

## NITRATE CONTAMINATION IN OREGON WELL WATER: GEOLOGIC VARIABILITY AND THE PUBLIC'S PERCEPTION<sup>1</sup>

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**ABSTRACT:** Approximately 4.5 million people in the United States who rely on well water are exposed to nitrate-N concentrations exceeding the 10 mg/l standard. In this study in the Southern Willamette Valley in Oregon we reassessed nitrate-N in rural wells sampled in 2000-2001, compared nitrate-N concentrations among geological units, and surveyed residents about their perceptions of well water quality. Nitrate-N concentrations were again sampled in 2002 and found to have increased significantly from the previous period. With rapid population growth in the area, the potential health risk in drinking well water that exceeds 10 mg/l nitrate-N warrants continued public education. Nitrate-N concentrations were found to be higher in the Holocene alluvium of the Willamette River and the Pleistocene sand and gravel post-Missoula Flood deposits. Researchers conducting future studies may choose to stratify and monitor wells by geologic unit and by other parameters that estimate input of nutrients to the environment. Opinions differed between agricultural landowners and nonagricultural landowners with regard to the impact that agricultural fertilizers may have on water quality. Participants were supportive of a range of regulatory actions that might be used by homeowners or landowners to address ground water contamination. Given that the area is now designated a Groundwater Management Area, understanding local stakeholders' perceptions is critical and strategic and has the potential to help public agencies manage potential conflicts of opinion among stakeholders, build consensus, and help guide the approach to restoring ground water quality.

(KEY TERMS: drinking water; geospatial analysis; ground water management; nitrate; public perception survey; water quality; wells)

Kite-Powell, Aaron C. and Anna K. Harding, 2006. Nitrate Contamination in Oregon Well Water: Geologic Variability and the Public's Perception. *Journal of the American Water Resources Association (JAWRA)* 42(4):975-987.

### INTRODUCTION

Nitrate contamination of ground water is a serious problem throughout the United States (U.S.), due to heavy reliance on ground water for drinking water. Thirty-seven percent of public-supply domestic water and 98 percent of self-supplied domestic water is drawn from ground water sources, accounting for approximately 46 percent of the overall U.S. population that relies on ground water for drinking water (Hutson *et al.*, 2004). In Oregon, more than 70 percent of the state's population is partially dependent on ground water for drinking water, and 95 percent of the rural population is entirely dependent on ground water for domestic purposes (ODEQ, 2001).

Nitrate is a common contaminant in Oregon due to contributions from nitrogen fertilizers, septic systems, animal feedlot operations and barnyards, and above-ground application of wastewater (Eldridge, 2003). In this study, nitrate concentration is reported as nitrate-nitrogen (nitrate-N), which represents the weight of nitrogen in the nitrate form. This also is the standard manner in which nitrate concentration is reported in drinking water. Nitrate-N concentrations above 3 mg/l in the ground water are representative of anthropogenic sources (Madison and Brunett,

<sup>1</sup>Paper No. 04174 of the *Journal of the American Water Resources Association (JAWRA)* (Copyright © 2006). **Discussions are open until February 1, 2007.**

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1985). While the U.S. Environmental Protection Agency (USEPA) has issued a public health-based drinking water standard of a maximum contaminant level (MCL) of 10 mg/l for nitrate-N (USEPA, 2002), there is no corresponding private well standard (ODEQ, 2003). Nevertheless, a majority of state agencies have adopted the public drinking water standard as the acceptable level for private wells (USEPA, 1987). Approximately 4.5 million people in the U.S. who rely on well water are exposed to nitrate-N concentrations exceeding the MCL (Nolan *et al.*, 1998). A nationwide U.S. Geological Survey (USGS) study of domestic wells sampled from 1992 to 1999 showed that 11 percent of the wells tested above 10 mg/l nitrate-N (Squillace *et al.*, 2002). Annual testing of domestic well water samples in Iowa reveals that 15 percent to 24 percent of all well samples exceed the MCL (Kross *et al.*, 1993). A statewide study in Kansas found that 28 percent of the wells exceeded 10 mg/l nitrate-N (Kross *et al.*, 1993).

Due to limited monitoring by either users or government agencies, little is known about the quality of Oregon's ground water. A 1993 assessment by the USGS of domestic wells less than 25 meters deep in the Willamette Basin, Oregon, found that 9 percent of the wells exceeded 10 mg/l nitrate-N (Hinkle, 1997). Twenty-three percent of the population surveyed in an intensely irrigated area of northeastern Oregon were exposed to concentrations at or above 10 mg/l nitrate-N (Mitchell and Harding, 1996). Since 1989, additional data are being compiled from individuals selling property with a private well. Oregon law requires the seller of a domestic well to test for nitrates and total coliform bacteria and to report the results to the Department of Health Services (ODHS, 2003).

The predominant health concern associated with excess nitrate intake is methemoglobinemia, or "blue baby syndrome," a condition that is more likely to affect infants less than six months old due to unique physiological factors at that age (Knobeloch *et al.*, 2000). Surprisingly little is known about the chronic or reproductive health outcomes resulting from the ingestion of nitrate (CDC, 1996; Bukowski *et al.*, 2001). Recent studies have linked nitrate ingestion to gastric cancer, bladder cancer, non-Hodgkin's lymphoma, ovarian cancer, and brain and central nervous system cancers (Weisenburger, 1991; Xu *et al.*, 1992; Morales-Suarez-Varela *et al.*, 1995; van Maanen *et al.*, 1996; Yang *et al.*, 1998; Mueller *et al.*, 2001; Weyer *et al.*, 2001).

In 2000-2001, the ODEQ selected an area in the Southern Willamette Valley to research nitrate contamination of ground water. The study area boundaries were the Cascade Range to the east, the Oregon Coast Range to the west, the Salem Hills to the north,

and the city of Eugene's urban growth boundary to the south (Figure 1). This area roughly approximates the limits of the Quaternary alluvium in the Southern Willamette Valley, and encompasses approximately 780 square miles (Eldridge, 2002).

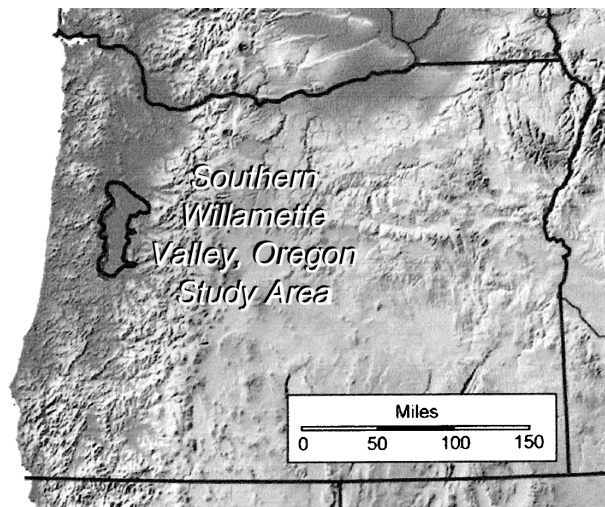


Figure 1. Southern Willamette Valley, Oregon, Study Area.

The Southern Willamette Valley is considered by ODEQ to be a priority area for ground water assessment and protection for several reasons; these include: the severity and extent of nonpoint source ground water contamination; the vulnerability of shallow ground water to impacts from the overlying land uses; the expectation that the population in this area will rapidly expand; and residents in the unincorporated areas of the Southern Willamette Valley rely on ground water as their primary drinking water supply (Eldridge, 2002). More than 80 percent of the ground water used in the Willamette Valley is pumped from the shallow sand and gravel aquifer (Hinkle, 1997). The unconfined shallow ground water is assumed to be the ground water resource most likely affected by anthropogenic activities (Eldridge, 2002).

Although the geology of the Willamette Basin influences the permeability of the soils and thus may be a factor in nitrate contamination of ground water, this relationship between geologic units and nitrate concentrations has not been extensively studied. The Southern Willamette Valley is a broad alluvial plain in northwestern Oregon (Figure 1). The valley sediments include fine grained Miocene and Pliocene fluvial lacustrine deposits at the bottom of the basins and coarse grained fluvial deposits of the Quaternary age, which originated from the Cascade Range and Missoula Flood sediment, in the upper levels (O'Connor *et al.*, 2001). Four major units of Quaternary age

sediment can be further divided into five distinct surficial geologic units in the Southern Willamette Valley. Each of these deposits has distinct characteristics that can substantially influence ground water flow and soil characteristics.

The Southern Willamette Valley is an intensive agricultural area. Many older homes located in the region rely on well water and typically have wells situated in shallow ground water, defined as less than 75 feet below ground surface (Eldridge, 2003). No studies have been conducted of residents in this area who are consuming nitrate in their well water to ascertain their knowledge, perceptions, and drinking water practices. Gaining an understanding of the public's perspective has the potential to help management agencies make practical decisions related to public education, manage potential conflicts of opinion among stakeholders, build consensus, and help guide the approach in setting future water quality regulations.

## METHODS

### *Data Collection*

We used three datasets in this study. The first set included nitrate-N measurements from 476 drinking water wells in the Southern Willamette Valley that ODEQ tested in 2000-2001. The ODEQ used judgment sampling procedures (Lohr, 1998) to focus on a geographical area that was of concern due to the possible high nitrate-N concentrations in drinking water wells. While this type of sampling tended to bias the data toward higher nitrate-N contamination, the overall spatial distribution of wells sampled within this region was broad.

The 100 wells that had measured nitrate-N concentrations greater than 7.0 mg/l in the earlier study were selected for the 2002 analysis. ODEQ staff reestablished contact with the current owners of these study wells and requested permission to access the wells previously sampled. As ODEQ's request to resample all the original targeted wells was not always successful, only 87 of the 100 targeted wells were included in the 2002 study. These 87 samples comprised the second dataset and were collected from the targeted wells over a three-month period, from May through July 2002. One of the authors of the present study (Kite-Powell) assisted the ODEQ staff in the field sampling.

Field sampling and laboratory analyses were conducted according to the standard procedures outlined in Sections 5.0 and 6.0 of the 1993 Statewide

Groundwater Monitoring Program Master Plan (ODEQ, 1993a,b; Eldridge, 2002). This plan included sampling procedures, documentation and custody, sample transport, health and safety, laboratory data quality assurance/quality control (QA/QC), equipment calibration and maintenance, data reduction/validation/ maintenance, performance audits, data assessment, corrective action, and confirmatory sampling requirements (ODEQ, 1993a; Eldridge, 2002). Technical staff from the ODEQ Laboratory and ODEQ's Western Region performed the field sampling. Prior to sample collection, the depth to water in the well was measured, where feasible, and recorded. Residents were asked about recent water usage, and if residents were present, an electronic water depth probe was used to gauge depth to water levels.

Wells were purged for approximately five minutes. Temperature, specific conductance, and pH were measured in the field using the YSI conductivity and temperature meter and Beckman-f 200 pH meter and thermometer (Eldridge, 2003). A global positioning system (GPS) reading was recorded, and pictures of wells and the surrounding area were taken as appropriate. Samples for nitrate/nitrite, ammonia, phosphate, and total Kjeldahl nitrogen (TKN) were collected in 500 ml high density polyethylene containers, acidified to a pH less than 2 with sulfuric acid, and cooled on ice after collection and during transport to the ODEQ Laboratory in Portland, Oregon. The ODEQ Laboratory performed all nitrate analyses using USEPA Method 353.2. Identical methods were used in the 2000-2001 and 2002 sampling periods (Eldridge, 2002).

The third dataset consisted of responses to a written mail survey from residents living in households where the water had been tested in 2000-2001. The 476 households in the 2000-2001 sampling were stratified into three groups based on the nitrate-N concentrations in their wells: low nitrate-N (0 to 2.99 mg/l) (n = 228); medium nitrate-N (3 to 9.99 mg/l) (n = 214); and high nitrate-N (10 to 28 mg/l) (n = 34). A subset of the 476 households (n = 200) was chosen, based on a random selection of 83 households from each of the low nitrate and medium nitrate groups and all 34 of the high nitrate group. Sample size calculations indicated that a 43 percent response rate from the 200 participants would achieve a 95 percent confidence level for analysis.

We developed a survey to measure residents' knowledge, concerns, and practices related to well water quality, adapting our survey from another instrument that measured public opinion about natural resource issues (Morris *et al.*, 1993). The survey inquired about demographics, association with the area under study, concerns regarding drinking water quality, opinions about water resource management

by certain sectors of society, and specific information on respondents' water systems and usage practices. The survey was developed with the assistance of the Oregon State University (OSU) Survey Research Center, senior hydrologists from the ODEQ, an OSU extension water quality specialist, and the ground water coordinator in the Department of Human Service's Drinking Water Program. To improve the instrument's validity and reliability, the survey was pilot tested with 10 rural residents in a neighboring area who also use drinking water wells. Suggestions recommended by the pilot participants were incorporated into the final survey. The research was approved by the OSU Institutional Review Board for the Protection of Human Subjects.

### *Data Analysis*

We used descriptive statistics to determine the distributional characteristics of the data. Statistical analysis was conducted using the chi-square test of independence, Mann-Whitney U test, Kruskal-Wallis test, and one-way ANOVA followed by Tukey's HSD post hoc test for significant results. All statistical analyses were conducted using SPSS v.11 (SPSS, 2001). Statistical significance was set at  $p$  less than 0.05. A spatial representation of nitrate levels and area geological/hydrogeological units was created using ArcView GIS 3.2a software (ESRI, 1996).

## RESULTS

### *Well Testing*

Results from the first round of nitrate testing during 2000-2001 ( $N = 476$ ) indicated that 48 percent of the samples had nitrate-N concentrations less than 3 mg/l nitrate-N; 45 percent of the samples were between 3 and 10 mg/l nitrate-N; and 7 percent of the samples exceeded 10 mg/l nitrate-N. The mean nitrate-N concentration for this sampling period was 4.1 mg/l, with a range between 0.0 to 22.6 mg/l. The second round of nitrate testing in 2002 ( $N = 87$ ) revealed that 6 percent of the samples had nitrate-N concentrations less than 3 mg/l nitrate-N; 46 percent of the samples were between 3 and 10 mg/ nitrate-N; and 48 percent of the samples exceeded 10 mg/l nitrate-N. The mean nitrate-N concentration was considerably higher, at 10.8 mg/l, with the range between 0.1 to 27.8 mg/l. Of the 87 households common to both studies, 64 of them (74 percent) experienced increases in nitrate-N concentrations from the first sampling

period in 2000-2001 to the second sampling period in 2002, among which 18 increased to more than 10 mg/l.

### *Nitrate Concentration and Geologic Units*

We examined the spatial relationship of nitrate-N in water in geologic units in the region to determine if mean nitrate-N concentrations in water were different between geologic units. Although the study area has 10 geologic units, 5 of the units contain 90 percent of the study's households. Spatial distribution is shown in Figure 2.

The largest total number of households occurs within the Missoula Flood deposits ( $Q_{ff2}$ ) geologic unit ( $n = 147$ ), which also contains more households than any other unit having nitrate-N concentrations in the low category ( $n = 87$ ). In contrast, 26 of 35 (74 percent) of the households classified as having high nitrate-N concentrations were located in the more permeable geologic units, Holocene alluvium of the Willamette River ( $Q_{alc}$ ) ( $n = 13$ ) and Pleistocene sand and the gravel post-Missoula Flood ( $Q_{g1}$ ) ( $n = 13$ ) (Figure 3).

Significant differences were found between mean nitrate-N categories (2000-2001 test results) in five of the geologic units ( $Q_{alc}$ ,  $Q_{alf}$ ,  $Q_{ff2}$ ,  $Q_{g1}$ ,  $Q_{g2}$ ) when they were analyzed using a Kruskal-Wallis test,  $\chi^2$  (4,  $N = 429$ ) = 56.1,  $p < 0.01$ . The test corrected for tied ranks. A Mann-Whitney U test was conducted to evaluate pairwise differences among the five groups. The results indicate that mean nitrate-N ranks for the Pleistocene sand and gravel post-Missoula Flood units were significantly higher than all other geologic units, with the exception of Holocene alluvium of the Willamette River. The geologic unit with the lowest mean nitrate rank was the Missoula Flood deposits.

### *Survey Results*

The response rate for the survey was 51 percent ( $n = 102$ ). Response rates were comparable for participants in each category: low ( $< 3$  mg/l) (49 percent); medium (3-10 mg/l) (54 percent); and high nitrate-N ( $> 10$  mg/l) (47 percent). The mean age of the participants was 61, with a range of 24 to 86 years. Among the population, 31 percent were more than 70 years old, while those younger than 35 comprised only 3 percent of the participants. Those in the age category of 20 to 35 years, who were most likely to have young children, did not have wells that were classified in the high nitrate-N category ( $> 10$  mg/l). Participants in the age category 51 to 65 were more likely to

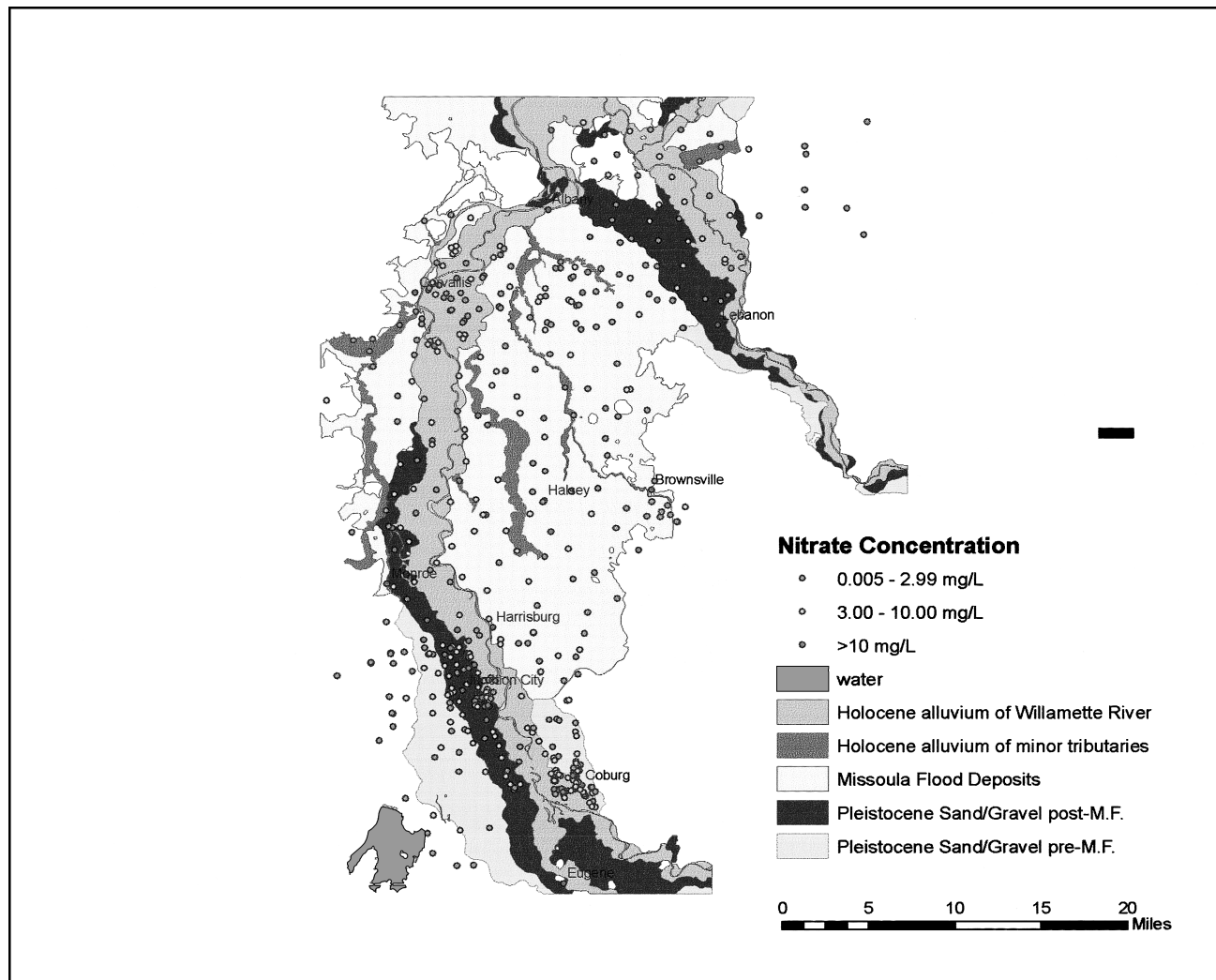


Figure 2. Spatial Distribution of Nitrate-N Concentrations in Relation to Geologic Units in the Southern Willamette Valley. (The five geologic units represented here contain 90 percent of the study's households.)

have medium and high nitrate-N concentrations in their well water. The mean length of residence for participants was 40 years, with 91 percent having lived in the area for 10 years or longer. Most of the participants, 86 percent, owned residential property. Additionally, 53 percent of the participants reported owning agricultural land.

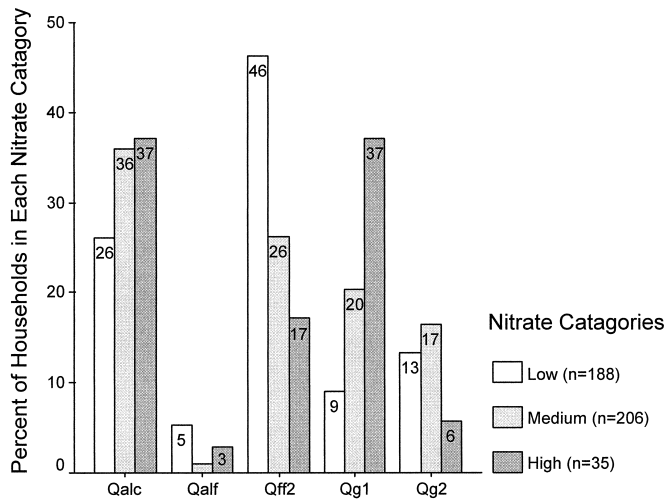
The source of drinking water for 89 percent of the participants was water from their domestic wells; 6 percent reported drinking exclusively bottled water; and 4 percent had drinking water delivered to their homes from another source. One household received local city water service, installed after the 2000-2001 test results were shared.

#### *Participant Concerns About Water Quality*

Participants were asked to comment on the quality of their drinking water, and 69 percent reported that they believed the quality of their well water was either "good" or "excellent." An analysis of variance test sought to determine if there was a difference between mean nitrate contamination levels and the response variables (excellent, good, fair, and poor). No significant differences were found.

Participants were also asked to gauge their concerns about agricultural fertilizer use adversely affecting their well water quality; 55 percent of the participants either "strongly agreed" or "agreed" with the statement "I am concerned that agricultural fertilizer use in the Southern Willamette Valley will increase the level of nitrate in my home's well water"

(Table 1). Differences between mean nitrate-N concentrations and the response variables (strongly agree, agree, disagree, strongly disagree, and not sure) were statistically significant,  $F(4, 97) = 2.97$ ,  $p < 0.02$ . A *post hoc* Tukey HSD test indicated that the mean nitrate-N concentrations for those who responded “strongly agree” ( $M = 8.1$ ,  $SD = 5.3$ ) was greater than the mean for those who responded “agree” ( $M = 4.4$ ,  $SD = 3.9$ ) and greater than the mean for those who responded “not sure” ( $M = 3.9$ ,  $SD = 3.1$ ). Another 19 percent were not sure if agricultural fertilizers were adversely affecting their well water quality.



Geologic Type Associated with Nitrate Category of Households

Figure 3. Households Within Geologic Units in Relation to Nitrate-N Concentrations ( $n = 429$ ). Note:  $Q_{alc}$  (holocene alluvium of the Willamette River);  $Q_{alf}$  (holocene alluvium of minor tributaries);  $Q_{ff2}$  (Missoula Flood deposits);  $Q_{g1}$  (pleistocene sand and gravel post-Missoula Flood); and  $Q_{g2}$  (pleistocene sand and gravel pre-Missoula Flood) (O'Connor *et al.*, 2001).

The same question of concern over agricultural fertilizer use having harmful effects on well water was cross tabulated with ownership of agricultural property and analyzed using a chi-square test of independence (Table 1). Possible responses were collapsed into the categories “agree” or “disagree,” and the response “not sure” was excluded from the analysis. This was done prior to analysis because the chi-square statistic is sensitive to sample size. Thus, when samples are very small, these differences can be hidden, and statisticians consider collapsing categories to reexamine data using larger cell frequencies when the combinations of categories are theoretically reasonable and meaningful (Portney and Watkins,

1993). Participants who did not own agricultural property were more likely to agree with the statement “I am concerned that agricultural fertilizer use in the Southern Willamette Valley will increase the level of nitrates in my well water” than were participants who owned agricultural property:  $\chi^2(1, n = 81) = 14.91$ ,  $p < 0.01$ . For a more detailed portrayal of how the responses (not collapsed) were distributed among those who did and did not own agricultural property see Figure 4.

Following up on the previous question about participants’ concern over agricultural fertilizer, participants were asked their opinion on how well certain types of landowners were managing their land in the Southern Willamette Valley to ensure good water quality. First, two questions were asked: “How well are farmers managing their land in the Southern Willamette Valley to ensure good water quality?” and “How well are private residents managing their land in the Southern Willamette Valley to ensure good water quality?” In response to the first question, 50 percent of the participants reported either good or excellent management by farmers to ensure good water quality, and 25 percent reported fair management. In contrast, 27 percent of participants responded that private residents are managing their land well to ensure good water quality, and 41 percent reported fair management by private residents. Further, 15 to 18 percent of participants indicated that they were not sure about the quality of management practices by farmers or private residents (Table 1). In addition, participants who said farmers were doing an unfavorable job in managing their land to ensure good water quality were more likely than expected to “strongly agree” with concerns over agricultural fertilizer use having a harmful impact on well water quality:  $\chi^2(4, n = 84) = 24.39$ ,  $p < 0.01$ , and vice versa.

Participants were asked to indicate what regulatory actions should be used and to indicate other actions that homeowners and landowners might take if ground water contamination exists. The vast majority (73 percent) of participants agreed that regulatory actions should be used to protect the ground water quality in the Southern Willamette Valley (Table 1). However, participants who did not own farmland were more likely than farmland owners to agree to the use of regulatory actions, and participants who owned farmland were more likely than those who did not own farmland to disagree with the use of regulations:  $\chi^2(4, n = 98) = 6.08$ ,  $p < 0.02$  (Figure 5).

To determine what actions participants would deem to be reasonable if there was a finding that the ground water in the Southern Willamette Valley had been affected, participants were provided a menu of actions and asked to respond to each action. The action elucidating the most support (77 percent) was

TABLE 1. Participants' Responses Regarding Well Water Quality and Management of Water Quality.

Survey Statement	N	Percent Agree <sup>a</sup>	Percent Disagree <sup>a</sup>	Percent Not Sure	$\chi^2$ Statistic	
If ground water contamination exists, regulatory actions should be used to protect the ground water quality in the Southern Willamette Valley.	99	73	15	12	$\chi^2 = 6.08^{a,b}$ ( $p < 0.02$ )	
I am concerned that agricultural fertilizer use in the Southern Willamette Valley will increase nitrate levels in my home's well water.	102	55	26	19	$\chi^2 = 14.91^{a,c}$ ( $p < 0.01$ )	
	N	Percent More Research	Percent Status Quo	Percent Undecided	$\chi^2$ Statistic	
Are you in favor of more research into techniques that may reduce the levels of agrichemicals, or do you believe current agricultural techniques are adequate?	101	54	21	25	$\chi^2 = 6.29^d$ ( $p < 0.05$ )	
	N	Percent Poor	Percent Fair	Percent Good	Percent Excellent	Percent Not Sure
How well are farmers managing their land in the Southern Willamette Valley to ensure good water quality?	99	10	25	38	12	15
How well are private residents managing their land in the Southern Willamette Valley to ensure good water quality?	100	14	41	24	3	18

<sup>a</sup>Participants' responses for "strongly agree and "agree" were condensed to "agree." Responses for "strongly disagree" and "disagree" were condensed to "disagree." "Not sure" responses were excluded from the analysis.

<sup>b</sup>Cross tabulation between regulatory actions to protect ground water quality and ownership of agricultural land.

<sup>c</sup>Cross tabulation between concern over agricultural fertilizer use negatively impacting well water and ownership of agricultural land.

<sup>d</sup>Cross tabulation between in favor of research and ownership of agricultural land.

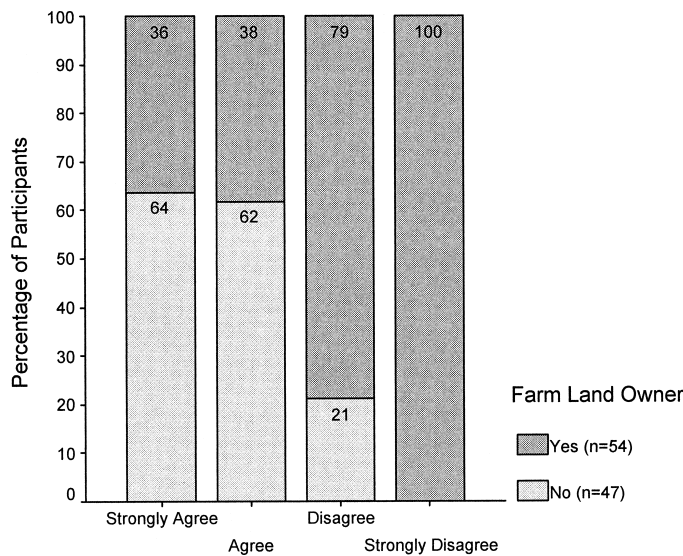


Figure 4. Responses to Statement, "I am concerned that agricultural fertilizer use in the Southern Willamette Valley will increase nitrate levels in my home's well water."

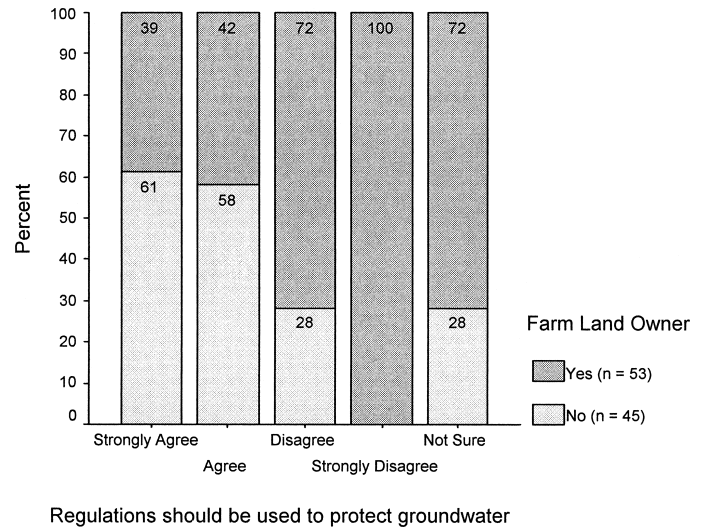


Figure 5. Responses to Statement "If ground water contamination exists, regulatory actions should be used to protect the ground water quality in the Southern Willamette Valley."

to implement best management plans for agricultural fertilizer use. Asking local and state government representatives for assistance in cleaning up the ground water received the least support (45 percent). Other actions, including using less fertilizer, testing wells, and testing soil, were well supported (Table 2).

To further elucidate what activities residents would support to reduce contamination, participants were asked if they favored research into techniques that may reduce the levels of agrichemicals. Although 54 percent favored more research, almost equal proportions of participants supported the status quo (21 percent) or were undecided on this matter (25 percent). Further, participants who were farm landowners were more likely than participants who were not farm landowners to support more research in this area:  $\chi^2(4, n=101) = 6.29, p < 0.05$ .

## DISCUSSION

The mean nitrate-N concentration for 476 wells sampled in the Southern Willamette Valley during 2000-2001 was 4.0 mg/l, with a range from less than 0.05 to 22.60 mg/l. Nitrate-N concentrations exceeded the MCL in 7.4 percent of these samples, increasing to 9 percent in wells less than 75 feet deep. This result is comparable to the results of a study conducted in the Willamette Basin in 1993 that found 9 percent of wells less than 25 m (82 ft) deep to exceed 10 mg/l (Hinkle, 1997). It is also comparable to results of a nationwide study in the mid-1990s in which rural wells were sampled throughout the U.S.,

and 11 percent of the 1242 nitrate-N samples were found to exceed 10 mg/l (Squillace *et al.*, 2002). The results are in contrast to those in Iowa in which an average of 18.3 percent of statewide samples exceeded the nitrate-N MCL, and in wells less than 45 feet deep this percentage increased to 35 percent (Kross *et al.*, 1993).

In contrast to the 2000-2001 sampling period, the mean nitrate-N concentration for the 87 wells sampled in 2002 was 10.8 mg/l, with 48 percent exceeding the MCL. Moreover, there was evidence of increasing nitrate-N concentrations in specific areas, with 74 percent of the households common to both studies experiencing increases from the first sampling period. Variation in these findings may be the result of resampling wells with higher overall nitrate-N concentrations during the 2002 sampling period. More likely, however, is that variability in the samples over this short time frame is an artifact associated with sampling variability (e.g., variability in well use in different seasons, analytical variability) rather than an indicator of variability in the aquifer as a result of land use practices. This is because short term land surface conditions (e.g., fertilizer application, irrigation fluxes) cannot be observed in well water samples, and ground water does not respond quickly to changes at land surface. Rather, local measurements of nitrate contamination are the result of the interactive effects of agricultural practices, ground water residence times, and local geologic features changing agricultural the ground water nitrate contamination (Bohlke and Denver, 1995). Hence, repairing the contaminated aquifer will be a long term undertaking.

TABLE 2. Participants' Responses Regarding Reasonable Actions for Homeowners/Landowners to Take When Ground Water Is Impacted.

Survey Statement	N	Percent Yes	Percent No	Percent Undecided
If there is a finding that the groundwater in the Southern Willamette Valley has been impacted by residential and/or agricultural land uses, which of the following do you think are reasonable actions for homeowners/landowners to take?				
a. Test well water on an annual basis?	100	67	18	15
b. Use less fertilizer on lawn or gardens?	98	57	15	28
c. Test soil to determine appropriate fertilizer application rates	100	67	10	23
d. Implement best management plans for agricultural fertilizer use?	100	77	7	16
e. Ask local and state government representatives for assistance in helping clean up the ground water?	99	45	23	31



The results from this study, in addition to the previous sampling data collected in 2000-2001, contributed to the recent declaration of the Groundwater Management Area for the Southern Willamette Valley (ODEQ, 2003), which cited "widespread nitrate contamination at levels greater than 7 mg/l in some areas of the Southern Willamette Valley" (ODEQ, 2003). The contributions of specific sources of contamination are under continued investigation, with the recognition that nitrate contamination may originate from a number of point and nonpoint sources, including animal feedlot operations, fertilizers for lawns and golf courses, bulk fertilizer facilities, septic systems, agricultural amendments, natural soil nitrogen, and atmospheric deposition. Many factors influence regional and local variation in nitrate-N concentrations; these include precipitation, cumulative soil thickness at the well, soil textures in the area surrounding the well, depth of the well sampled, well construction, nitrate loading, poorly functioning septic systems near the well, ground water flow, and geology of the region (O'Connor *et al.*, 2001; Eldridge, 2003).

This population experiences exposure to relatively high nitrate-N concentrations through their drinking water, as well water is the main source of drinking water for most of the participants. The likelihood of methemoglobinemia, however, appears at present to be low because those exposed to nitrate-N concentrations above the MCL were 50 years of age or older. This risk may change in the future, as the Southern Willamette Valley is one of Oregon's fastest growing regions and the area depends on ground water for almost all of the drinking water (ODEQ, 2004). This poses a potential health risk for new homeowners with young children who will be drinking from wells in which nitrate-N concentrations currently exceed the MCL. Additionally, 91 percent of the participants have lived in this region for 10 years or more, and studies of long term exposure to nitrate-N in drinking water are still inconclusive as to what risk this poses. Moreover, very little is known about the additive and synergistic effects of exposures to typical (and multiple) chemical combinations, such as nitrate and pesticides, that are likely to be present in agricultural areas.

This study retrospectively assessed the relationship between nitrate 2000-2001 concentrations and the geologic unit in which households were located. Results of this study are in agreement with the suggested theoretical differences in permeability of the five main geologic units in the region (O'Connor *et al.*, 2001). The more permeable geologic units, Pleistocene sand and gravel post-Missoula Flood ( $Q_{g1}$ ) and Holocene alluvium of the Willamette River and its major tributaries ( $Q_{alc}$ ), were much more likely to have nitrate-N concentrations of at least 10 mg/l. The

Pleistocene sand and gravel was deposited during two separate periods, one before the Missoula Floods ( $Q_{g2}$ ) and one after ( $Q_{g1}$ ). These coarse grain proximal alluvial fan and braided stream deposits make up most of today's Willamette aquifer. How the ground water moves through this geologic unit, as well as all others, is primarily a function of clast size and how the sediments have been sorted. Of the two Pleistocene deposits, unit  $Q_{g1}$ , which was deposited after  $Q_{g2}$ , is generally the more permeable of the two because it has experienced less weathering and compaction (O'Connor *et al.*, 2001).

In comparison, the less permeable Missoula Flood deposits ( $Q_{ff2}$ ) were less likely to have wells with nitrate-N concentrations of 10 mg/l or more. Rather, this geologic unit had the largest percentage of wells with nitrate measurements between 0 and 3 mg/l. This deposit is composed of bedded clay, silt, and sand that cover the central Willamette Valley in as much as 35 m of fine grained sediment (Woodward *et al.*, 1998). Due to its fine grained sediment, it forms a poorly drained, low permeability hydrogeologic unit that acts as a leaky confining layer above the sand and gravel it overlays (Woodcock, 2002). Any precipitation or irrigation percolates through the top layers of soil but is slowed and held in large quantities for future discharge into surface waters and the Willamette aquifer. In addition, some precipitation and irrigation water will be lost to evapotranspiration (Woodcock, 2002). This finding of differences in permeability among these geologic features suggests a need for more targeted monitoring of well water in specific geologic regions and perhaps ground water quality management policies that account for regional variability. Because permeability is only one factor that may contribute to the occurrence of nitrate in ground water, it may also be useful to stratify by input of nutrients to the environment, which may be estimated from parameters such as fertilizer application, manure production and application, and septic system density.

This study provides information about residents' perceptions of potential sources of contamination and the influence these sources had on their well water quality. Understanding local stakeholders' perceptions is critical and strategic, as they provide input to the Groundwater Management Area (GWMA) Committee that is in the process of developing a ground water management plan for the area of concern in the Southern Willamette Valley. The management plan includes developing and implementing best management practices to lessen future ground water contamination and determining appropriate means to protect public health and the ground water resource (ODEQ, 2004). As an advisory board to the ODEQ (the lead agency), the GWMA Committee will review and

critique draft alternatives and prepare the final recommendations to be included in the Action Plan for the Groundwater Management Area. The committee ensures public involvement throughout the planning process and disseminates information about the GWMA Action Plan to all interested, affected, and/or concerned groups and citizens. ODEQ and other state agencies will consider recommendations from the GWMA Committee along with input from other members of the public during the review of the final Action Plan.

The majority of participants (55 percent) responded that agricultural fertilizers harmed well water quality. Those who “strongly agreed” with the statement were also those who had higher mean nitrate levels in their wells when compared to those who either “agreed” or were “not sure.” This suggests that individuals with the highest mean nitrate-N concentrations in their wells may be attributing nitrate contamination to agricultural fertilizers. On the other hand, those who disagreed (26 percent) with the statement had equally high mean nitrate-N concentrations in their wells, between 4.9 mg/l and 5.4 mg/l, suggesting that they attributed nitrate contamination to some other cause. Notably, almost one-fifth of the participants were not sure if fertilizers affected water quality. There were differences in opinions about the impact of fertilizers between residents who owned agricultural property and those who did not own agricultural property, with those who did not own agricultural property more likely to express concern over the harmful effect of fertilizers on their well water. Participants who owned agricultural property expressed more concern about the impact septic systems might have on water quality and were less concerned about the effects on water quality of agricultural fertilizer. These differences in opinion may be a source of conflict between farmers and other residents and will need to be acknowledged and discussed as the ground water management plan is developed and implemented.

The responses by 50 percent of the participants rating farmers’ land management as either good or excellent may be influenced by the fact that 53 percent of the participants were farm landowners who would likely respond positively about their own land management practices. The data, however, were not analyzed to determine if the positive responses were attributed to farmers or nonfarm residents, so it is not possible to confirm whether this is the case. The importance of this finding, however, is that participants have different opinions about how farmers and nonfarm residents are managing their respective lands, and that an opportunity exists for all stakeholders in the area to be educated about various land management practices that will protect the ground

water. As the Action Plan is developed and receives input from the citizen GWMA Committee, it may be helpful to share these perspectives and discuss practices by farmers that are viewed to be protective of ground water and, alternatively, to discuss practices by nonfarm residents that are viewed by the local stakeholders as contributing to ground water contamination. Both farmers and nonfarm residents are equally important resources in the development of the Action Plan, and a joint effort will be needed.

Participants were very supportive of a range of regulatory actions that might be used by homeowners or landowners to address contamination of ground water. Although there was less support for the use of regulations by participants who owned farmland, these findings should be of interest to the GWMA Committee, as these responses reflect support for specific actions to implement strategies. These actions include testing wells on an annual basis; using less fertilizer on lawns or gardens; testing soil to determine appropriate fertilizer application rates; and implementing best management plans for agricultural fertilizer use. Participating state and local agencies should take note that participants were much less supportive of asking local and state government for assistance in remediating ground water. Given that ODEQ is the lead agency, it may be important for state and local officials to continue to strengthen relationships with their various stakeholder constituencies and ensure involvement of the public throughout the GWMA planning process. In addition, given that nearly one-fourth of the participants were undecided as to several of the options, it appears that the ODEQ and the GWMA Committee have an important role in disseminating technical information to enable stakeholders to learn more about ground water contamination and the effectiveness of various options as they participate in the process.

Finally, there is considerable opportunity for education about the role of research in introducing techniques that may reduce levels of chemicals used in agriculture, as almost half of the participants (46 percent) were more supportive of the *status quo* or were undecided about the role of research. On the one hand, these findings may indicate that participants do not believe that reduction of chemicals is important. On the other hand, it may indicate that the participants are not aware that various agencies and organizations (including ODEQ, Oregon Department of Agriculture, OSU Extension Service, Oregon Water Resources Department, Oregon Department of Human Services) are continually engaged in research of alternative practices for farmers and nonfarm residents that could contribute to resolution of the problem.

### *Study Limitations*

We acknowledge limitations to this research and potential sources of bias that may have influenced the results. First, this study represents a judgment sample of household wells in an area chosen by the ODEQ where a nitrate contamination problem was known to exist. Although the locations of household wells in this study were spread over a broad spatial scale, the findings of the study are not generalizable beyond the study area.

In addition, the list of participants for the mailed survey was drawn from the households whose wells had been previously sampled by the ODEQ, primarily so that comparisons could be made between well water contaminant levels in the households and the perceptions of the sampled residents toward well water quality issues. Participants were advised of the well test results from the 2000-2001 sampling and were likely sensitized to the issues related to nitrates in ground water. Having this information about their well water may have influenced the manner in which they responded to the survey questions. We are not aware that an educational program was developed as a result of the earlier sampling, but it is quite possible that residents followed up the testing by becoming more educated about possible sources of nitrate contamination and developed opinions about the impact of certain practices that were queried in the survey, such as application of fertilizers, land management practices, and research. Further, we were only able to report attitudes and opinions from those who exhibited interest in the topic and were willing to respond to the survey. However, residents who were selected for the study and did not respond (48 percent) may have different opinions than those who completed and returned the surveys, contributing to a nonresponse bias. For example, we do not know if nonrespondents would have indicated the same high level of support for specific actions (e.g., implementing best management practices) or the high level of agreement related to the management of water quality (e.g., use of regulatory actions).

In addition, the survey was developed for the purpose of this study, and although it was pilot tested with a sample similar to that of the study population, the survey was not subjected to rigorous validity and reliability testing. Finally, participants may be influenced by current events or participants' tendencies to respond in a way that will convey a favorable impression of themselves, which will also introduce response bias.

### CONCLUSIONS

Nitrate-N concentrations were found to differ significantly between geologic units. Households located in areas where the Holocene alluvium of the Willamette River and the Pleistocene sand and gravel post-Missoula Flood deposits dominated the geologic structure showed higher concentrations of nitrate-N. It is recommended that future studies and continued monitoring of well water quality in the Southern Willamette Valley should stratify wells by geologic unit. It also may be useful to stratify by input of nutrients to the environment. Including these variables in a representative study of nitrate-N concentrations in the Southern Willamette Valley might elucidate predictor variables for contaminated well water. Due to high nitrate-N concentrations found in this study, monitoring of well water in specific geologic units is recommended.

Household nitrate-N concentrations in the 2002 sampling period were significantly higher than those in the 2000-2001 sampling period. The potential risk of methemoglobinemia with the population growth in the area warrants continued public education of the risks involved with drinking well water contaminated with nitrate-N at values above 10 mg/l.

Efforts should be made to inform the areas residents of the well water contamination problems, and advice should be given on how best to reduce exposure. Local health departments, medical offices (especially obstetricians-gynecologists and pediatricians), and extension offices in the area may be reliable sources of information for area residents not already engaged in the GWMA process. These resources could distribute fact sheets that describe areas of contamination, sources of contamination, general knowledge about areas of higher risk, best means to reduce exposure to contaminated well water, and recommendations explaining the importance of testing well water. Having this information may encourage area residents to become more involved in local community meetings on ground water management and help agencies to craft policies that are inclusive of the regional stakeholders.

We found differences in opinion between agricultural landowners and nonagricultural landowners with regard to the adverse effect that agricultural fertilizer may have on water quality in the Southern Willamette Valley. Both groups expressed some concern over ground water quality, but differences in opinion about sources of potential contamination were apparent. Agricultural landowners assigned less importance to agricultural sources of contamination than residents who did not own agricultural land. This difference may prove to be a future cause of

conflict when solutions to ground water contamination are proposed by state agencies, and as such, it should be openly acknowledged. Differing opinions about how farmers and nonfarm residents manage their respective properties to ensure good water quality offer an opportunity for all stakeholders in the area to learn about various land management practices that will protect the ground water.

Finally, the recent declaration of the Southern Willamette Valley as a Groundwater Management Area is recognition that measures must be taken to reduce contamination and restore ground water quality. More evidence on the source of nitrate might help to inform current perceptions about the influence of specific land use practices and may provide more incentive to change practices contributing to contamination. Participants were favorable toward the adoption of best management practices and other options. A number of strategies, however, will be needed to influence change, including economic incentives and disincentives, zoning and land use restrictions, and environmental regulations. It will also be important to advise residents that restoring a contaminated aquifer is a long term undertaking. ODEQ has been designated the lead agency to work with other state agencies and local stakeholders to develop an Action Plan, which will include the development and implementation of best management practices to address ground water contamination and protection. Public education, research, and demonstration projects will also be established to increase public awareness of ground water quality concerns and mobilize them to take actions leading to ground water protection and restoration of the water quality. The results of this study will be shared with all parties actively involved in this endeavor, including state government, local governments, residents, and other stakeholders.

#### ACKNOWLEDGMENTS

Thanks to Gail Glick Andrews at Oregon State University for assistance with the survey and for valuable insights throughout the study. We gratefully acknowledge Audrey Eldridge and Jack Arendt at the Oregon Department of Environmental Quality for the use of well water data and for the opportunity to work together on the data collection.

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