well water. Pottebaum (1990) gathered information about costs of treatment systems but did not examine the rate at which well owners would install systems.

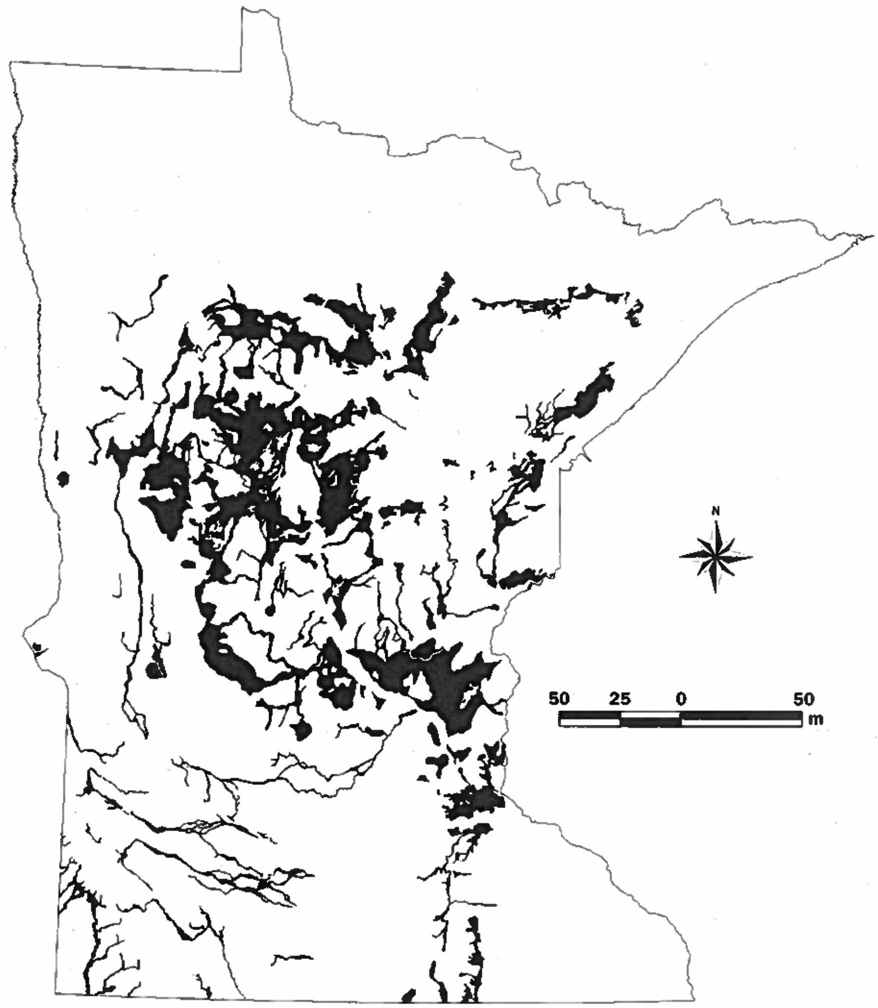
The primary purpose of this study was to determine how private well owners in the glacial outwash soils of Minnesota respond to elevated NO_3 concentrations and to quantify their costs. Other objectives were to demonstrate a low-cost statistical sampling method for determining NO_3 concentrations in private wells and to examine well owners' perceptions and attitudes about drinking water quality to help water resource planners and researchers address NO_3 problems more effectively.

Materials and Methods

The study focused on areas of deep sandy glacial deposits in central Minnesota (figure 1). Land cover across the region is about 20% lakes and wetlands, about 40% agricultural, and about 40% forest and brush, with small amounts of developed land including communities and recreational properties. Almost 10% of the cropland in the region is irrigated.

A mail survey was developed and targeted at owners of private wells in 11 counties with high proportions of sandy glacial outwash: Becker, Cass, Dakota, Hubbard, Itasca, Morrison, Otter Tail, Sherburne, Stearns, Todd, and Wadena (figure 2). To avoid homeowners on municipal water systems and to target sandy outwash areas, the mailing addresses were identified by starting with land parcel databases from each county. Parcels were identified by township or municipality, so those within municipal boundaries could be easily eliminated. Parcels were also eliminated if they had no

Figure 1
Sandy outwash regions of Minnesota.



Note: Areas with the attribute "Outwash—Undivided as to Moraine Association" from Hobbs and Goebel (1982).

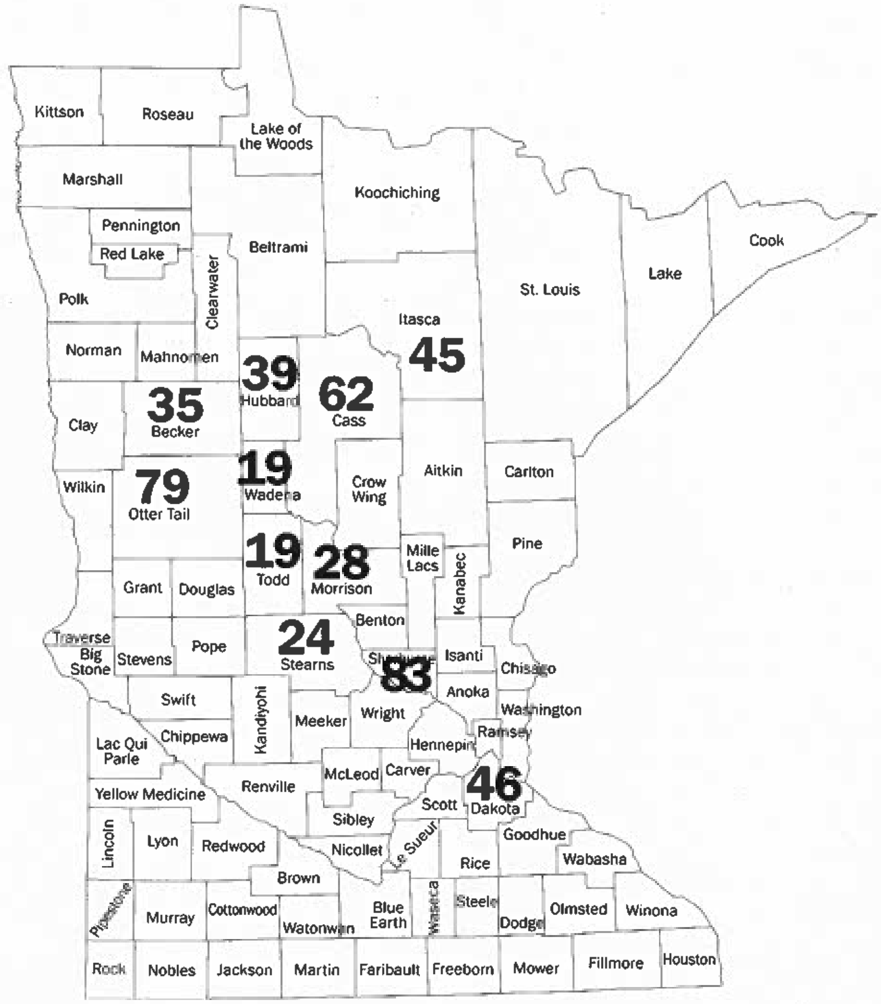
buildings, were public properties, had out-of-state addresses or incomplete addresses, or had the same owner as a previous parcel. The list was then limited to properties on sandy outwash deposits by using a geographic information system (GIS) overlay of surficial geology—specifically, areas labeled "Outwash—Undivided as to Moraine Association" from the Minnesota Geological Survey map of quaternary (surficial) geology acquired from the Land Management Information Center (figure 1; Hobbs and Goebel 1982). If the list of parcels for a county was not in a GIS format, the list was limited to properties in townships primarily on sandy outwash. The resulting list of parcels was divided into homesteaded (owner address same as property address) and nonhomesteaded properties. Nonhomesteaded properties were thought to be second homes and recreational properties. From the final list, 600 addresses were randomly selected from the homesteaded parcels and 200 addresses from the nonhomesteaded parcels.

An alternative source of well owner addresses was the Minnesota County Well Index (CWI), a database which includes the location, initial NO_3 concentration, depth, and geology of wells across the state. We chose not to draw the sample from the CWI because it contains only a fraction of the wells in the state, including very few wells drilled before 1974, and it probably under-represents sand point wells (Minnesota Geological Survey and Minnesota Department of Health 2007; Wahl and Tipping 1991).

The survey methodology followed procedures described by Dillman (2000). In the summer of 2006, the 800 property owners were sent a survey with 25 questions about characteristics of their well, NO_3 testing of the well, actions taken in response to elevated NO_3 concentrations, costs of these actions, and respondents' concerns and perceptions about water quality. The cover letter offered participants a free NO_3 testing kit to encourage participation and as a low-cost method to collect NO_3 measurements for each well. A week later, a reminder postcard was sent to all addresses. Three weeks after the initial mailing, a duplicate survey was sent to nonrespondents. After three months, 483 people (60%) had returned surveys. Response rates were the same for homesteaded and nonhomesteaded properties. Respondents were sent a NO_3 testing kit consisting of instructions, a 120-mL (4-oz) bottle, and return postage. Water samples were returned by 370 (77%) of the people who were sent kits. If respondents indicated they had a NO_3 treatment system, they were sent two bottles and asked to sample both before and after the treatment system. Participants were asked to take the sample immediately before mailing it and to mail it early in the week. Samples were analyzed within a day of arriving at the lab. Levels of NO_3-N in the water samples were determined using a Hach DR4000 or DR5000 spectrophotometer (method 10049, Hach 2005). Before analysis, 1 ml (0.03 oz) of 1% HCl solution was added to a sample of about 100 ml (3.4 oz). If results were over 10 mg L^{-1}, a 10× dilution of the sample was analyzed.

Survey results were used to estimate average actual expenditures for treating or replacing contaminated water. The actions of well owners who were aware of the NO_3-N concentration of their well were compared to those who were not aware by using chi-squared tests. Although respondents were allowed to report duplicate responses (e.g., they may both drink bottled water and have a treatment system), duplicate answers were removed for the chi-squared analysis by assigning each respondent to a single action in the priority order of new well installation, treatment system, and then drinking bottled water. A logistic regression was used to model the occurrence of elevated NO_3 concentrations from well type, well age, and surrounding land use. Pearson's chi-squared tests were used to determine differences in responses between people who are concerned versus not concerned about NO_3 contamination and differences among types of water quality concerns. Data analysis was done with R statistical software (R Development Core Team 2006).

Figure 2
Distribution of returned surveys.



Results and Discussion

Table 1 and figure 3 are based on results from three survey questions asking about well age, depth, and type of construction. Most respondents (77%) knew all three characteristics. About two-thirds of the wells were drilled, and one-fifth were sand point wells. The proportion of sand points was even lower among the newer wells. At least one-third of the wells can be considered susceptible to contamination because they were a sand point, more than 30 years old, or less than 50 ft (15 m) deep. At least 40% of the wells can be considered less susceptible because they were drilled and they were either less than 15 years old or greater than 100 ft (30 m) deep.

The age categories of 30 and 15 years were chosen to roughly correspond to the implementation of Minnesota's Water Well Construction Code in 1974 and the Minnesota Ground Water Protection Act of 1989. The 1974 code required well drillers to submit logs for every well installed. The 1989 Act improved compliance with well construction and reporting standards (Helland 2001). Data from most well logs since 1974 have been entered into Minnesota's CWI. The code also applies to homeowners installing sand point wells, but the compliance rate is unknown. At least 15% of the drinking water wells in this survey are not included in the CWI because they were installed before

Table 1
Reported well characteristics.

Depth	Age <15 y	15 to 30 yr	>30 yr	Don't know	Sum
All well types (*N* = 468)					
<50 ft	5%	8%	7%	2%	22%
51 to 100 ft	20%	14%	3%	1%	37%
101 to 300 ft	12%	9%	2%	0%	23%
>300 ft	1%	1%	0%	0%	2%
Don't know	5%	5%	3%	3%	16%
Sum	43%	37%	15%	6%	100%
Drilled wells (*N* = 304)					
<50 ft	1%	1%	1%	0%	3%
51 to 100 ft	19%	12%	1%	1%	33%
101 to 300 ft	11%	8%	2%	0%	21%
>300 ft	1%	1%	0%	0%	2%
Don't know	2%	2%	0%	1%	6%
Sum	34%	25%	4%	2%	65%
Driven or sand point wells (*N* = 104)					
<50 ft	3%	7%	6%	1%	17%
51 to 300 ft*	0%	1%	1%	0%	3%
Don't know	0%	1%	1%	0%	2%
Sum	4%	9%	8%	2%	22%

Note: English units are used to match the wording of the survey questions.
* Sand point wells are generally no deeper than 25 feet.

mid-1970. When asked if their well had a CWI number, 22% of respondents said yes, 29% said no, and 50% did not know. Among owners of sand point wells, none said yes, 57% said no, and 43% did not know.

Three-quarters of the tested wells had NO_3-N concentrations below 1 mg L^{-1} (figure 4). Almost 6% tested greater than 10 mg L^{-1}. This rate is comparable with results from other studies in Minnesota discussed in the introduction. Surprisingly, NO_3 concentrations did not differ among the well types, but the odds of elevated NO_3 concentrations were significantly higher in wells where the principal land use within one-quarter mile was agricultural (table 2).

The Minnesota Department of Health recommends a routine NO_3 test every two to three years for private wells used for drinking water (Minnesota Department of Health 2007). Only 29% of respondents had tested their well water for NO_3 within the past three years (figure 5). Of the remainder who had not tested in the past three years, nearly three-quarters did not feel a need to test because either they did not drink the water, the water was filtered, or they presumed the water was fine (table 3). Some were not aware that their carbon filters and water softeners did not remove NO_3. Cost and inconvenience were less common barriers to testing.

Responses to and Costs of Elevated Nitrate. Responses to elevated nitrate vary partly because some well owners do not know their water NO_3 concentration and others choose to respond at various concentrations. In this survey, half of respondents said they would begin treating or finding an alternative water source before the concentration reached 10 mg L^{-1} NO_3-N, while the other half would wait until it reached 10 or higher (figure 6). When they decide to take action, 74% said they would get (or already have) a NO_3 removal system (table 4, column 1). (Respondents were told the approximate cost of a system when answering this question.) However, actual actions differ from intended actions: treatment systems were installed by only 28% of all respondents who thought they had water with more than 10 mg L^{-1} NO_3-N (table 5, column 7).

Reported costs of responses to elevated NO_3 are shown in table 6. Average expenses in response to NO_3 contamination were \$190 y^{-1} to buy bottled water, \$800 to buy a NO_3 removal system plus \$100 y^{-1} for maintenance, and \$7,200 to install a new well. To avoid NO_3 contamination, a new well may be drilled into a deep aquifer. These deeper waters typically have a high mineral content requiring the additional cost of a water softener. Reported annual maintenance costs for a treatment system may be limited to filter replacement and may not include the cost of electricity or the cost of waste water disposal. Reverse osmosis systems typically generate at least four units of waste water for each unit of product water.

Total direct spending for elevated NO_3 concentrations was calculated by summing the costs of each response to NO_3 contamination after weighting the costs by the proportion of well owners choosing each response. To estimate the level of behaviors attributable to NO_3 contamination rather than to other concerns, the prevalence of behaviors among well owners with less than 2 mg L^{-1} NO_3-N was subtracted from the prevalence among well owners with greater than 10 mg L^{-1} NO_3-N (table 4, column 5). This was multiplied by the average cost of each response from table 6. Thus, where NO_3 concentrations are elevated, an additional 16% of the population bought treatment systems at an average cost of \$798 plus \$100 y^{-1}, 16% bought bottled water at a cost of \$190 y^{-1}, 25% installed a new well at a cost of \$7,200, and the remainder continued their same behavior at no additional cost. The result of summing these weighted costs is \$1,927 in initial costs plus \$46 y^{-1}. This represents the average one-time cost per well if the NO_3-N concentration in an aquifer rose above 10 mg L^{-1}. If the cost of a new well were spread over 50 years and the cost of the treatment system were spread over 20 years, then the average long-term annual cost per well of elevated NO_3 concentrations is \$89. The largest component of the one-time cost is attributed to the 25% of people who installed a new well. That proportion is based on the eight people in this survey who said they installed a new well because of elevated NO_3 concentrations.

Spending for NO_3 contamination would likely be higher if all well owners were aware of contamination. In fact, most well owners have not tested their water recently. Once they learn about contamination, they may drink bottled water or do nothing for some time before buying a treatment system or replacing a well. Thus, rates of installing treatment systems or taking other actions would be higher if every well owner was aware of nitrate concentrations and had time to respond. Table 5 illustrates the higher rates of actions taken by people who knew the results from a recent well water test.

An alternative method for calculating costs is based on incremental NO_3 concentrations: the cost of using a NO_3 removal system to reduce a NO_3-N concentration by 1 mg L^{-1} was calculated by dividing the cost of each individual NO_3 removal system by the reduction in NO_3-N achieved by that system (data not shown). By this calculation, the average cost to reduce NO_3-N by 1 mg L^{-1} was \$227 in initial costs plus \$13 y^{-1} for all systems that were treating NO_3-contaminated water.

This study assumes that costs of NO_3 contamination can be separated from other costs. In reality, well owners likely make decisions about treating or replacing their drinking water source based on multiple factors including perceptions of various contaminants, taste, convenience, cost, and reliability. The survey did not attempt to assess the relative importance of these other factors in drinking water choices.

The survey was designed to estimate replacement costs represented by either treating contaminated water or finding an alternative source. Replacement costs do not represent the total societal costs of NO_3 contamination but help trace economic flows and thus are useful for planning at a local level. Total costs of NO_3 contamination are better represented by the willingness of individuals to pay for risk reduction (Kuchler and Golan 1999), which was not addressed by this survey.

Perceptions and Attitudes. Few respondents perceived a decline in groundwater quality, and 62% felt they had ample opportunities to learn about their water quality (figure 7). Concern about NO_3 contamination was about the same as concern about bacterial or chemical contamination but was significantly greater than concern about contamination with iron or other minerals (figure 8). Compared with people who are not concerned, the 71% of people who are "very" or "somewhat" concerned about NO_3 contamination were significantly more likely to say they test their water, drink bottled water, and think property values have declined in the county due to poor water quality (data not shown). The perception of

Figure 3
Reported well characteristics.

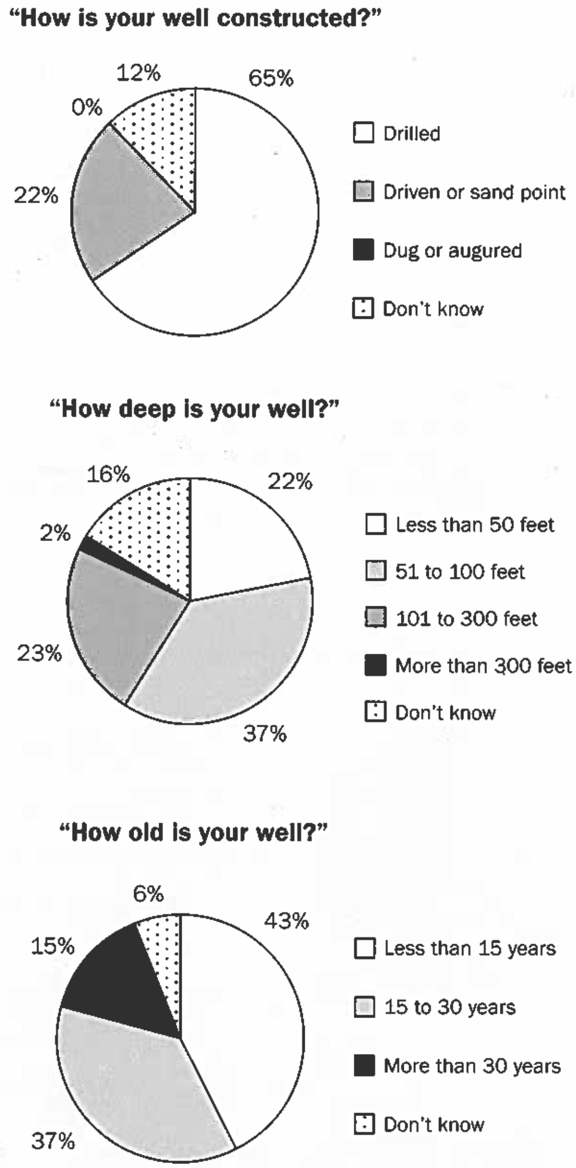


Figure 4
Well water nitrate-nitrogen concentrations of 370 water samples submitted for testing.

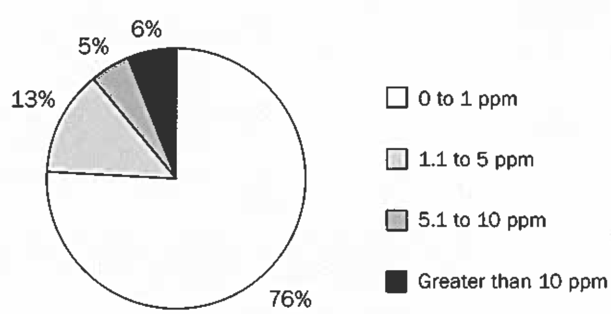


Table 2
Where are nitrate-nitrogen concentrations elevated?

Category of wells	Proportion of the category of wells with the following NO_3-N concentration: <10 mg L^{-1}	>10 mg L^{-1}	Unknown
Well construction			
Drilled (*N* = 304)	79%	6%	15%
Sand point (*N* = 104)	80%	4%	16%
Age of well			
Less than 15 years (*N* = 199)	79%	3%	18%
15 to 30 years (*N* = 172)	79%	6%	15%
More than 30 years (*N* = 69)	72%	10%	17%
Principal land use within a quarter mile of the well			
Agricultural (*N* = 139) (cropland, pasture, and grassland)	70%	10%*	20%
Non-agricultural (*N* = 328) (forest, lawn, homes, water, or mixed uses)	82%	3%	15%

*Where the principal land use around the well was agricultural, the odds of elevated well NO_3 concentrations were significantly higher than at other locations, even after accounting for well type, age, and depth ($p < 0.01$).

Figure 5
"When was your drinking well water last tested for nitrate?"

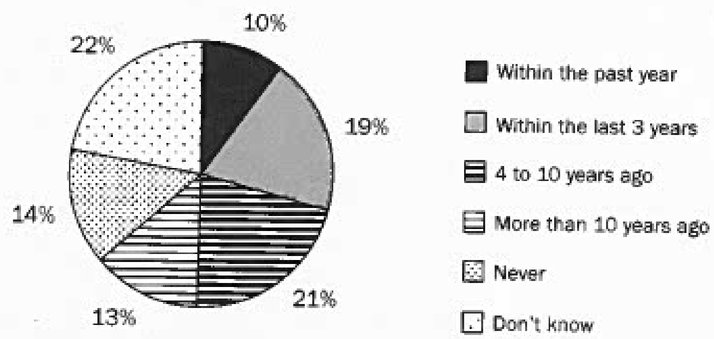
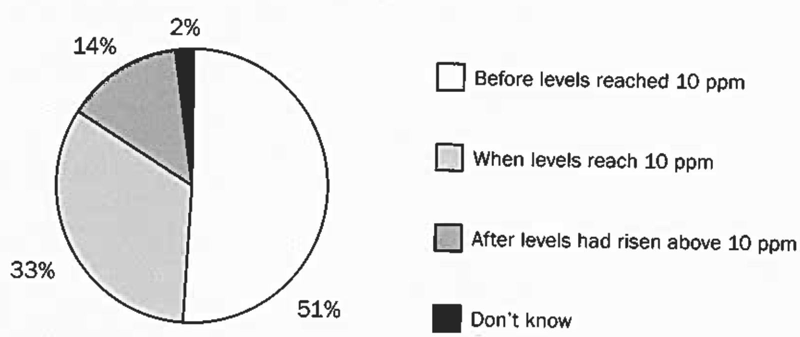


Figure 6
"At what nitrate level would you begin treating your water or finding an alternative source of drinking water?"



Note: Participants were told that the US Environmental Protection Agency considers NO_3-N levels above 10 mg L^{-1} to be unsafe, especially for infants and the elderly.

Table 3
Why don't people test regularly?

Response choice	Percent of respondents
Don't feel a need to have it tested	50%
The water is probably fine	23%
I don't know how to test my water	18%
It is not convenient	9%
Have not had time	9%
It costs too much	4%
Other (didn't know to test; just moved)	18%

Table 4
Responses to elevated nitrate-nitrogen: All well owners.

	Hypothetical actions*	Actual actions			
	N = 471	All respondents N = 483	Owners of 0 to 2 mg L^{-1} NO_3-N wells N = 299	Owners of >10 mg L^{-1} NO_3-N wells N = 33	Increased prevalence associated with NO_3 contamination (col. 4 – col. 3)
	(1)	(2)	(3)	(4)	(5)
Install treatment system	73.9% †	7.5%	6.0%	21.9%	15.9%
Drink bottled water‡	14.4%	10.4%	9.0%	25.0%	16.0%
Install a new well	3.4%	1.7%	0%	25.0%§	25.0%
Nothing	4.7%	83.0%	82.9%	37.5%‖	–
Move	1.5%				

Note: Duplicate responses allowed.

* What respondents said they would do if water NO_3 became unsafe for drinking.

† Including 6% who already have systems.

‡ Only includes those who drink bottled water in response to elevated NO_3. Additional people drink bottled water for other reasons.

§ All eight respondents who said they installed a new well because of elevated NO_3 were included in this high NO_3 group. Water samples submitted for this survey were from their new well and thus had low NO_3 concentrations.

‖ At the time of the survey, most of this group did not know their NO_3-N concentration was >10 mg L^{-1}.

a NO_3 problem may elicit costs even where NO_3 concentrations are not elevated.

Summary and Conclusions

We surveyed a representative sample of private drinking water wells by using a combination of county land parcel lists to identify well owners and a mailed NO_3 test kit. This methodology avoided the high cost of on-site visits. Most people do not test their drinking water on a regular basis because they do not feel a need for testing. Cost and inconvenience were less common explanations for lack of testing. Some were not aware that their carbon filters and water softeners do not remove NO_3. Of the wells tested in this survey, 6% had NO_3-N concentrations >10 mg L^{-1}, and another 5% were between 5 and 10 mg L^{-1}. The proportion of wells with elevated NO_3 was greater where the principal land use within a quarter mile of the well was agricultural versus non-agricultural. Costs of treating or avoiding NO_3 contaminated water can be substantial. Average cost

Table 5
Responses to elevated nitrate-nitrogen: Percentages of well owners who are aware and not aware of their nitrate-nitrogen concentration.

	Hypothetical actions*†		Actual actions					
			All respondents*		Owners of 0 to 2 mg L^{-1} NO_3-N wells		Owners of >10 mg L^{-1} NO_3-N wells*	
	Aware N = 106	Not aware N = 365	Aware N = 106	Not aware N = 377	Aware N = 46‡	Not aware N = 253	Aware N = 22	Not aware N = 11
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Install treatment system§	87.7*	74.6	14.2*	4.8	13.3*	4.0	27.8*	7.1
Drink bottled water‖	7.5*	16.6	5.7	9.5	4.4	8.9	16.7	21.4
Install a new well	2.8	3.7	7.5*	0	0	0	44.4*#	0
Nothing	1.9*	5.1	72.6	85.7	82.2*	87.0	11.1*	71.4
Move	0	1.9						

Note: No duplicate responses allowed.

* Difference between well owners who are aware and not aware of their NO_3-N concentration is significant (p-value < 0.05).

† What respondents said they would do if water NO_3-N concentration became unsafe for drinking.

‡ N = 46 is from the 68 people who submitted water samples, not the entire 106 who knew their nitrate concentration.

§ Hypothetical responses includes 9% who already have systems.

‖ Only includes those who drink bottled water in response to elevated NO_3. Additional people drink bottled water for other reasons.

Six respondents who said they installed a new well because of elevated NO_3 were included in this high NO_3 group, although water samples submitted for this survey were from their new well and thus had low NO_3 concentrations.

Table 6.
Costs of actions taken in response to elevated nitrate.

	Reported cost average (range)		
	Initial costs	Annual costs	Total annualized costs*
NO_3 removal systems:			
Reverse osmosis: own (*N* = 16 of 25)†	$855 ($85 to $1700)	$87 ($25 to $200)	$130
Reverse osmosis: lease (*N* = 2 of 4)	$0	$360 ($240 to $480)	$360
Distillation (*N* = 4 of 6)	$961 ($190 to $3,000)	Not reported	–
Anion exchange (*N* = 1 of 1)	$1,600	Not reported	–
Weighted average all systems (*N* = 23 of 36)	$798	$100	$140
New well (*N* = 10 of 8)‡	$7,200 ($3,000 to $15,000)	–	$144
Bottled water (*N* = 41 of 50)	–	$190 ($36 to $600)	$190

* Initial cost of treatment systems was divided by the projected 20-year life span of the systems. Cost of a well was divided by 50 years.

† Numbers in parentheses indicate the number of respondents who reported costs and the total number who reported taking that action in response to elevated nitrate concentrations.

‡ Ten respondents reported costs, but only eight installed their well in response to nitrate contamination.

Figure 7
Perceptions of water quality.

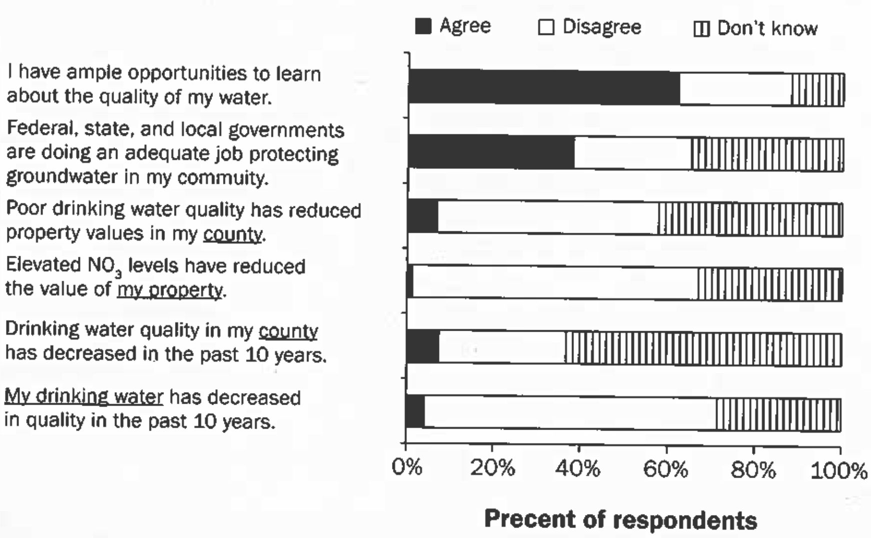
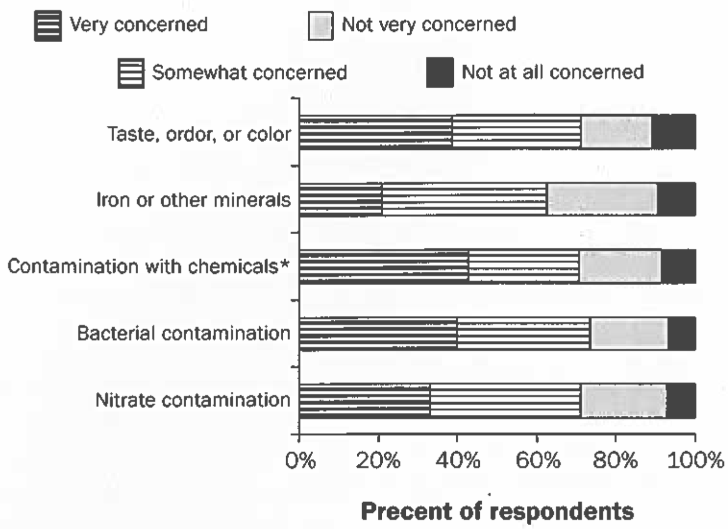


Figure 8

"How concerned are you about the following water quality issues related to your drinking water?"



Note: The sum of respondents who were "very" or "somewhat" concerned was significantly lower for minerals than for other water quality issues (Chi-squared test, $p < 0.01$).

* Actual survey wording was "Contamination with herbicides, volatile organic compounds, or other chemicals."

of a NO_3 removal system was $800 to install and $100 y^{-1} to maintain, and average cost of a new well was $7,200 plus the cost of a water softener in cases where water is drawn from a deep aquifer. If the NO_3-N concentration in an aquifer rose above 10 mg L^{-1}, the one-time average cost per well owner would be $1,927 plus $46 y^{-1}, based on the distribution of responses to elevated NO_3 in this survey. These direct costs of groundwater NO_3 contamination represent the low end of total cost estimates, which should also include non-use values such as the value of knowing a clean aquifer will exist in the future. Quantifying the costs can help justify the expenses associated with protecting groundwater.

Acknowledgements

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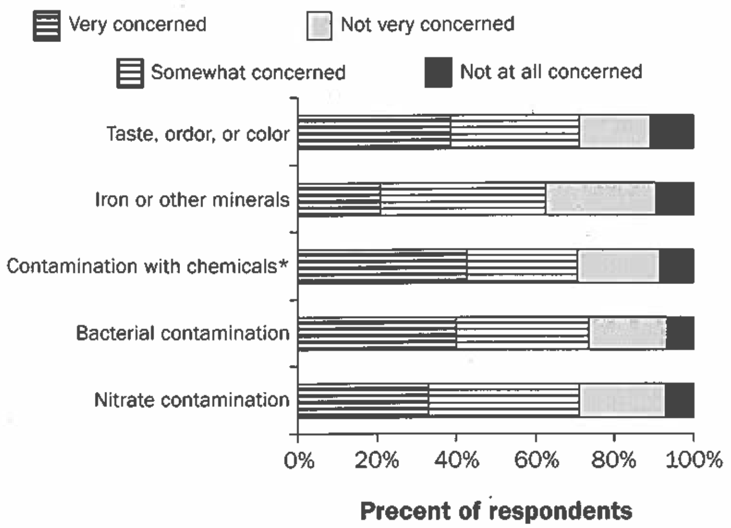
Figure 8

"How concerned are you about the following water quality issues related to your drinking water?"



Note: The sum of respondents who were "very" or "somewhat" concerned was significantly lower for minerals than for other water quality issues (Chi-squared test, $p < 0.01$).

* Actual survey wording was "Contamination with herbicides, volatile organic compounds, or other chemicals."

of a NO_3 removal system was \$800 to install and \$100 y^{-1} to maintain, and average cost of a new well was \$7,200 plus the cost of a water softener in cases where water is drawn from a deep aquifer. If the NO_3-N concentration in an aquifer rose above 10 mg L^{-1}, the one-time average cost per well owner would be \$1,927 plus \$46 y^{-1}, based on the distribution of responses to elevated NO_3 in this survey. These direct costs of groundwater NO_3 contamination represent the low end of total cost estimates, which should also include non-use values such as the value of knowing a clean aquifer will exist in the future. Quantifying the costs can help justify the expenses associated with protecting groundwater.

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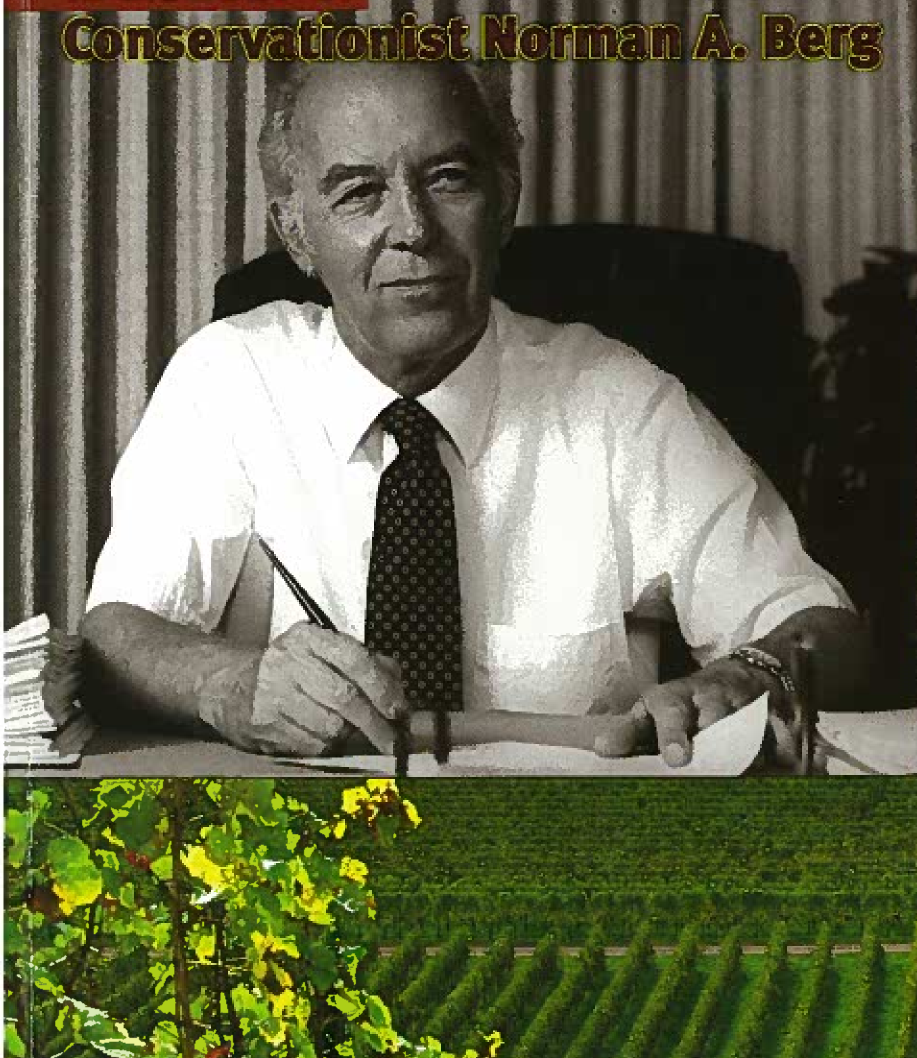

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