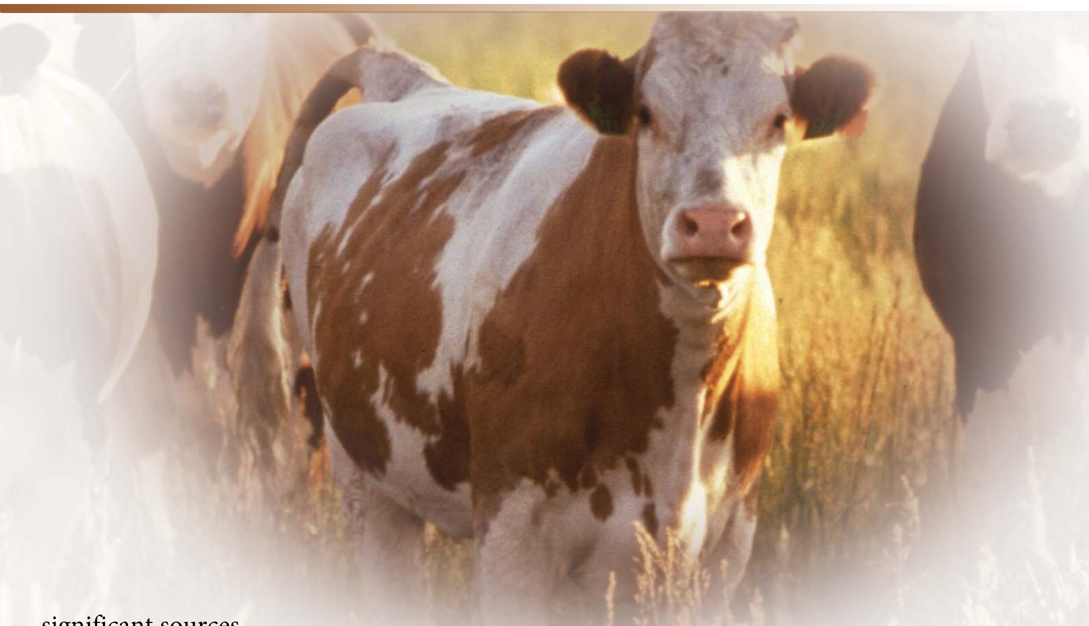

Nitrates in Southwest Groundwater

Michael R. Rosen – Nevada Water Science Center, USGS and Christian Kropf – Dept. of Water Resources, Washoe County, Nevada

One of the most common contaminants found in groundwater worldwide is nitrate (NO_3^-), the oxidized form of dissolved nitrogen. Accumulating from both natural and anthropogenic sources, nitrate in low concentrations is a necessary nutrient for plants, but at high concentrations can impact human health and wreak havoc on ecosystems (see sidebar, top right). Nitrate is highly soluble, thus it is readily leached from soils and is mobile in groundwater. In the Southwest, nitrate contamination issues are compounded by low precipitation, high evapotranspiration, and resultant low recharge that would otherwise dilute subsurface nitrate.

Sources

Natural sources: The atmosphere is 78 percent nitrogen gas. The natural process of fixation transforms inert atmospheric nitrogen into bioavailable compounds, including nitrate and ammonia, which can be used by living organisms. Fixation occurs in the atmosphere by lightning strikes, and terrestrially by certain bacteria that often live with plants, particularly legumes. After the plants die and decay, the stored nitrogen is released to the soil where it may be converted to nitrate and mobilized into the aquifer by precipitation, irrigation, or other sources of recharge.

The largest natural source of nitrogen in groundwater occurs from incomplete utilization of nitrate by sparse vegetation in arid regions. This nitrate accumulates in the unsaturated zone of alluvial aquifers below the root zone. Walvoord and others (2003) estimated that up to 2,000 pounds of bioavailable nitrogen per acre is available in arid regions of the Southwest, where recharge is insufficient to move it away. Such deposits have become locally significant sources of nitrate contamination to groundwater where human activities changed the hydrologic system by either raising the water table or moving more water through the vadose zone, such as from infiltration basins, thereby releasing the nitrate. Other, relatively minor natural nitrate sources in the Southwest include igneous rocks, deep geothermal fluids, and dissolution of some evaporite minerals.

Anthropogenic sources: The three primary anthropogenic sources of nitrogen in rural areas are farm animals, fertilizers and manure applied to crops and landscapes, and human waste from septic tanks and small land treatment systems. Animal wastes from confined animal feeding operations are a major source of nitrate contamination of shallow groundwater (particularly if lagoons are unlined), acting almost as point sources because of the large concentration of animals in small areas. Fertilizers are significant nitrogen sources in high-production pastures and vegetable farms. Soil tilling can mineralize natural organic nitrogen stored in the soil to nitrate, which can then be leached from soils and mobilized during recharge events. In urban areas, elevated nitrogen concentrations result from leaking sewer pipelines and high-density septic systems where rapid urbanization has outgrown the sewer infrastructure (see page 24).

Localized high nitrate concentrations also are associated with treated wastewater used for irrigation, fertilizer applied to turf, landfills and other types of industrial waste sites, and even some mine tailings.

Occurrence

To assess the extent of high nitrate concentrations in the United States, 33 regional aquifers used for water supply were evaluated by Nolan and Stoner (2000). On average, more than 15 percent of the wells contained water with nitrate concentrations above the U.S. Environmental Protection Agency maximum contaminant level (MCL) of 10 milligrams of nitrogen per liter (mg/l nitrate-N). Although relatively few regional studies of nitrate occurrence have been undertaken in the Southwest, most states have water-quality databases containing some information on statewide nitrate occurrence. In most southwestern states that have surveyed nitrate-N concentrations, about 5 to 15 percent of wells have concentrations above 10 mg/l, with some reaching over 100 mg/l.

A recent U.S. Geological Survey study of nutrient and pesticide concentrations in alluvial aquifers in Arizona, California, Nevada, New Mexico, south-central Colorado, and Utah reported that nitrate exceeds the MCL in more than 25 percent of the agricultural wells sampled and 10 percent of urban wells (Paul and others, 2007). In agricultural areas, the probability of exceeding the MCL for nitrate is mostly influenced by three factors: fertilizer use, irrigation, and aquifer oxidation-reduction (redox) conditions. At smaller scales, differences in nitrate concentrations between agricultural and urban land use are influenced more by groundwater redox conditions.

In Arizona, high nitrate-N concentrations (15 to 40 mg/l) associated with agricultural practices were noted near Phoenix in the West Salt River Valley. Confined animal feeding operations and septic systems also are a major source of nitrate here, producing concentrations as high as 20 mg/l. Concentrations as high as 150 mg/l in groundwater beneath confined feeding operations in New Mexico also have been reported. Dissolved minerals from evaporite deposits present in the West Salt River aquifer may also elevate groundwater nitrate-N concentrations by about 5 mg/l. In California, high nitrate-N concentrations occur mainly in agricultural areas, particularly in the San Joaquin Basin (up to 75 mg/l), but high densities of septic systems are sources in urban-fringe areas, where concentrations have reached 35 mg/l. High nitrate-N concentrations in Nevada (as much as 100 mg/l) also are generally associated with high-density septic-system usage. In areas of Nevada where septic systems are used heavily, such as Carson Valley and Washoe County in the north and Pahrump in the south, some domestic wells have groundwater nitrate concentrations exceeding the MCL.

The rising use of infiltration basins in the Southwest to increase aquifer storage or dispose of treated wastewater can leach nitrogen out of the vadose zone, raising the groundwater nitrate concentrations. For example, wastewater treated to about 2 mg/l nitrate-N was released into an infiltration basin near Reno, Nevada. Nitrate concentrations in groundwater from downgradient wells within 100 feet of the basin remained relatively stable for seven years, abruptly increased to more than three times

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Photo: Keith Weller, USDA-ARS

Why Should We Care?

Nitrate in groundwater today causes concern for humans and ecosystems. More than 50 years ago it was recognized that high concentrations of nitrate (greater than 20 mg/l as nitrogen) in drinking water supply wells could cause health problems such as methemoglobinemia ("blue baby disease"). Infants under the age of 6 months are more susceptible to this disease because they lack the enzyme that converts methemoglobin back to hemoglobin. High nitrate concentrations have also been linked to hypertension, central nervous system birth defects, certain cancers, non-Hodgkin's lymphoma, and diabetes (see Rosen and others, 2006 for references). In 1975, the U.S Environmental Protection Agency established a maximum contaminant level (MCL) for nitrate-nitrogen (NO_3-N) of 10 mg/l to regulate drinking water in the United States based on these human health concerns. In 1993 the World Health Organization established a similar MCL (11.3 mg/l NO_3-N), now adopted by many countries worldwide.

Although nitrogen is an essential nutrient for plant growth, high concentrations in groundwater can deteriorate water quality in receiving lakes and streams. Nitrate concentrations of less than 1 mg/l NO_3-N in groundwater can nevertheless cause serious effects in plant communities where growth is limited by the amount of nitrogen available, such as in Lake Tahoe. Additional nitrogen can cause eutrophication of the water body, wherein excessive plant growth (favoring certain species over others) and decay disrupts the normal balance of the ecosystem, ultimately leading to a lack of oxygen in the water for fish and other species.

The Many Forms of Nitrogen

Nitrogen makes up most of the atmosphere and its compounds are found everywhere on the surface of the planet. The gas is inert, but the compounds are among the most reactive. Nitrogen compounds can make things grow (fertlilizer, amino acids) as well as kill them (cyanides); they can blow things up (TNT, ammonium nitrate) or produce inert atmospheres in laboratories (gas). The abundance of intentionally and unintentionally produced compounds means much ends up in groundwater.

ammonia (NH_3): A common chemical both manufactured and produced in human and animal waste; a nutrient in low doses, toxic in high doses; used as fertilizer. In groundwater, significant only where pH is greater than 9.

ammonium (NH_4^+): the most stable form of nitrogen in oxygen-depleted (usually confined) aquifers; a product of ammonia and water under certain pH and temperature conditions.

denitrification: microbial reduction of nitrate to nitrogen gas under oxygen-poor conditions; the most significant natural degradation process of nitrate in groundwater.

nitrate (NO_3^-): a highly soluble, relatively stable form of nitrogen in oxygen-rich soils and aquifers; the most common form of groundwater contamination.

nitrate as nitrogen (NO_3-N or nitrate-N): standard means of reporting measured nitrogen in a nitrate analysis of water; assumes nitrate is the dominant form of nitrogen present and excludes any other forms. Divide nitrate concentration by 4.4 to obtain the nitrogen equivalent: 44 mg/l NO_3^- = 10 mg/l NO_3-N.

nitrite (NO_2^-): intermediate compound in the transformation of ammonium to nitrate or nitrate to nitrogen gas; generally unstable but high concentrations may occur near organic waste disposal sites.

nitrification: the oxidation of ammonium to nitrate.

nitrogen: a stable, inert gas that makes up 78 percent of Earth's atmosphere; the end product of denitrification.

nitrosamine: a suspected carcinogen that can be produced when ion-exchange technology is used to remove nitrogen from drinking water.

organic nitrogen: can occur in either oxygen-rich or oxygen-poor water but is rarely significant in uncontaminated aquifers.

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the average wastewater concentration for two years, and then returned to earlier levels (see figure, below). Cores from the unsaturated zone of the wells showed nitrate-N concentrations up to 50 mg/l in the upper 10 feet of soil, suggesting that the infiltrating wastewater mobilized the buried nitrate and carried it into the aquifer as a pulse.

Trends

Statistically significant, regional-scale trends in groundwater nitrate concentrations in the Southwest are difficult to determine because long-term nitrate records do not exist at suitable scales. However, nitrate is known to be increasing locally (see, for example, Rosen, 2003). A recent national trend analysis of nitrate from wells in agricultural and urban lands found increasing trends in the San Joaquin Basin of California, but no significant trends in Carson City/Reno alluvial aquifers or in the Rio Grande Basin of New Mexico from 1988 to 2004 (Rupert, 2008).

Next Steps

Far more consistent and long-term monitoring over large areas is needed in the Southwest to assess regional or aquifer-wide nitrate trends. Groundwater contaminant transport models and groundwater age dating will be important tools for assessing and predicting trends and groundwater nitrate budgets. Relatively few Southwest basins have used groundwater models for assessing nitrate budgets, but an ongoing study in Carson Valley, Nevada may provide an example of the utility of determining nitrogen sources and amounts for management decisions. ■

Contact Michael Rosen at USGS.gov

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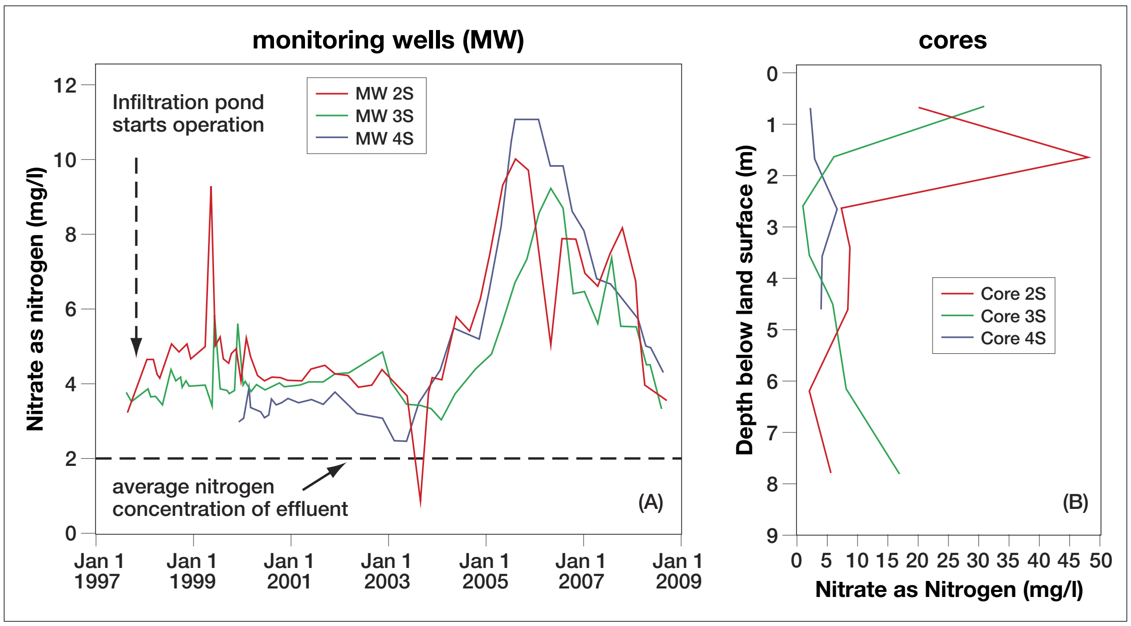

(left) Eight years after an infiltration pond began operating, a pulse of high-nitrate groundwater was observed in monitoring wells. (right) Nitrogen concentrations in sediment samples taken from the same wells are highest in the upper 10 feet.