

# Nitrate Pollution in Groundwater: A Grower's Guide

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Photo by Harry MacCormick, Sunbow Farms

*Wheat harvest in the southern Willamette Valley. Many agricultural practices, including fertilization and irrigation, affect the level of nitrate in groundwater.*

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## An introduction to nitrates in groundwater

Nitrogen is a naturally occurring element that is essential for the life of plants and animals. Low levels of nitrogen (in the form of nitrate) are normal in groundwater and surface water. However, elevated nitrate caused by human activity is a pollutant in the water. Nitrate enters groundwater from many sources, including nitrogen-rich geologic deposits, wild-animal wastes, precipitation, septic system drainage, feedlot drainage, dairy and poultry production, municipal and industrial waste, and fertilizer (Follett, et al. 1991).

Although agriculture is not the only source of nitrate in groundwater, it has been identified as a major contributor in all of the Groundwater Management Areas (GWMA) declared by the Oregon Department of Environmental Quality (DEQ). Northeastern Malheur County was the first GWMA (1989), with the lower Umatilla Basin being the second (1990). In 2004, the southern Willamette Valley was declared a GWMA (Figure 1, page 2).

## Why are high levels of nitrate in groundwater a problem?

The U.S. Environmental Protection Agency (EPA) has set a maximum level of 10 parts per million (ppm) for nitrate in drinking water. Nitrate is believed to compromise the ability of the blood to carry oxygen to body tissues. This condition is commonly referred to as “blue baby syndrome,” but is technically known as methemoglobinemia. Little is known about the long-term effects of nitrate exposure.

We do know that the presence of elevated levels of nitrate in groundwater sometimes is directly connected to surface activities. The relationship between groundwater nitrate contamination and surface activities suggests that there is also a possibility for other contaminants, such as Dacthal and other pesticides, to reach the groundwater.

In addition to degradation of drinking water, high nitrate levels in groundwater can also negatively affect the health of streams and rivers. Many groundwater aquifers flow into surface-water streams, where they deliver their nitrate. This nitrate acts as a nitrogen fertilizer source in streams. Nitrogen in streams can lead to excessive aquatic plant and algal growth. This growth is part of a process called eutrophication, which occurs when water is over-enriched with nutrients. The resulting algal blooms block sunlight from penetrating the surface, thus contributing to oxygen-deficient waters. Low oxygen levels in the water create a degraded and eventually intolerable habitat for fish.

### How does nitrate from agriculture enter our groundwater?

Approximately 11.5 million tons of nitrogen fertilizer are applied to crops in the United States annually. In the Pacific Northwest, both commercial fertilizers and organic fertilizer sources such as manure are the largest non-point source of nitrate pollution in waterways (Puckett 2008).

Nitrate is very water-soluble. Once dissolved, it easily moves out of the area of application. Without careful and precise application and timing of nitrogen fertilizers, nitrate can leach through the soil into the groundwater. Over-irrigation increases nitrate leaching, reducing the efficiency of nitrogen fertilization and increasing the nitrate level in groundwater.

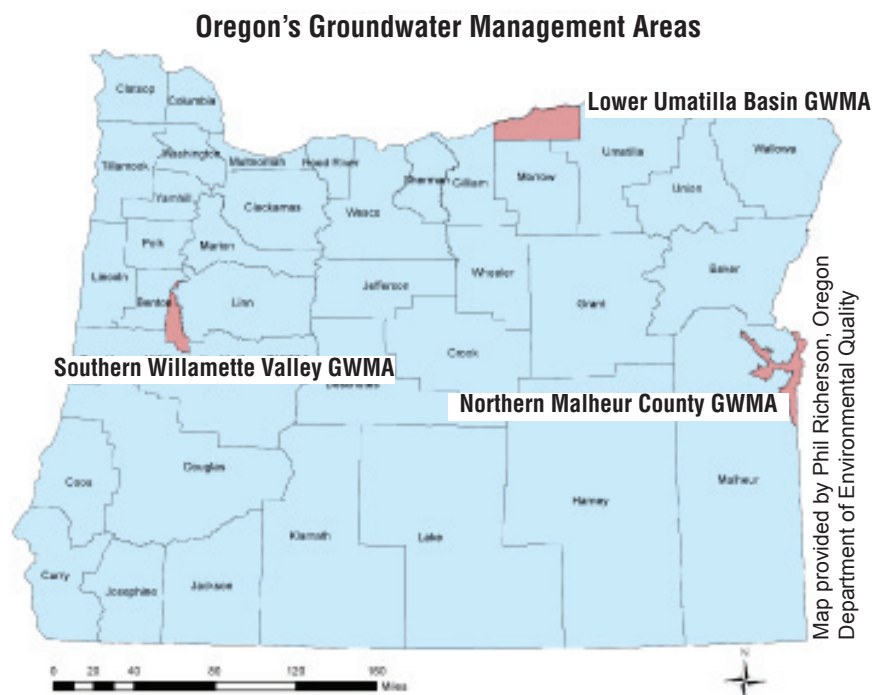


Figure 1. Groundwater Management Areas (GWMA) declared by the Oregon Department of Environmental Quality.

Nitrate leaching is more likely where shallow-rooted crops such as onions and potatoes are grown on coarse-textured soil. These crops require careful watering as they have difficulty reaching deep into the soil for nutrients leached below their shallow root zone.

### Nitrate levels in different basins

#### *Northern Malheur County*

In the early 1980s, most growers in northern Malheur County applied nitrogen fertilizer in excess of what crops could recover, sometimes up to double what the crop demanded. Excess nitrogen leached through the soil and into the groundwater. The aquifers in northern Malheur County have a residence time<sup>1</sup> for water that is shorter than that in other parts of the state.

<sup>1</sup>Residence time (also known as removal time or apparent age of water) is the average amount of time that a *particle* spends in the groundwater.

After the declaration of the GWMA in 1989 by DEQ, community members served on a citizens' committee that worked with DEQ to create a voluntary Action Plan to address groundwater nitrate. DEQ set a goal to decrease nitrate levels to below 7 ppm or to demonstrate changes in practices that would lead to lower groundwater nitrate (Richerson 2010).

Nitrate levels averaged about 17 ppm in 1991, but have decreased to about 12 ppm today due to cooperative efforts and implementation of best management practices. This decrease has occurred even while the amount of land used for onion cultivation has doubled over the past 30 years. The decrease in nitrate has been aided by the relatively short residence time of water in the aquifers in this region.

### ***Lower Umatilla Basin (LUB)***

As in Malheur County, a citizens' committee was assembled, and a voluntary Action Plan was implemented. Unlike Malheur County's success, however, nitrate levels in the LUB have not declined. The rate of increase has merely flattened, and nitrate levels across the GWMA are nearly stagnant. For example, many growers have reduced their nitrogen applications over the past decades, yet little progress has been seen in nitrate reduction in the groundwater.

There are many reasons for the lack of improvement as compared to Malheur County. The slow flow, complexity of the aquifer, reductions in irrigation, and lining of irrigation canals are just a few of the factors linked to static nitrate levels in the LUB. Greater aquifer complexity in the lower Umatilla makes monitoring difficult.

In the LUB, the age of groundwater varies from 3 years in some areas to more than 45 years in others. Some wells are not affected by management practices that occur in the immediate area of the well. However, better

irrigation practices and the lining of irrigation canals eliminate the water that can seep into the soil. This water can dilute and reduce the nitrate concentration in groundwater. Currently (2012) a second action plan is being developed with an unknown implementation date.

Nitrate in groundwater has had an impact on local communities as they drill new wells or plan for water treatment.

### ***Southern Willamette Valley***

This GWMA has an approved action plan, but it is too soon to know whether progress is being made.

### **What can I do?**

Local citizens, the OSU Experiment Station and Extension Service, state and federal agencies, growers' associations, and watershed councils continue to work together to reduce the amount of nitrogen applied, while simultaneously increasing or, at a minimum, maintaining yields. With careful planning and monitoring, nitrogen fertilizer and irrigation rates can be reduced, while sustaining crop yields and quality. These changes can save growers both time and money. Below are some specific ways you can reduce your contribution to nitrate pollution. Combining any of these methods will further lessen your nitrate outputs.

- Adjust nitrogen application rates
- Adjust nitrogen application timing
- Use tissue sampling and soil testing
- Utilize residual nitrogen
- Monitor soil moisture
- Optimize irrigation scheduling
- Change irrigation systems

### ***Adjust nitrogen application rates***

Agriculture is the largest consumer of nitrogen in all three GWMA's. Thus, a reduction in nitrogen fertilizer rates (N rate) must be considered as a way of reducing the amount of

nitrate reaching the groundwater. There are many ways to reduce the amount of fertilizer you apply while maintaining crop yield.

First, make sure your N rate is suitable for your crop, soil, and crop rotation. Excess nitrogen can be detrimental to a crop. Determine the N rate based on a monitoring program. Test the soil for nitrate-N and, in some situations, also test for ammonium-N before applying any nitrogen fertilizer; the closer the soil test is to the time of N application, the more meaningful the test is. The deeper the soil is sampled, the better; a minimum depth of 2 feet is recommended. Once the nitrate content of the soil is known, the quantity of nitrogen fertilizer needed can be better determined.

Precision placement equipment, such as sidedressers, along with timely fertigation, reduce your application rate by allowing you to apply nitrogen fertilizer near the plant row (Figure 2). In doing so, more nitrogen is recovered by the plant. Ultimately, less nitrogen is needed because less is lost. In contrast, broadcasting nitrogen fertilizer means that more N will be lost.

Drip irrigation further facilitates precision placement of small increments of nitrogen fertilizer during plant development (see “Change irrigation systems,” page 5). Poor nitrogen efficiency is closely associated with poor water use efficiency.

### ***Adjust nitrogen application timing***

Precise application timing will also reduce the amount of nitrogen fertilizer needed. Virtually no nitrogen is used by a plant during its early growth stages. Thus, applying nitrogen fertilizer in the fall or before planting in the spring will increase nitrate losses to leaching.

Precision placement equipment, on the other hand, allows for application after planting and throughout the season. Applying nitrogen during the growing season minimizes nitrogen loss by applying fertilizer closer to the time when the plant needs it. The more closely nitrogen application is matched to a crop’s use of nitrogen,



*Figure 2. A sidedresser used for precise placement of fertilizer next to rows.*

the more efficient the crop will be in utilizing it (Sullivan, et al. 2001). With experience, tissue and soil analysis can help you determine when the plant needs more nitrogen fertilizer and how much to apply.

### ***Use tissue sampling and soil testing***

Plant tissue analysis is a useful tool for determining nitrogen requirements during the growing season. The best indicator of a plant’s nitrogen supply is nitrate. Tissue sampling, in combination with soil testing, makes it possible to monitor nitrogen nutrition to maintain maximum yields while reducing nitrogen inputs. Tissue sampling results can alert you to nitrogen over-application as well as to the need for nitrogen, so you can adjust your application regime accordingly.

The plant part to sample depends on the crop. For potatoes (Lang, et al. 1999) and beets, sampling leaf petioles is the most accurate way to detect a nitrogen shortage. Appropriate nitrate-nitrogen content for potato petioles has been established for various times during the growing season. You can use these values to determine whether your crop has adequate nitrogen. For onions, roots are sampled for nitrate.

There are several standards for a post-season check on whether crops used nitrogen efficiently. For example, wheat protein is a good indicator of whether too much or too little nitrogen was

applied. Similar indicators exist for corn and other crops.

### *Utilize residual nitrogen*

Crop rotation is another practical way to reduce nitrogen fertilizer loss to the groundwater. Shallow-rooted plants (e.g., onions and potatoes) often leave nitrogen in the field after the growing season. This residual nitrogen is a combination of nitrogen that has moved below the shallow root zone and nitrogen from fragile crop residue that is rapidly mineralizing and becoming available for the next crop (Sullivan, et al. 2001).

This nitrogen can be retrieved if deep-rooted crops (e.g., corn, wheat, beets) are planted in the next growing season. Nitrogen fertilizer beyond the reach of a shallow-rooted crop can be recovered by a deeper rooted crop if neither rainfall nor irrigation is great enough to leach the nitrogen out of the deeper root zone and into groundwater.

### *Optimize irrigation scheduling*

Proper irrigation scheduling increases irrigation efficiency. To achieve greater efficiency, you must consider irrigation timing, the amount of water applied, the needs of the crop, and how much water the soil holds. Applying the correct amount of water will help you avoid the negative consequences of over-irrigating, including increased crop disease, surface runoff, leaching of nutrients into groundwater, and excessive power costs. Under-irrigating also negatively impacts yield and/or quality.

In the past, determining when and how much to irrigate was left largely to farmer intuition. Now, soil moisture sensors of various types can provide valuable information about when and how much to irrigate. Examples include Watermark soil moisture sensors (GMS, Model 200SS, Irrrometer Co., Riverside, CA), neutron probes, and real-time sensors such as Decagon soil moisture sensors (Pullman, WA).



Photo by Clint Shock

*Figure 3. Irrrometer Watermark Monitor used with Watermark Soil Moisture Sensors for irrigation scheduling in an onion field.*

Sensors vary in expense and ease of use, but all allow for precision irrigation, which can save water and improve crop quality (Figure 3). Growers can find irrigation prediction models for a variety of crops at IRZ Consulting (<http://www.irz.com/>) for the Columbia Basin and at AgriMet (<http://www.usbr.gov/pn/agrimet/>) for a variety of places in the Pacific Northwest, including the Treasure Valley.

### *Change irrigation systems*

There are three major types of irrigation systems used in Oregon's GWMA's: furrow, sprinkler, and drip. Sprinkler systems include center pivot, solid set, and handlines. Conversion from furrow to sprinkler or drip irrigation will result in water and nutrient savings. Furrow irrigation is assumed to be 40 to 50 percent efficient with water use, pivot irrigation is assumed to be 80 to 90 percent efficient, and drip irrigation is assumed to be 95 percent efficient. More efficient irrigation systems, when properly designed and managed, lose less water and fertilizer to both surface runoff and deep percolation. Suggestions for each irrigation method are summarized below.



Photo by Clint Shock

*Figure 4. View of furrow-irrigated Malheur County agriculture from atop the Malheur Butte.*

**Furrow** irrigation is the least efficient method of irrigation, with the most water lost to deep percolation and surface runoff (Figure 4). However, there are several ways to improve furrow irrigation efficiency.

Laser leveling of fields increases slope uniformity and lets water move evenly across the field. Fields that are not uniform in slope need more water so that plants in every corner of the field are irrigated. Meanwhile, some parts of the field are over-irrigated or have surface pooling of water, leading to deep percolation.

Using gated pipe instead of siphon tubes allows for more uniform application of water to each furrow, while conserving water. Adding a weed screen to gated pipe will prevent debris from clogging the system and will conserve water (Figure 5).

Scheduling irrigations so that the crop is not irrigated too frequently will increase furrow irrigation efficiency. Finally, the use of a polymer such as PAM will maintain furrow integrity and keep return flow water free from soil.

**Sprinkler** irrigation systems such as center pivots and side roll sprinklers or wheel lines are an alternative to furrow irrigation. These sprinkler systems have been widely adopted due to their ease of use. Most sprinkler systems allow



Photo by Clint Shock

*Figure 5. A weed screen used to filter irrigation water.*

for more even and controlled water application, which increases water efficiency in the field. When less water is applied, less water is lost to deep percolation. Nitrogen fertilizer can be carefully added into a sprinkler irrigation system. Regular nozzle maintenance or replacement, along with irrigation scheduling, are the most common ways to increase water efficiency with sprinkler systems.

**Drip** irrigation systems apply approximately 60 percent of the water a furrow irrigation system would use, making drip potentially the most water-efficient irrigation method. Drip works by applying the water directly to the root zone of the plant, so that very little, if any, water is lost to surface evaporation or deep percolation. In addition, often no surface runoff occurs.

While designing a drip system can be complicated, and installation can be costly, growers like drip because it improves product quality and uniformity, while decreasing overall water application. In many cases, the savings outweigh the initial costs of the system.

Acreage in the Treasure Valley watered by drip irrigation has continued to increase over the past 15 years, particularly among onion growers (Figure 6, page 7). Drip irrigation is not well suited to some of the very sandy soils located in some other regions.

## Summary

Water is an important resource, both for crop production and human health. We all have a responsibility to keep it as clean as possible. The judicious use of water and fertilizers will help ensure that our waters will improve in quality.

## Where can I learn more?

### Nitrate and drinking water

<http://www.deq.state.or.us/wq/pubs/factsheets/groundwater/nitratedw.pdf>

### Northern Malheur County Groundwater Management Area

<http://www.deq.state.or.us/wq/groundwater/nmcgwma.htm>

### Malheur County sustainable best management practices

<http://www.cropinfo.net/bestpractices/mainpagebmp.html>

### Irrigation criteria for row crops

<http://hortsci.ashspublications.org/cgi/reprint/46/2/178>

### Nitrogen management of potatoes

<http://potatoes.wsu.edu/research/images/lang.pdf>

## How can I get involved in community action plans?

A number of watershed councils, GWMA committees, and soil water conservation districts have evolved out of the citizens' action plans. Each of these groups conducts public forums and welcomes input from community members. Contact ODA, DEQ, and/or your local extension office or watershed council to find out when the next meeting is and to get and stay involved.

**To find your watershed council in Oregon, visit** <http://oregonwatersheds.org/oregoncouncils>



Photo by Clint Shock

Figure 6. Use of drip irrigation in a Malheur County onion field.

## References

- Follett, R.F., D.R. Keeney, and R.M. Cruse. 1991. Managing Nitrogen for Groundwater Quality and Farm Profitability. Soil Science Society of America, Inc.
- Lang, N.S., R.G. Stevens, R.E. Thornton, W.L. Pan, and S. Victory. 1999. Potato Nutrient Management for Central Washington. Washington State University Cooperative Extension, EB1871. 18 pp. <http://potatoes.wsu.edu/research/images/lang.pdf>
- Puckett, L.J. 2008. *Nonpoint and Point Sources of Nitrogen in Major Watersheds of the United States*. U.S. Geological Survey. Water Resources Investigations Report 94-4001.
- Richerson, P.M. 2010. *Third Northern Malheur County Groundwater Management Area Nitrate Trend Analysis Report*. DEQ Water Quality Division.
- Sullivan, D.M., B.D. Brown, C.C. Shock, D.A. Horneck, R.G. Stevens, G.Q. Pelter, and E.B.G. Feibert. 2001. Nutrient Management for Sweet Spanish Onions in the Pacific Northwest. Pacific Northwest Extension Publication PNW 546. 26 pp.

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