K·STATE Research and Extension

Nitrate and Groundwater

Nitrate is a common contaminant in groundwater. Groundwater with excessive nitrate contamination can have immediate and long-term health effects. Groundwater supplies about 50% of the drinking water in the United States. Almost all private water supplies are from wells or springs. This publication addresses the drinking water nitrate standard, water testing, nitrate sources, the reduction of nitrate contamination risk, and groundwater treatment methods.

Maximum Contaminant Level (MCL)

The maximum contaminant level (MCL) for nitrate in drinking water is 10 ppm or 10 mg/L nitrate-nitrogen (NO_3 - N). Long-term exposure at two to three times the MCL can produce an increase of methemoglobin, which may not show outwardly but causes stress that may be blamed on other causes. Pregnant women and people with health infirmities should be protected from high-nitrate sources. The long-term effect occurs when nitrate is more than twice the MCL. Nitrite is unstable in the environment so it rarely exists in groundwater in concentrations that are above the MCL.

Human Health Concern for Nitrate

The immediate health concern is the conversion of nitrate to nitrite in the digestive tract by nitrate-reducing bacteria. Nitrite is readily absorbed into the blood where it combines with the hemoglobin that carries oxygen and forms methemoglobin, which cannot carry oxygen. The resulting reduced oxygen supply to the body tissues produces physical stress. In infants, this condition is called methemoglobinemia, or blue baby syndrome, because of blue color around eyes and mouth.

Infants, human and animal, are the most susceptible to nitrate poisoning because bacteria that convert nitrate to nitrite are abundant in their digestive systems. By the time a child is 6 months old, the digestive system produces acid that prevents nitrate-reducing bacteria from thriving, and the risk is greatly reduced.

Animal Health and Nitrates

Animals respond similarly, but the digestive tract may mature more quickly. Older ruminant animals, such as sheep, cattle, and goats, have a different digestive system that allows nitrate-reducing bacteria to thrive. Horses have a large cecum where nitrate-reducing bacteria also thrive. High-nitrate effects on livestock include reduced conception rates, spontaneous abortions, reduced rate of gain, and poor performance in dairy cows including reduced milk production.

Importance of Water Testing

Water testing to measure nitrate levels is recommended because nitrates are tasteless, odorless, and colorless. A test for nitrate is recommended at least annually for all private water supplies for human and livestock use. If nitrate is suspected in drinking water, multiple samples, tested annually, are essential to ensure safe water. Water samples should be collected and submitted according to instructions from a certified laboratory. It is recommended that testing be performed by a KDHE certified laboratory. A list of labs can be found at *www.kdhe.ks.gov/1286/Environmental-Laboratory-Accreditation*

Laboratories certified for drinking water tests report nitrate-nitrogen (NO_3-N) levels. Feed analysis reports from some laboratories may include nitrate (NO_3) levels. There is a difference between the nitrate-nitrogen and nitrate levels. To convert NO_3 to NO_3-N, divide by 4.5. For example, 45 mg/L NO_3 is equivalent to 10 mg/L NO_3-N.

Extent of Nitrate in Groundwater

Nitrate, from both natural and human activities, is a common groundwater contaminant. Researchers agree that naturally occurring nitrate-nitrogen concentrations in groundwater seldom exceed 3 to 4 ppm. National surveys of well water by the EPA and United States Geological Survey (USGS) showed that 3% and 6% of wells, respectively, had nitrate concentrations exceeding the MCL.

While national data indicate that nitrate contamination of groundwater is not common to all areas, data collected in Iowa, Kansas, and Nebraska revealed localized areas where well water nitrate above the MCL is more common than it is nationally.

Sources of Nitrate

Understanding nitrate sources and how nitrate reaches groundwater requires knowledge of the nitrogen cycle and groundwater recharge. Worldwide, nitrogen is the plant nutrient most limiting for crop production. Since early times, people have added nitrogen to crops by using animal waste, human waste, legumes, or fertilizers.

Nitrogen is naturally part of the environment. The air we breathe is more than 78% nitrogen gas. Nitrogen accumulates in soil during the process of soil formation. Virgin prairie soils contain as much as 6,000 to 10,000 pounds per acre of organically bound nitrogen. Once these soils are tilled to grow crops, organic matter content begins to decrease. As organic matter is oxidized, nitrogen is released primarily as nitrate. Leaching is the downward movement of water with nitrate through the soil. If nitrate is not used by the growing crop, it is subject to leaching to groundwater.

Figure 1 shows that nitrogen enters the cycle from several sources. This cycle operates in both natural and cropland ecosystems. In most natural ecosystems, nitrogen is usually in short supply and nitrogen cycling is efficient, with low losses. In some ecosystems, however, nitrogen is abundant and loss potential is high, explaining why groundwater under some natural ecosystems can be high in nitrate.

In cropland agriculture, especially with irrigated land, greater nitrogen inputs are used for higher crop yields, efficiencies of nitrogen use are lower, and the potential for nitrogen losses to groundwater is greater. Nitrogen not removed through crop harvest can reach groundwater as nitrate.

Nitrogen sources. Animal manure, human wastes, compost, organic wastes, legume crops, and cover crops are organic sources of nitrogen. Before plants can use nitrogen, it must be converted to ammonium (NH_4) or nitrate (NO_3). A few nitrogen fertilizers are in the nitrate form, but most fertilizers are in the ammonium form.

Nitrate is soluble in water and moves with water through the soil profile. Ammonium is soluble in water, but is tightly absorbed on exchange sites in the soil. Ammonium nitrogen, regardless of initial source, is rapidly converted to nitrate by soil bacteria at soil temperatures above 50 degrees Fahrenheit. When nitrogen is added to the soil, either from organic or inorganic sources, it becomes a part of the nitrogen cycle. When total nitrogen inputs exceed the amount used by plants, nitrate accumulates in the soil and may be leached to groundwater.

Nitrogen is lost from the system by leaching, denitrification, volatilization, and immobilization. From the standpoint of groundwater quality, leaching is the only concern. The potential for nitrate leaching varies with soil type and rainfall or irrigation. Sandy soils under high rainfall or irrigation have high leaching potential. The downward movement of nitrate through soils was occurring before the presence of humans, so it is unrealistic to expect to eliminate this movement. Fertilizer application beyond crop requirements and poor management of any nitrogen source can increase the potential for nitrate leaching.

Groundwater recharge. Groundwater is water below the land surface that fills or saturates the spaces between rock and soil particles. The top of this saturated zone is called the water table. Although groundwater seems to be trapped in geologic formations, there is some movement. A saturated zone that holds sufficient water and allows enough movement to supply wells is called an aquifer.

The amount of water that enters the soil and eventually recharges the groundwater varies seasonally and with location. Most recharge occurs during wet years or wet seasons. During dry seasons, particularly with active plant growth or where water is pumped for irrigation, water tables may decline. In areas with porous soils, considerable recharge may occur each year, especially with high rainfall.

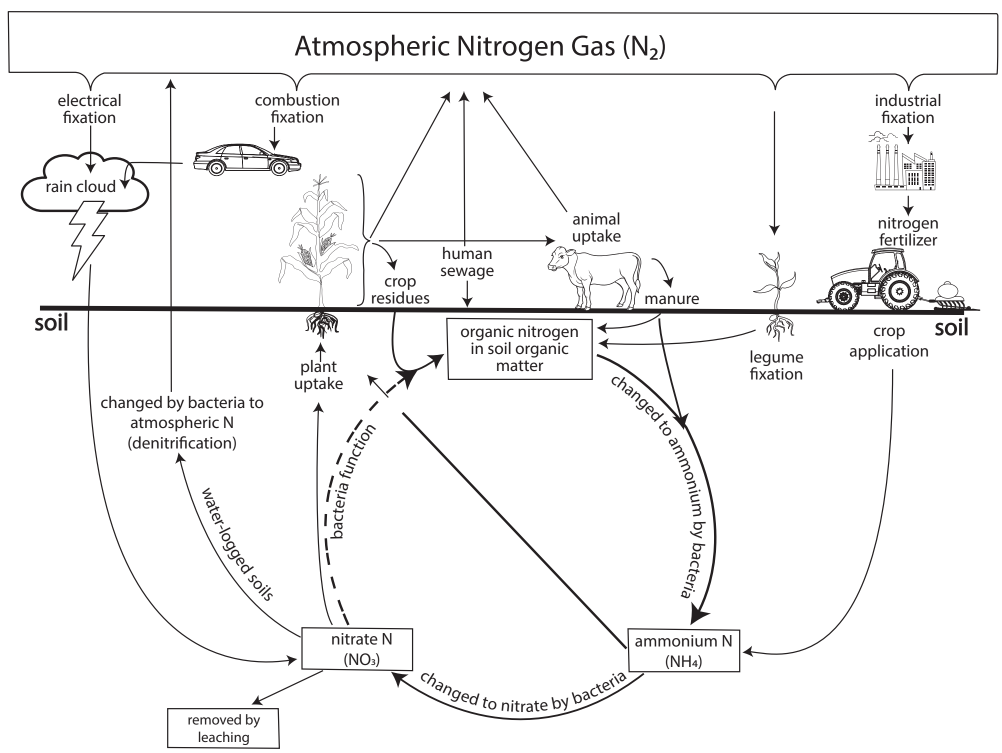

Figure 1. *The nitrogen cycle.* (*Fertilizers and Soil Amendments, 1981. Prentice-Hall, Inc. Adapted with permission.*)

In more arid regions, there may be many years where little or no recharge occurs, and water tables may be quite deep. Improvements or degradation of groundwater quality occur slowly over time, depending on the volume of groundwater recharge and degree of contamination.

Crop and livestock production and disposal of human wastes contribute the largest share nitrate in groundwater. These activities have resulted in increased rates of nitrate movement, including increasing nitrate losses to groundwater. Farmers, ranchers, communities, and homeowners should follow management practices that minimize the leaching of nitrate from soils and other sources.

Farmstead Management

Wells should not be located close to or downslope from nitrogen sources. Careful management of nitrogen sources within several hundred feet of the well is important. The risk of high-nitrate groundwater is minimized when sources of nitrogen, such as septic systems, fertilizer storage, livestock facilities, and silos, are more than 400 feet from the well.

Fertilizer Management

Spills should be cleaned immediately when storing or handling nitrogen fertilizer near a well. Equipment used for fertilizing should be cleaned in fields where fertilizer is applied, not near wells.

Livestock Facility Management

Confined livestock facilities may cause nitrate contamination of water wells and should be designed to convey feedlot and manure storage runoff away from the well. Feedlots should be cleaned regularly and wastes applied to cropland at agronomic rates. When feedlots are in continuous use, the soil develops a surface seal, minimizing downward percolation. Feedlots used intermittently or that have been abandoned often pose the most serious risk because the surface seal breaks down, allowing nitrate to leach to groundwater. To minimize nitrate leaching from abandoned or intermittently used feedlots, remove the accumulated organic waste, or plant and harvest crops on the soil.

Homesite Management

Onsite wastewater (septic) systems can potentially contribute nitrate. Wastewater systems are available to reduce nitrogen outflow, and research is ongoing to improve efficiency. Shallow systems with good perennial grass cover help utilize nitrogen and minimize losses to groundwater. Nitrogen fertilizer should not be applied over the septic absorption system area.

Lawns and gardens around a home can be a source of nitrogen if fertilizer applications are not carefully controlled. Fertilizer applications should be limited to lawn and garden requirements. Clippings left on the lawn recycle nitrogen to the soil. During dry conditions, grass should be watered only once or twice a week to encourage deep rooting and minimize percolation losses. Local K-State Research and Extension offices can offer information about collecting soil samples from farm and home landscapes, including the use of a soil probe.

Cropland Management

Nitrogen fertilizer, animal manure, and legume crops are essential to supply the nitrogen needed for crop growth. Careful nitrogen management minimizes the potential for groundwater contamination. Crop growers need to have realistic yield goals, to calculate fertilizer rate recommendations, especially for nitrogen. When more nitrogen is present in the soil than is removed by the crop, the excess may enter groundwater and wells. When planning nitrogen rates for a crop, consider all potential nitrogen sources. These include a previous legume crop, applied organic material, residual nitrate in the soil, and nitrogen in irrigation water. These sources contribute nitrogen to the crop.

A profile nitrogen test is recommended to determine the amount of nitrate in the soil. Research in Kansas has confirmed the value of residual nitrate in the soil profile to meet crop nitrogen requirements. Irrigation water should be analyzed to determine nitrate content. Fertilizer nitrogen rates should be reduced, giving credit for all nitrogen sources.

To arrive at an optimum nitrogen fertilizer rate, growers must consider the crop, productive capacity of the soil, and moisture availability. Timing of nitrogen fertilizer application is critical. On coarse-textured, highly permeable soils, split or side dress applications of nitrogen generally result in increased nitrogen efficiency and decreased losses because of the shorter time between application and crop uptake. On medium- and fine-textured soils, time of application is not as critical. Additionally, nitrification inhibitors used in conjunction with ammonium nitrogen fertilizer can reduce nitrate leaching on coarse-textured, sandy soils. The inhibitors temporarily inactivate the soil bacteria that convert ammonium to nitrate. As long as nitrogen is in the ammonium form, leaching is minimal.

A final point to consider is placement of nitrogen fertilizer. Research from Kansas State University indicates greater crop uptake with injection or deep incorporation (4 inches or more) of nitrogen fertilizers and manure or sewage sludge. Any management practice that results in more of the applied nitrogen being taken up by the crop lessens the potential for nitrate contamination of groundwater.

Drinking Water Treatment

Selecting a treatment option depends on quality and quantity of water to be treated, nitrate content, initial water quality, initial cost, operating cost, required management, and environmental impact.

There are three methods for removing nitrate from drinking water: distillation, reverse osmosis, and anion exchange. These processes vary greatly in cost, reliability, and operation requirements.

Distillation is suitable for small quantities of water (less than one gallon per day).

Reverse osmosis is used for large quantities of water (more than 1,000 gallons per day) and high-sulfate water.

Anion exchange operates similarly to ion exchange water softening. Negatively charged sulfate and nitrate ions are exchanged for chloride, and the exchange media is recharged by a high concentration of chloride in salt brine. When deciding whether to use anion exchange for nitrate removal, the environmental consequences of the salt must be considered. Salt, sodium, and chloride added to the environment may leach to groundwater and reach wells.

Summary

High-nitrate levels in water are a health concern. Excess nitrogen can be converted to nitrate, moves with water, and may reach groundwater. Nonagricultural and agricultural sources of nitrogen contribute to the total nitrate levels. All nitrate sources require careful management to minimize the risk for contamination of groundwater and private wells. Careful management of livestock lots and use of the proper rate of nitrogen are the most important factors, but other management practices also are important. Recommended practices that minimize the risk of contamination should be given careful and immediate attention.

Additional Information

K-State Research and Extension offices — *www.ksre.k-state.edu/about/statewide-locations/*

Local health departments — *www.kdhe.ks.gov/2085/Directories-Maps*

Local environmental offices or county sanitarian — *www.kdhe.ks.gov/BusinessDirectoryII.aspx?lngBusinessCategoryID=49*

Testing Private Water Systems (MF3655) — *bookstore.ksre.ksu.edu/download/MF3655*

Private Well Maintenance and Protection (MF3666) — *bookstore.ksre.ksu.edu/download/MF3666*

Private Wells — Safe Location — *bookstore.ksre.ksu.edu/download/MF3667*

Acknowledgments

Information in this publication was drawn from:

Lamond, R. E., G. M. Powell, & D. Devlin (1999). *Nitrate and Groundwater* (MF857). Kansas State University.

This project has received funding and support from K-State 105, Kansas State University's economic growth and advancement initiative for all 105 counties in Kansas. Learn more at *k-state.edu/105*.

Authors

Pat Murphy
Extension Engineer, Retired

Stacie Minson
Watershed Specialist

Joe Harner
Extension Engineer, Retired

Herschel George
Watershed Specialist, Retired

Dan Wells
Environmental Administrator
Kansas Department of Health and Environment

Melissa Harvey
Communications and Marketing Coordinator

K·STATE
Research and Extension

Kansas State University Agricultural Experiment Station and Cooperative Extension Service

K-State Research and Extension is an equal opportunity provider and employer. Issued in furtherance of Cooperative Extension Work, Acts of May 8 and June 30, 1914, in cooperation with the U.S. Department of Agriculture, Director of K-State Research and Extension, Kansas State University, County Extension Councils, Extension Districts.

MF857 October 2024