DRINKING WATER NITRATE AND IRRIGATED AGRICULTURE IN CALIFORNIA

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ABSTRACT

Nitrate contamination of groundwater in California has led to new government regulation of agricultural practices in the state's Central Valley (CV) and Central Coast Regions (CC, which includes the Salinas Valley). Regulations in 2007 were imposed on dairies in the Central Valley, but more recently, all irrigated farming in both regions has been targeted. These regulations require monitoring and reporting (e.g., of fertilizer and manure applications), nutrient management plans, and adherence to technical standards that will limit N applications. The regulations differ somewhat in approach and in many of the details, but in all three cases, a role for Certified Crop Advisers or other nutrient management professionals is described. Improved methods of irrigation and nutrient management are now in use by many growers, but for more widespread adoption, logistical, economic and other barriers must be overcome. Also, in many parts of California, percolation from agricultural fields is the major source of aquifer recharge. To improve aquifer quality will require not only reduction in the mass of nitrate leached from crop fields but also provision of some additional source of clean water for recharge.

INTRODUCTION

Groundwater is essential to California, and nitrate is one of the state's most widespread groundwater contaminants. California's governments, communities, and agricultural industry have struggled over nitrate contamination for decades. The California Department of Public Health (CDPH) has set the maximum contaminant level (MCL) for nitrate in drinking water at 45 mg/liter as nitrate, equivalent to 10 mg/liter expressed as nitrogen. Under the state's Porter-Cologne Act and Safe Drinking Water Act, nitrate concentrations in public drinking water exceeding the MCL require that actions be taken to provide safe drinking water.

In the 2012 UC Davis report "Addressing Nitrate in California's Drinking Water", which focuses on the state's Tulare Lake Basin (TLB, essentially the southern half of the San Joaquin Valley) and Salinas Valley, the authors estimate that roughly 254,000 people, about 10% of the population, are currently at risk for nitrate contamination of their drinking water (Harter, Lund et al., 2012). Of these, 220,000 are connected to community public (>15 connections) or state small water systems (5–14 connections), and 34,000 are served by private domestic wells or other systems smaller than the threshold for state or county regulation and which are largely unmonitored (Harter, Lund et al., 2012). Many of the communities affected by high nitrate drinking water are economically disadvantaged and lack the technical, managerial, and financial resources to treat water or obtain alternative supplies. Even where government funds can be found to install treatment systems, most disadvantaged communities cannot afford the ongoing operations and maintenance costs. Providing clean water to such communities is a matter not only of public health but also of environmental justice.

SOURCES OF GROUNDWATER NITRATE

The UC Davis report covers 3.12 million acres in the Tulare Lake Basin and the Salinas Valley. The authors estimate that in recent years more than 50% of all nitrogen applied to cropland has been leached past the root zone and will eventually reach the groundwater. Removal of harvested N in crops is estimated at only 34% of all inputs of N (Table 1). The study also looked at the impact of other sources of N including septic tanks, wastewater treatment plants, urban turfgrass, etc. and concluded that irrigated cropland accounts for 96% of nitrate found in groundwater in the study area.

Table 1. Nitrogen mass balance for 3.12 million acres of irrigated cropland in the Tulare Lake Basin and Salinas Valley. (Derived from Fig. ES-2, page 4, Harter, Lund et al., 2012.)

	N inputs per year			N outputs per year	
	1,000 tons actual N	% of inputs		1,000 tons actual N	% of inputs
Total	420	100	Total	420	100
Fertilizer	225	54	Crop harvest removal	130	34
Dairy manure[2]	140	33	Nitrate leaching loss	195	51
Other[1]	55	13	Loss via runoff and to atmosphere	56	15

[1]Irrigation water, wastewater, food processing wastes, biosolids, non-dairy manure, atmospheric deposition

[2]Estimate of N excreted by animals as manure minus N volatilized in animal housing and manure storage areas

The report's authors based their conclusions on an analysis (published as a separate technical report, Viers et al.) using typical crop yields, crop nitrogen content, and fertilizer application rates. Manure from dairies was allocated to cropland under several scenarios (all applied on dairy forage crop acreage, half applied on dairy, half over rest of county, etc.). An alternative scenario that was not included is one in which dairies transport manure off-farm in response to recently implemented waste discharge regulations (see below), while farms receiving this manure decrease N fertilizer purchases, thus improving the N balance of the entire region.

These total numbers for the entire area analyzed in the UC Davis study tell us little about spatial variability of nitrate leaching loss and which crops, management practices, or soils contribute the most, but they support several previous studies indicating that large losses of nitrogen from the root zone are common and to be expected under conditions found in productive, irrigated agriculture under Mediterranean climate conditions.

REGULATIONS TO PROTECT GROUNDWATER QUALITY

A brief description of three recent nitrate regulatory approaches in California is provided here. This description focuses on N application limits and reporting and monitoring requirements; also the role of Certified Crop Advisers or other crop management professionals.

Central Valley Dairy Waste Discharge Requirements General Order R5-2007-0035

In May 2007, waste discharge requirements were imposed on all milk cow dairies in the Central Valley. There are about 1.7 million milk cows in the Central Valley (2010 figure), nearly all housed in confinement year round. The regulation sets limits to total N application limits from all sources on all crop fields receiving liquid or solid manure that are under the control of the dairy. This limit is in the form of a technical standard that limits N applied (from all sources) to each field in one season to 140% of the amount removed in the harvested crop. Farmers are required to document harvest N removal by sampling the harvested crop. Farmers are required to prepare annual reports and to keep on file nutrient management plans that are signed by Certified Crop Advisers. It appears that many dairies have responded to this order by transporting some or all of their solid manure off farm; however statistics that would document this are not easily accessed. For more information on see http://www.waterboards.ca.gov/centralvalley/water_issues/dairies/dairy_program_regs_requirements/

Central Valley Irrigated Lands Regulatory Program

The Central Valley Regional Water Quality Control Board in California adopted the first in a series of waste discharge requirements in December 2012. It is anticipated that by the end of 2013, Waste Discharge Requirements will be developed for all regions in the Central Valley, replacing Conditional Waivers. Of the estimated 35,000 growers in the Central Valley, there are about 25,000 landowners/operators who are part of one of eight water quality coalition groups:"

All growers will be required to prepare nitrogen management plans. Farmers whose land lies above the most vulnerable groundwater aquifers will be required to submit information to one of eight coalitions regarding their N use efficiency. The coalitions will receive this information and produce regular statistical reports related to crop N use efficiency. Many details remain to be determined. The East San Joaquin Water Quality Coalition representing some 3,000 growers producing a great diversity of permanent and annual crops will go first in this process. A key part of the process will be a nitrogen balance sheet, sometimes called a nitrogen management plan or NMP, which must be signed by a Certified Crop Adviser or other crop management professional, then submitted to the grower's coalition. In one version of the balance sheet currently under discussion, the balance sheet will be used to calculate a ratio of total N inputs (fertilizer, manure and other organic materials, and N in irrigation water) to the quantity of N required to produce the targeted yield. It is unclear at this point where the required N values for the Central Valley's many crops will come from. One idea is that experts will agree upon a set of "book values" representing a reasonable amount of N per unit of harvest sufficient to cover harvest N removal plus a modest additional amount to cover unavoidable losses and inefficiencies in well-run operations.

Central Coast Waste Discharge Requirements

(Much of the information provided in this section is abstracted from the website: http://www.waterboards.ca.gov/centralcoast/water_issues/programs/ag_waivers/)

In its review of the groundwater nitrate contamination on the Central Coast region of California, which includes the Salinas Valley, the Regional Water Quality Control Board stated "Studies indicate that irrigated agriculture contributes approximately 78 percent of the nitrate loading to groundwater in agricultural areas of the Central Coast of California…. Groundwater age data in relation to nitrate concentration indicate that the rate of nitrate loading to the shallow aquifer is not yet decreasing in the areas sampled. In areas east of Gilroy, groundwater nitrate concentrations more than double the drinking water standard correspond to younger groundwater ages (less than seven years old and in some cases less than two years old), indicating that the nitrate pollution is due to recent nitrate loading and not legacy farming practices…Hundreds of drinking water wells serving thousands of people throughout the region have nitrate levels exceeding the drinking water standard."

In March, 2012, the Central Coast Water Board adopted an updated Conditional Waiver of Waste Discharge Requirements for Discharges from Irrigated Lands (Agricultural Order No. RB3-2012-0011). The Order places farms in one of three tiers, based on risk to water quality. For many farms (Tier 1 and Tier 2), the new requirements are similar or less stringent than existing regulations. Farms in Tier 3 have more stringent requirements." Growers will be placed in Tier 3 if they grow crop types with high potential to discharge N to groundwater at the farm/ranch, and farm/ranch total irrigated acreage is equal to or greater than 500 acres.

The Order covers 435,000 acres and 3,000 agricultural operations and includes the Salinas Valley. It is estimated that about 11% of the acreage and 3% of farmers -- mostly these are large farms growing leafy green vegetables and berry crops -- will fall into Tier 3. Shown in Table 2 is a partial list of actions required of Tier 3 growers under the Order.

Table 2. Some of the actions required of Tier 3 growers (high risk of nitrate leaching) under regulations adopted in March 2012 by California's Central Coast Regional Water Quality Control Board.

<table>
<tr><th>Grower Action</th><th>Deadline</th></tr>
<tr><td>Determine Crop Nitrogen Uptake (if discharge has High Nitrate Loading Risk)</td><td>October 1, 2013</td></tr>
<tr><td>Submit INMP elements in electronic Annual Compliance Form (if discharge has High Nitrate Loading Risk), including Nitrogen Balance Ratio</td><td>October 1, 2015, and annually thereafter by October 1</td></tr>
<tr><td>Submit progress towards Nitrogen Balance Ratio target equal to one (1) for crops in annual rotation (e.g., cool season vegetables) or alternative, (if discharge has High Nitrate Loading Risk)</td><td rowspan="2">October 1, 2015</td></tr>
<tr><td>Submit progress towards Nitrogen Balance Ratio target equal to 1.2 for annual crops occupying the ground for the entire year (e.g., strawberries or raspberries) or alternative, (if discharge has High Nitrate Loading Risk)</td></tr>
<tr><td>Submit INMP Effectiveness Report (if discharge has High Nitrate Loading Risk)</td><td>October 1, 2016</td></tr>
</table>

According to the Order, the Nitrogen Balance ratio refers to the total number of nitrogen units applied to the crop (considering all sources of nitrogen) relative to the typical nitrogen uptake of the crop (crop need to grow and produce, amount removed at harvest plus the amount remaining in the system as biomass). Growers producing crops in annual rotation (such as a cool season vegetable in a triple cropping system) must report progress towards a

Nitrogen Balance ratio target equal to one (1). A target of one (1) allows a Discharger to apply 100% of the amount of nitrogen required by the crop to grow and produce yield for every crop in the rotation. (Nitrogen applied includes any product, form or concentration, including but not limited to, organic and inorganic fertilizers, slow release products, compost, compost teas, manure, extracts, nitrogen present in the soil and nitrate in irrigation water.)

Beyond three years, growers must demonstrate improved irrigation and nutrient management efficiency, improved Nitrogen Balance ratios, and reduced nitrate loading to groundwater. In the long term, the Nitrogen Balance ratio should compare the total amount of nitrogen applied to the crop against the total nitrogen removed at harvest, rather than the typical nitrogen crop uptake, to accurately calculate the nitrogen remaining and available to the crop or that could load to groundwater.

NITRATE SOURCE REDUCTION SOLUTIONS

The UC Davis report (Harter, Lund et al., 2012) states that to address the problem of nitrate contamination of groundwater requires actions in four areas: (a) safe drinking water actions for affected areas, (b) reducing sources of nitrate contamination to groundwater, (c) monitoring and assessment of groundwater and drinking water, and (d) revenues to help fund solutions. Safe drinking water actions include treatment (household, community, or regional), alternative supply, and blending.

Reducing nitrate loading to groundwater is possible, sometimes at a modest expense. But nitrate source reduction works slowly and cannot effectively restore all affected aquifers to drinking water quality. The study authors concluded (by use of groundwater modeling) that nitrate concentrations will increase over the next several decades, due in part to nitrate already "in the pipeline" from recent and past manure and fertilizer applications well in excess of crop uptake and harvest removal. However, within the framework of the state's Porter-Cologne Act, unless groundwater were to be de-designated as a drinking water source, reduction of nitrate loading to groundwater is required to improve long-term water quality.

Current Best Management Practices for Reducing Nitrate Leaching

No one practice or set of practices -- imposed by regulation or adopted voluntarily -- will be effective in reducing nitrate leaching across the diverse cropping systems in California to reduce leaching of nitrate. Tools and approaches must be tailored to individual situations.

A first step in identifying appropriate practices is to focus attention on the crop species, irrigation system types, and soils that present the greatest risk of nitrate leaching. The UC Nitrate Hazard Index provides a simple method for identifying the combinations of crop, soil, and irrigation system that present the greatest hazard (Wu et al., 2005). If the hazard index value suggests a low risk of nitrate leaching loss, the grower must still implement sound management practices, but extraordinary procedures are not required. Where risk is high, careful attention and more precise management are needed, and "typical" management may not suffice. For example, winegrapes have relatively low N requirements, and their deep roots and the common use of drip irrigation result in little deep percolation and a low risk of nitrate leaching loss. In contrast, attention to optimizing crop recovery of applied N is more critical in spinach. This crop is often grown on well-drained loamy soils and it is usually sprinkler irrigated throughout the crop cycle; it has shallow roots, and it requires high levels of N up to the time of harvest. Improvements to groundwater quality can be achieved by targeting mitigation efforts to such hazardous situations.

Over the past 40 years, technologies that favor efficient use of nitrogen by crops have been developed in California. Some of these are in common use by farmers, and some have potential for expanded use. Among the important practices adopted by farmers in recent years are the following:

- Conversion from furrow and other surface irrigation methods to drip and microsprinkler systems, which have the potential to reduce deep percolation. Use of drip does not guarantee less deep percolation losses. Some drip systems are operated on "autopilot" and apply far more water than needed to meet crop demand. Also, the cost of conversion so far has not allowed for adoption of these systems for most agronomic crops, including the dairy forages.
- N fertigation through drip lines and microsprinklers, making it much easier to precisely match N fertilizer applications to crop N demand.
- Weather based irrigation scheduling tools, such as the California Irrigation Management Irrigation System (CIMIS), which alone or in combination with monitoring of soil or plant water status, can help growers with irrigation timing and amount decisions.
- Soil nitrate testing to guide N fertilizer rates and timing.
- Use of cover cropping and development by the University of California of simple methods for estimating the N content of cover crop biomass at the time of incorporation.
- Measurement of irrigation water nitrate content and consideration of this to adjust N fertilizer application rates.

For increased farmer adoption of the nitrogen-efficient practices, barriers to implementation must be overcome (Dzurella et al., 2012). These include obvious barriers like increased management or labor costs and less-obvious constraints such as "ranch logistics" and land tenure issues. An example of ranch logistics as a barrier is when an irrigation district's delivery schedule or the farmer's pumping capacity constrains the ability to adjust the timing of irrigations on individual fields. Another type of logistical constraint is created by spatial variability. For example, variability within a single field of soil infiltration rate and soil water-holding capacity imposes an upper limit on irrigation system performance.

Future Potential Solutions

Newer approaches requiring additional research and development include the following examples:

- Increased use by farmers of adaptive management tools such as field nitrogen budgets or balance sheets, which over time can be used to track improvements in crop N use efficiency; also end-of-season plant tissue N or soil nitrate testing.
- Web-based tools to facilitate the tracking by managers of irrigation and nitrogen on a large number of fields or sub-field blocks. For annual cropping systems, increased use of soil nitrate testing, including in some situations use of quick test methods has already been developed for coastal vegetable production, but improved methods for data management and delivery of the information to field managers will help routinize the use of these practices.
- Decision aids that can forecast N mineralization from soil organic matter, manure, and other organic amendments. Predicting N mineralization remains a big challenge for agriculture. For models to be anything more than fancy guess work, they must be

calibrated to specific crop rotations, soils, and tillage regimes. On-farm, zero-N fertilizer plots are one approach to calibration.

- Economical methods for recycling of solid and liquid dairy manure into more concentrated, uniform products that are more reliable for use as fertilizers and soil amendments in a wider variety of cropping systems.

GROUNDWATER QUALITY: It's not just about farming practices

Groundwater aquifers in the more arid parts of California where the land is intensively farmed, e.g., much of the San Joaquin Valley, have for several decades been recharged significantly by irrigation water that percolates past the crop root zone. As growers manage water more tightly -- for example, by converting to drip irrigation and using weather-based irrigation scheduling – the volume of recharge from cropland will be decreased. Even if farmers reduce the mass quantity of N leached below the root zone, the concentration of nitrate in the percolate will almost certainly still exceed the nitrate drinking water standard. Lower percolation rates mean that travel time through the unsaturated zone is longer. But for groundwater quality to be improved, not only must there be a reduction in nitrate leaching, but there must be at least some additional clean recharge entering aquifers to dilute nitrate, as well as to avoid overdraft. If, all of the water "saved" by on-farm irrigation improvements is used to irrigate additional acres or is transported out of the basin, we can speculate that aquifer quality will continue to be degraded and overdraft will accelerate.

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