Nitrate and Groundwater

Protection of groundwater from nitrate contamination is an often overlooked health concern. About 40 public water supplies in Kansas have obtained an alternative water source, drilled new wells, installed treatment equipment, or are working on plans to meet the nitrate standard. Nitrate and nitrite can have both immediate and long-term health effects. Nitrate is a common contaminant in groundwater. Recent surveys in Kansas found 24 percent of private wells and 28 percent of farmstead wells above the nitrate standard. Iowa and Nebraska studies also report high nitrate in wells with similar frequency.

Groundwater supplies about 50 percent of the drinking water in the United States, and also in Kansas. Almost all private water supplies are groundwater from wells or springs. This publication addresses the drinking water nitrate standard, water testing, nitrate sources, reducing nitrate contamination risk, groundwater clean up, and treatment methods.

Health Concern for Nitrate

The immediate health concern is the reduction (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. It forms methemoglobin, which cannot carry oxygen. The reduced oxygen supply to the body tissues produces physical stress. When severe enough, nitrate poisoning is life threatening because of suffocation. This condition is called methemoglobinemia, or blue baby syndrome, in infants 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. Animals respond similarly, but the digestive tract may mature more quickly.

Ruminant animals, (such as sheep, cattle, and goats) have a somewhat different digestive system that allows nitrate-reducing bacteria to thrive in adults. Horses have a large cecum where this bacteria also thrives. Thus, adult cattle, sheep, goats and horses are more susceptible to nitrate poisoning than people or other animals.

When nitrate is ingested in water and feed and not converted to nitrite, it is absorbed and excreted in the urine. Healthy people can consume much higher concentrations than the nitrate standard or **maximum contaminant level (MCL)** with little short-term effect. The MCL for nitrate is 10 ppm or 10 mg/L nitrate-nitrogen (NO_3-N). Long-term exposure at two to three times the MCL can produce a few percent methemoglobin, which may not show outwardly but causes stress that may be blamed on other causes. Effects on livestock can include reduced conception rates, spontaneous abortions, reduced rate of gain, generally poor performance in dairy cows including reduced milk production. Pregnant women, those with health infirmities and pregnant or breeding animals should be protected from high nitrate sources.

The long-term effect occurs when nitrate is more than twice the MCL. Possible cancer and other effects are suspected and are being researched.

When nitrite is present in water, it is readily absorbed and attached to hemoglobin acting directly. However, nitrite is unstable in the environment so it rarely exists in groundwater in concentrations that are above the MCL. More information about health effects of nitrate and nitrite for people and animals is found in K-State Research and Extension publication *Understanding Your Water Test Report*, MF-912.

Importance of Water Testing

Testing is the only way to detect nitrate because it is tasteless, odorless, and colorless. A nitrate and bacteria test is recommended at least annually for all private water supplies for human and livestock use. If nitrate is suspected in drinking water or if water supplies are susceptible to nitrate contamination, multiple sampling and testing annually are essential to ensure safe water. Choose a laboratory certified for nitrate from the K-State Research and Extension publication *Testing to Help Ensure Safe Drinking Water*, MF-951.

Laboratories certified for drinking water tests report nitrate-nitrogen (NO_3-N). Some laboratories doing feed analysis report nitrate (NO_3). There is a major difference between the nitrate-nitrogen and nitrate scales. 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 State Geological Survey (USGS) showed that only about 3 and 6 percent of wells respectively had nitrate concentrations exceeding the MCL.

While national data indicate that nitrate contamination of groundwater is not widespread, it is an increasing concern in the Midwest, especially in Kansas and adjacent states. Data collected in Iowa, Kansas, and Nebraska showed localized areas where wellwater nitrate above the MCL is many times more common than nationally.

Sources of Nitrate in Groundwater

Understanding nitrate sources and how it reaches groundwater requires knowledge of the nitrogen cycle and groundwater recharge.

The nitrogen cycle. Worldwide, nitrogen is the plant nutrient most limiting for crop production. Since early times, people have sought to add nitrogen to crops by using animal waste, human wastes, legumes or fertilizers.

Nitrogen is naturally part of the environment. The air we breathe is more than 78 percent nitrogen gas (N_2). 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. If not used by the growing crop, it is subject to leaching to groundwater.

The illustration in 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 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 and green manure 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 more commonly fertilizers are in the ammonium form, initially.

Nitrate is soluble in water and easily 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 (Figure 1). From the standpoint of groundwater quality, leaching is the only concern. Other loss mechanisms contribute to low nitrogen efficiencies, but not directly to groundwater contamination.

Leaching is the downward movement of water with nitrate through the soil. The potential for nitrate leaching varies with soil type and rainfall or irrigation. Sandy soils under high rainfall or irrigation have high leaching potential.

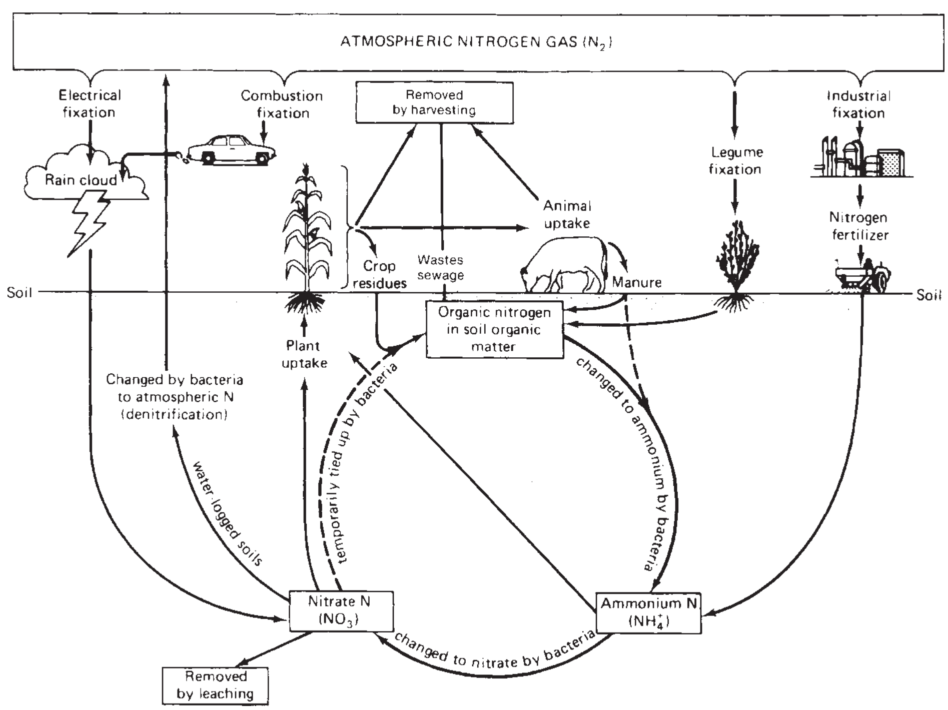

***Figure 1.** The nitrogen cycle.*
From: Fertilizers and Soil Amendments. *Roy H. Follett, Larry S. Murphy, and Roy L. Donahue. ©1981 by Prentice-Hall, Inc. Adapted and used with permission.*

Because the downward movement of nitrate through soils was occurring before the presence of humans, its unrealistic to expect to stop or eliminate this movement. However, over-application of fertilizer and poor management of any nitrogen source can increase the potential for nitrate leaching.

Groundwater recharge. Groundwater is water below the land surface that totally fills or saturates the spaces between 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, when water tables rise and shallow or perched water tables may develop. 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. 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 groundwater recharge and contamination.

This brief discussion of the nitrogen cycle and groundwater recharge shows that nitrate contamination of groundwater is complex. Of the human activities that contribute nitrate to groundwater, crop production, livestock facilities, and disposal of society's wastes produce the largest share. Our activities have resulted in increased rates of nitrate movement, including increasing nitrate losses to groundwater. Farmers, homeowners, and others should follow management practices that minimize the leaching of nitrate from soils or other sources.

Reducing Nitrate Contamination Risks

Analysis of data from the farmstead well study shows that when sources of nitrogen such as septic systems; fertilizer storage, handling, and cleanup; livestock facilities; and silos were more than 400 feet from the well, the risk of high nitrate was minimized. Thus, wells should not be located close to or downslope from these or any other sources where high nitrogen may be possible.

Careful management of nitrogen sources within several hundred feet of the well is important. When nitrogen fertilizer is stored, handled, or equipment is cleaned near the well, any spill should be cleaned up immediately. Equipment used for fertilizing should be cleaned in fields where fertilizer is applied. One pound of nitrogen can contaminate 12,000 gallons of water to the level of the drinking water standard for nitrate.

Livestock facilities may pose the greatest risk for nitrate contamination and must be designed to convey runoff away from the well. Lots must be cleaned regularly and wastes applied to cropland at agronomic rates. When lots are in continuous use, the soil develops a surface seal, minimizing downward percolation.

Livestock lots used intermittently or that have been abandoned often pose the most serious risk because the surface seal soon breaks down, allowing nitrate to leach to groundwater. Removal of accumulated organic waste and planting and harvesting crops in abandoned and intermittently used lots is essential to minimize nitrate leaching.

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

Large lawn and garden areas surrounding the home can be an important source if nitrogen fertilizer applications are not carefully controlled. Fertilizer applications should be no more than required by a lawn or garden. Remember, clippings left on the lawn recycle nitrogen to the soil. Grass should be watered only once or twice a week to encourage deep rooting and minimize percolation losses.

Farm•A•Syst: Farmstead Assessment System EP-33 through 48 available from the K-State Department of Biological and Agricultural Engineering, and the K-State Research and Extension publication *Managing the Farmstead to Minimize Groundwater and Well Contamination*, MF-948 provide additional information on managing potential nitrate sources around your farmstead or home site.

Nitrogen fertilizer, animal and human wastes, and legume crops are essential to supply the nitrogen needed for crop growth. Careful nitrogen management minimizes the potential for groundwater contamination. Growers need to have realistic yield goals, the basis of fertilizer rate recommendations, especially for nitrogen. Setting unrealistically high yield goals results in over-fertilization and a greater nitrate carryover. When more nitrogen is present in the soil than is removed by the crop, the excess may be lost to groundwater and reach wells.

When planning nitrogen rates for a crop, it is important to consider all potential nitrogen sources. These include previous legume crop, applied organic material, residual nitrate in the soil, and nitrogen in irrigation water. All of these sources contribute to the total nitrogen needs of a 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 in meeting crop nitrogen requirements. Irrigation water should be analyzed to determine nitrate content. Fertilizer nitrogen rates should be reduced, giving credit for all nitrogen sources. Finally, 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 sidedress 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 reduce nitrate leaching on coarse-textured, sandy soils. These 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. Recent research 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.

Groundwater Cleanup

It is possible to correct a high nitrate problem once it exists, but it can be time-consuming and expensive. Cleanup costing several times as much as protection points out the importance of careful management to protect groundwater quality. The best option is to avoid excess nitrate in the soil by profile nitrogen testing and accounting for all nitrogen sources.

Treatment To Remove Nitrate

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. For details see K-State Research and Extension bulletins *Distillation*, MF-885, and *Reverse Osmosis*, MF-884.

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. Anion exchange has lower operating cost than other methods and is well suited for large quantities of water with low sulfate. With high sulfate water nitrate selective exchange media is essential. When iron levels are elevated, treatment to reduce iron may be required to prevent fouling of the exchange media. 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.

Choosing 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. Distillation seems favorable for small quantities of water (less than one gallon per day); reverse osmosis seems more favorable for large quantities of water (more than 1,000 gallons per day) and high-sulfate water.

Summary

High nitrate levels in water are a health concern. Excess nitrogen is readily converted to nitrate, moves with water, and may reach groundwater. Nonagricultural and agricultural sources of nitrogen contribute to the total. All sources require careful management to minimize the risk for contamination of groundwater. 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.

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