# Distribution of Elevated Nitrate Concentrations in Ground Water in Washington State

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## Abstract

Logistic regression was used to relate anthropogenic (manmade) and natural variables to the occurrence of elevated nitrate concentrations in ground water in Washington State. Variables that were analyzed included well depth, ground-water recharge rate, precipitation, population density, fertilizer application amounts, soil characteristics, hydrogeomorphic regions, and land-use types. Two models were developed: one with and one without the hydrogeomorphic regions variable. The variables in both models that best explained the occurrence of elevated nitrate concentrations (defined as concentrations of nitrite plus nitrate as nitrogen greater than 2 milligrams per liter) were the percentage of agricultural land use in a 4-kilometer radius of a well, population density, precipitation, soil drainage class, and well depth. Based on the relations between these variables and measured nitrate concentrations, logistic regression models were developed to estimate the probability of nitrate concentrations in ground water exceeding 2 milligrams per liter. Maps of Washington State were produced that illustrate these estimated probabilities for wells drilled to 145 feet below land surface (median well depth) and the estimated depth to which wells would need to be drilled to have a 90-percent probability of drawing water with a nitrate concentration less than 2 milligrams per liter. Maps showing the estimated probability of elevated nitrate concentrations indicated that the agricultural regions are most at risk followed by urban areas. The estimated depths to which wells would need to be drilled to have a 90-percent probability of obtaining water with nitrate concentrations less than 2 milligrams per liter exceeded 1,000 feet in the agricultural regions; whereas, wells in urban areas generally would need to be drilled to depths in excess of 400 feet.


## Background

More than 60 percent of the population of Washington State uses ground water for their drinking and cooking needs. Nitrate concentrations in ground water are elevated in parts of the State as a result of various land-use practices, including fertilizer application, dairy operations and ranching, and septic-system use. Shallow wells generally are more vulnerable to nitrate contamination than deeper wells (Williamson and others, 1998; Ebbert and others, 2000).

In order to protect public health, the Washington State Department of Health requires that public water systems regularly measure nitrate in their wells. Public water systems serving more than 25 people collect water samples at least annually; systems serving from 2 to 14 people collect water samples at least every three years. Private well owners serving one residence may be required to sample when the well is first drilled, but are unregulated after that. As a result, limited information is available to citizens and public health officials about potential exposure to elevated nitrate concentrations for people whose primary drinking-water sources are private wells. The U.S. Geological Survey and Washington State Department of Health collaborated to examine water-quality data from public water systems and develop models that calculate the probability of detecting elevated nitrate concentrations in ground water. Maps were then developed to estimate ground water vulnerability to nitrate in areas where limited data are available.

## Where is ground water most vulnerable in Washington State?

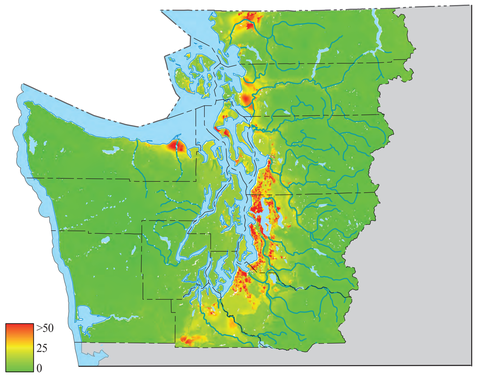
Shallow wells in areas with a high percentage of agricultural land use and (or) high population density are most likely to have elevated nitrate concentrations in the water. Maps showing the estimated probability of elevated nitrate concentrations indicate that the agricultural regions are most at risk followed by urban areas. Areas of the State that are not affected by agricultural or urban activities had much lower probabilities of detecting elevated nitrate concentrations.

Shallow wells (145 feet deep or less) in agricultural areas of eastern Washington have a greater than 90 percent probability of nitrate concentrations exceeding 2 milligrams per liter (mg/L) (areas in red on vulnerability map of Washington) and shallow wells in urban and agricultural areas of the Puget Sound area have a greater than 50 percent probability of nitrate concentrations exceeding 2 mg/L (areas in red on map of Puget Sound). Nitrate concentrations at or greater than 2 mg/L generally are greater than naturally occurring levels and indicate human-related sources of nitrate such as fertilizer and sewage (Nolan and others, 1998).

## What is ground-water vulnerability?

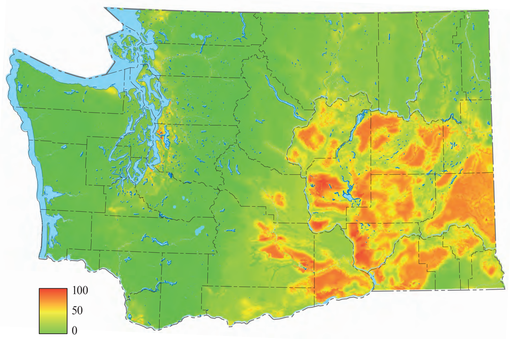
Ground-water vulnerability is an estimate of the potential for contamination of ground water to a compound, such as nitrate, based on human-related and natural factors. Ground-water vulnerability maps are designed to estimate the potential for contamination of ground water in an area based on human-related and natural factors.

Vulnerability map of Puget Sound for wells 145 feet deep




Probability that nitrate concentration will exceed 2 mg/L, in percent

Vulnerability map of Washington for wells 145 feet deep




Probability that nitrate concentration will exceed 2 mg/L, in percent

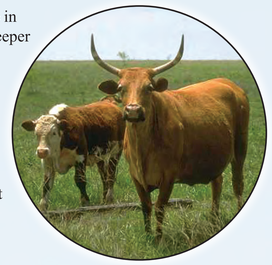
## Why is vulnerability of ground water to nitrate of concern?

Nitrate reduces the ability of red blood cells to carry oxygen. In most adults and children these red blood cells rapidly return to normal. In infants, however, it can take much longer for the blood cells to return to normal after exposure to nitrate. Infants who drink water with high levels of nitrate (or eat foods made with nitrate-contaminated water) may develop a serious health condition due to the lack of oxygen. This condition is called methemoglobinemia or "blue baby syndrome." Some studies have determined that an increased risk of spontaneous abortion or certain birth defects occur if the pregnant mother drank water high in nitrate. Other health risks include bladder and ovarian cancer and non-Hodgkins lymphoma (Centers for Disease Control and Prevention, 1996; Ward and others, 1996; Weyer and others, 2001; Fewtrell, 2004).

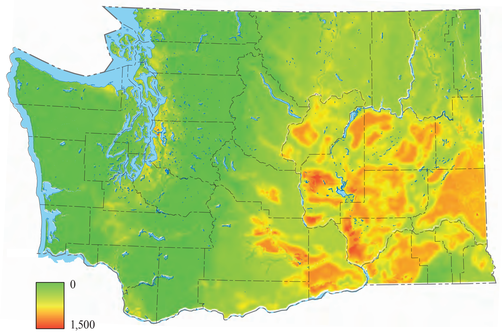
Once the concentration of nitrate in ground water increases, it cannot be easily reduced. In many cases, water systems must install costly treatment systems, and resort to bottled water while a treatment system is being designed and installed. Nitrate in a drinking water supply may indicate that the well is vulnerable to other sorts of contamination. When vulnerable areas can be located, the process of protecting water supplies from contamination can begin.

## Can having a deep well increase the probability of obtaining low nitrate ground water?

Yes. In areas with a high probability of nitrate in ground water greater than 2 mg/L, wells drilled deeper can increase the probability of obtaining water with low nitrate concentrations. For a 90-percent chance of obtaining low nitrate ground water, wells installed in the agricultural areas of eastern Washington generally would need to be drilled to a depth of at least 750 feet. Likewise, wells in the urban and agricultural areas of the Puget Lowlands would need to be drilled to a depth of at least 400 feet.



Map showing well depth needed to obtain ground water with a likely nitrate concentration less that 2 mg/L




Well depth, in feet

## How were the vulnerability maps created?

Using logistic regression, the occurrence of elevated nitrate concentrations (at or greater than 2 mg/L) in samples from public supply wells was related to natural and human-caused factors to assess ground-water vulnerability to nitrate. Data were from the Washington State Department of Health from 1995 through 2006. Significant factors were well depth, percentage of agricultural lands within a 4-kilometer radius of the well, population density near the well, average annual precipitation, and soil drainage class.

The maps were created using the logistic regression model and geographic information system (GIS) coverages of land use, soil characteristics, population density, and precipitation. Maps can be created to depict the probability of elevated nitrate concentrations for wells of any depth or to depict the necessary well depths to obtain a certain probability of having low nitrate water.

## How should these maps be used?

The vulnerability maps developed for this study illustrate the estimated probability of nitrate concentrations exceeding 2 mg/L in ground water in Washington. The vulnerability maps do not show actual nitrate contamination of ground water. They are intended for regional scale use only and have limitations for use at the field-scale. Many unaccounted for field-scale complexities affect the concentration of nitrate in ground water and in a given well. For example, the models do not account for point sources of nitrate or preferential pathways in the soil. Although a well may be installed in a region with an estimated high probability of elevated nitrate concentration, the well may actually yield water with low nitrate concentrations due to complexities that cannot be represented in regional-scale models such as those developed in this study.

## Summary

This study was designed to estimate the probability of detecting elevated nitrate in ground water in Washington State. Elevated nitrate concentrations can cause health risks in certain individuals. Vulnerability maps showing the estimated probability of detecting elevated nitrate concentrations indicate that agricultural regions are at most risk followed by urban regions. Areas of the State that are not affected by agricultural or urban areas had much lower probabilities of detecting elevated nitrate concentrations. Maps also were generated that show that for a 90-percent probability of obtaining water with nitrate concentrations less than 2 mg/L, wells would have to exceed 750 feet deep in agricultural regions. Wells in urban areas generally would need to be drilled in excess of 400 feet deep.

## References Cited


Centers for Disease Control and Prevention, 1996, Spontaneous abortions possibly related to ingestion of nitrate-contaminated well water, La Grange County, Indiana, 1991–1994: Morbidity and Mortality Weekly Report, v. 45, p. 569–572.

Ebbert, J.C., Embrey, S.S., Black, R.W., Tesoriero, A.J., and Haggland, A.L., 2000, Water quality in the Puget Sound Basin, Washington and British Columbia, 1996–98: U.S. Geological Survey Circular 1216, 31 p.

Fewtrell, Lorna, 2004, Drinking-water nitrate, methemoglobinemia, and global burden of disease—A discussion: Environmental Health Perspectives, v. 112, no. 14, p. 1371–1374.

Nolan, B.T., Ruddy, B.C., Hitt, K.J., and Helsel, D.R., 1998, A National look at nitrate contamination in ground water: Water Conditioning and Purification, v. 39, no. 12, p. 76–79.

Ward, M.H., Mark, S.D., Cantor, K.P., Weisenburger, D.D., Correa-Villase, Adolofo, and Zahm S.H., 1996, Drinking water nitrate and risk of non-Hodgkin's lymphoma: Epidemiology, v. 7, no. 5, p. 465–471.

Weyer, Peter, Cerhan, J.R., Kross, B.C., Hallberg, G.R., Kantamneni, Jiji, Breuer, George, Jones, M.P., Zheng, Wei, and Lynch, C.F., 2001, Municipal drinking water nitrate level and cancer risk in older women: The Iowa Women's Health Study, Epidemiology, v. 11, p. 327–338.

Williamson, A.K., Munn, M.D., Ryker, S.J., Wagner, R.J., Ebbert, J.C., and Vanderpool, A.M., 1998, Water quality in the central Columbia Plateau, Washington and Idaho, 1992–1995: U.S. Geological Survey Circular 1144, 35 p.



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