Agricultural Impacts on Groundwater Nitrate

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Nitrate is perhaps the most widespread groundwater contaminant besides salt, both in the United States and globally. As many as 10 percent of public water-supply wells in California exceed the maximum contamination level (MCL) of nitrate and must be treated or blended with high-quality water (see map, right). In some areas of California, well over one-third of domestic wells (typically shallow) may exceed the nitrate MCL.

Nitrate in groundwater originates from natural sources, organic sources (decaying plant materials, human/animal waste discharged in septic systems, animal yards, manure storage lagoons, and wastewater treatment plant discharge), atmospheric deposition, and inorganic fertilizer. Naturally occuring concentrations in the Southwest are generally less than 2 milligrams per liter nitrate as nitrogen (mg/l nitrate-N).

Agriculture's use of inorganic fertilizer and animal manure is the most dominant and widespread nitrate source in the Southwest, although urban areas, primarily unsewered areas, can also contribute significant nitrate to groundwater. The major regions with high groundwater nitrate pollution are therefore not surprisingly the major agricultural regions: Imperial, Central, Salinas, and other coastal valleys in California; the Snake River Plain in Idaho; the Wasatch Front in north-central Utah; the Rio Grande Valley in New Mexico; and the Gila and Salt River valleys in Central Arizona.

Where Does It Come From?

In 2007, California farmers applied 740,000 tons of nitrogen in fertilizer to 6.7 million acres of irrigated farmland. Plants are able to take up less than 50 percent of the nitrogen in fertilizer, which means, based on 2007 figures, more than 110 pounds of nitrogen per acre per year (lbs N/acre/year) go unused. About 25 percent of that volatilizes into the atmosphere as ammonia and nitrogen gas from the root zone and less than 10 lbs N/acre/year enters surface water as nitrate, ammonium, or dissolved organic nitrogen. Hence, more than 80 lbs N/acre/year may leach into the groundwater beneath irrigated lands, usually as nitrate.

Animal and human wastewater applications add more. Dairy manure, the largest source of animal manure in California, accounts for approximately 240,000 tons of additional nitrogen (as organic nitrogen and ammonium) much of which is applied to forage crops, where—after transformation

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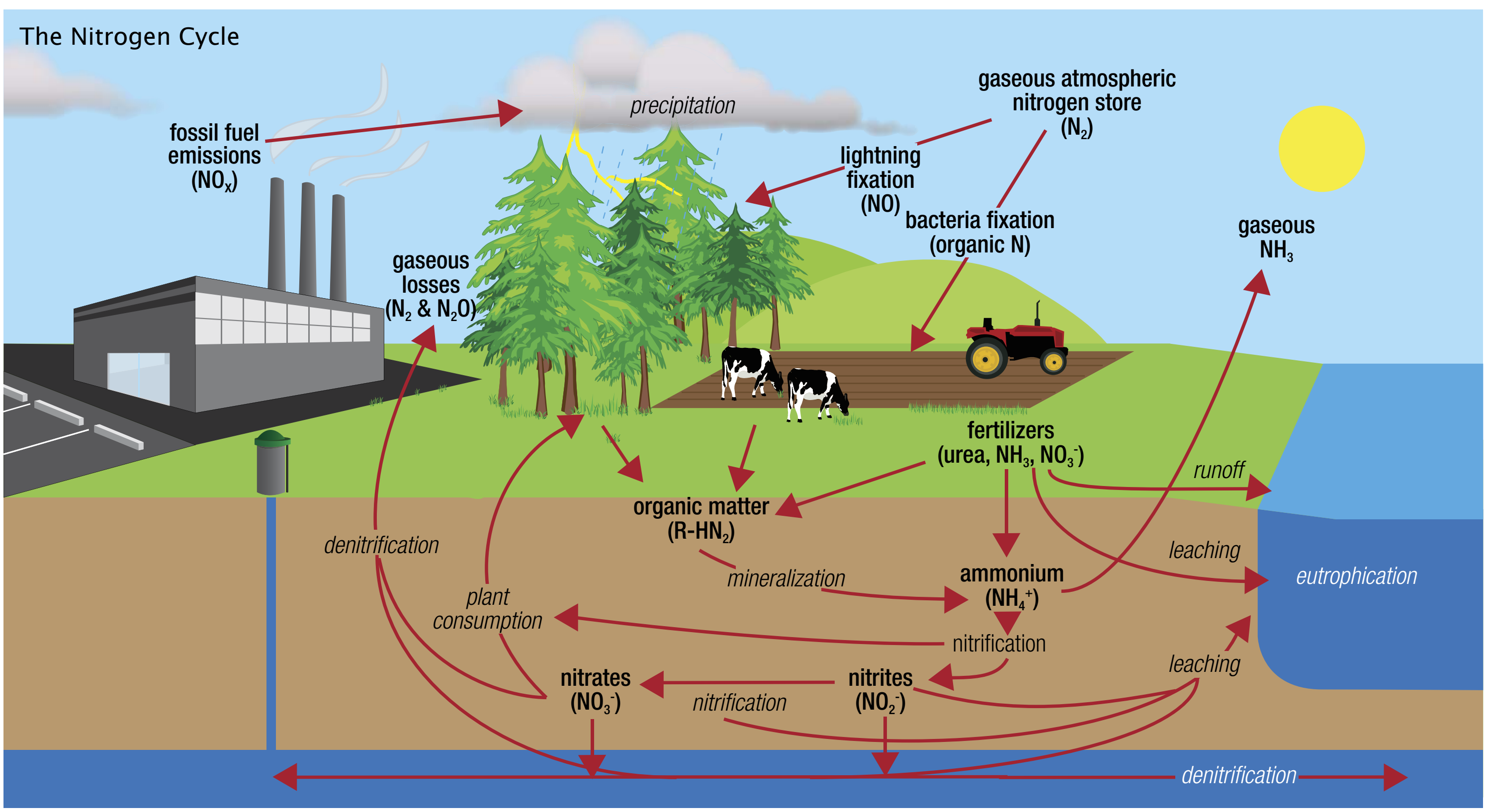

The nitrogen cycle illustrates the various forms and transformations of nitrogen compounds.

to nitrate—any unused nitrogen is leached by precipitation and irrigation water to groundwater.

What is the impact to groundwater of average farm losses of 80 lbs N/acre/year? The MCL of 10 mg/l nitrate-N (NO_3-N) corresponds to 27 pounds of nitrate fertilizer leached in one acre-foot of recharge water. Typical recharge rates in many irrigated systems are one-half to two acre-feet per acre of irrigated land per year. Agricultural groundwater recharge with NO_3-N levels at the MCL therefore equals approximately 15 to 50 pounds of NO_3-N per acre entering the subsurface per year. Without attenuation, 80 lbs N/acre/year would lead to groundwater NO_3-N concentrations at the water table that are two to four times higher than the MCL. But in many areas, subsurface attenuation does occur.

What Happens Underground?

After reaching the soil's root zone, ammonia either volatilizes or is used by plants. Nitrate also may be assimilated by plants; it may be denitrified through microbial action, releasing gaseous nitrogen; or it may be leached below the root zone (see diagram, left).

The more denitrification that occurs in the root zone, the less nitrate is leached down to the water table. But denitrification requires anoxic conditions, which in the root zone occur locally and are often limited to prolonged flooding/irrigation conditions. Heavy, clay-rich soils and anoxic groundwater favor denitrification whereas shallow, coarse-textured, highly permeable soils and aquifers, common in agricultural regions of the Southwest, are typically high in dissolved oxygen and most vulnerable to nitrate contamination. In California, measured nitrate concentrations closely match the risk of groundwater contamination estimated from land-use characteristics and the vulnerability of the groundwater system.

Within aquifers, nitrate concentrations generally decrease with depth. This may be due to the presence of aquitards or interbedded clay layers that provide anoxic conditions for denitrification. But in many areas, it is simply age: large-scale commercial fertilizer production and use began in the 1940s and 1950s. Only younger (less than 60 years) and therefore more shallow groundwater is affected by excessive nitrate leaching from agricultural areas. In many regions, nitrate concentrations have been and are still increasing (Burow and others, 2008).

What Can We Do?

Agricultural sources of surface water and groundwater nitrate contamination fall largely outside of the direct regulatory power of either the U.S. Environmental Protection Agency or state agencies. The most important approach has therefore been to develop best management

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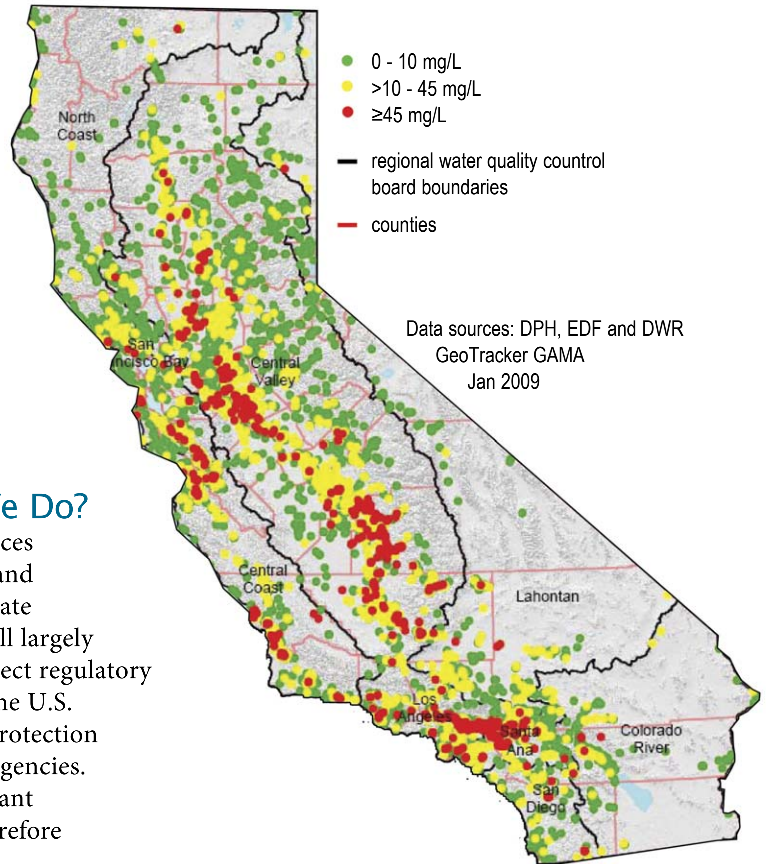

Nitrate concentrations in public supply wells, monitoring wells, and domestic wells measured in 2007. Red wells exceed the drinking-water limit (44 mg/l nitrate = 10 mg/l nitrate-N). From Ekdahl and others, 2009.

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practices, implement pilot projects, and educate farmers about optimal fertilization practices.

In California, the 1969 Porter-Cologne Act (California's version of a Clean Water Act) mandated that the state regulate not only discharges to surface water but also potential contaminant discharges to groundwater. Many of the original waivers for nonpoint-source dischargers (including irrigated agriculture) were discontinued in 2002; those discharges are now being regulated. This led to the recent imposition of extensive regulatory controls, including management practices protocols and groundwater monitoring, for the entire Central Valley dairy industry under a 2007 General Order. Similar programs soon may be instituted for all of California's irrigated lands under an expanded Irrigated Lands Waiver program. In addition, a recent California State Water Resources Control Board decision directed its regional boards to develop basin plans for managing salt and nutrient contamination from both point and nonpoint sources.

A key challenge in regulating nonpoint sources of groundwater contamination is designing effective monitoring programs. Monitoring the amount of nitrate being leached is complicated by regional and farm-to-farm differences in nitrogen management; the highly varying nitrogen requirements among crops; nonuniformity of nitrogen application rates within fields; and heterogeneity of and uncertainty about nitrogen attenuation potential in the root zone prior to root uptake, in the vadose zone below the root zone, and in groundwater across small and large spatial scales.

Approaches being used to assess nitrate loading to groundwater include:

- control and monitor nitrate application and management practices to minimize nitrogen leaching;
- measure soil nitrogen to guide agronomic practices and assess leaching from the root zone; and
- monitor nitrate and ammonium in groundwater.

Regulatory groundwater monitoring programs have traditionally been used to regulate specific sources and individual landowners. The challenges in monitoring farms or dairies, however, are the large number of sources within each operation, their spatiotemporal variability, and the typically large property size (several hundred to thousands of acres) compared to traditional point-source sites. This makes complete groundwater site monitoring impractical. The common approach of using one monitoring well upgradient and two downgradient of the source provides but a random sample of the varied nitrate loading to groundwater within a farm.

A Better Approach to Groundwater Monitoring

More successful regulatory approaches use groundwater monitoring not as a landowner- or site-specific regulatory tool, but to evaluate the success of regulating nitrogen (or other contaminant sources) management practices across entire watersheds. The California Department of Pesticide Regulation, for example, regularly surveys a network of randomly selected domestic wells for pesticide occurrence. These survey results affect management practices allowed in specific areas for specific pesticides. In the European Union, the Netherlands monitors soil and shallow and deep groundwater in an extensive network of farm-based monitoring stations to assess the success of nutrient management regulations. The stations are randomly located on farms across the country and grouped by soil and hydrogeologic regions as well as farm categories. Groundwater-quality information is used to refine state regulations of farm management practices, but not to prosecute individual farms. This allows for a comprehensive assessment of groundwater nitrate trends across the state and more effective regulation of agricultural source activities. ■

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References

Burow, K.R., J.L. Shelton, and N.M. Dubrovsky, 2008. Regional nitrate and pesticide trends in groundwater in the Eastern San Joaquin Valley, California, J. Environ. Qual., 37: S-249–S-263.

Ekdahl, E.J., M.P. Carpio-Obeso, and J. Borkovich, 2009. Using GeoTracker GAMA to investigate nitrate concentrations in California groundwater, 1980-2008, presented at Groundwater Monitoring: Design, Analysis, Communication, and Integration with Decision Makking Conference, Orange, CA, Feb. 25-26, 2009.