Addressing Nitrate in California's Drinking Water

With a Focus on Tulare Lake Basin and Salinas Valley Groundwater

Report for the State Water Resources Control Board Report to the Legislature

California Nitrate Project,
Implementation of Senate Bill X2 1

Center for Watershed Sciences
University of California, Davis
http://groundwaternitrate.ucdavis.edu

Prepared for the California State Water Resources Control Board

The health of our waters
is the principal measure
of how we live on the land.

—*Luna Leopold*

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Acronyms and Abbreviations

AB	Assembly Bill
ac	Acre (about 0.4 hectares)
AF	Acre-foot (about 1,233 cubic meters)
AMBAG	Association of Monterey Bay Area Governments
AQUA	Association of People United for Water
ARRA	American Recovery and Reinvestment Act
AWP	Agricultural Waiver Program
BD	Biological Denitrification
BMP	Best Management Practices
CAA	Cleanup and Abatement Account
CalEPA	California Environmental Protection Agency
CAL FAC	California Food and Agriculture Code
CalNRA	California Natural Resources Agency
CCR	California Code of Regulations
CCR	Consumer Confidence Report
CDBG	Community Development Block Grant
CDFA	California Department of Food and Agriculture
CDPH	California Department of Public Health
CoBank	Cooperative Bank
CPWS	Community Public Water System
CRWA	California Rural Water Association
CV-SALTS	Central Valley Salinity Alternative for Long-Term Sustainability
CVSC	Central Valley Salinity Coalition
CWA	Clean Water Act
CWC	Community Water Center
CWSRF	Clean Water State Revolving Fund
DAC	Disadvantaged Communities
DPEIR	Draft Program Environmental Impact Report (of the Central Valley ILRP)
DPR	California Department of Pesticide Regulation
DWR	California Department of Water Resources
DWSAP	Drinking Water Source Assessment and Protection
DWSRF	Drinking Water State Revolving Fund
EDA	U.S. Economic Development Administration

EDR	Electrodialysis Reversal
ERG	Expense Reimbursement Grant Program
ERP-ETT	Enforcement Response Policy and Enforcement Targeting Tool
FFLDERS	Feed, Fertilizer, Livestock, Drugs, and Egg Regulatory Services
FMIP	Fertilizing Materials Inspection Program
FP	Food Processors
FREP	Fertilizer Research and Education Program
GAMA	Groundwater Ambient Monitoring and Assessment
Gg	Gigagram (1 million kilograms, about 1,100 tons)
ha	Hectare (about 2.5 acres)
HAC	Housing Assistance Council
HSNC	Historical Significant Non-Compliers
HUD	U.S. Department of Housing and Urban Development
I-Bank	California Infrastructure and Economic Development Bank
ILRP	Irrigated Lands Regulatory Program
IRWM	Integrated Regional Water Management
ISRF	Infrastructure State Revolving Fund
IX	Ion Exchange
KCWA	Kern County Water Agency
kg	Kilogram (about 2.2 pounds)
L	Liter (about 1.06 liquid quarts)
lb	Pound (about 0.45 kilogram)
LLNL	Lawrence Livermore National Lab
MCL	Maximum Contaminant Level
MCWRA	Monterey County Water Resources Agency
mg	Milligram (about 0.00003 ounce)
MHI	Median Household Income
MUN	Municipal or domestic water supply (beneficial use)
NDWC	National Drinking Water Clearinghouse
NMP	Nutrient Management Plan
NPDES	National Pollutant Discharge Elimination System
NRWA	National Rural Water Association
NUE	Nitrogen Use Efficiency
NWG	Nitrate Working Group

O&M	Operations and Maintenance
OW	EPA’s Office of Water
PES	Payment for Ecosystem Services
PHG	Public Health Goal
PNB	Partial Nutrient Balance
POE	Point-of-Entry (for household water treatment)
Porter-Cologne	Porter-Cologne Water Quality Control Act (California Water Code § 13000 et seq.)
POU	Point-of-Use (for household water treatment)
PPL	Project Priority List
PWS	Public Water System
RCAC	Rural Community Assistance Corporation
RCAP	Rural Community Assistance and Partnership
RO	Reverse Osmosis
RUS	Rural Utilities Service
SB	Senate Bill
SDAC	Severely Disadvantaged Communities
SDWA	Safe Drinking Water Act
SDWSRF	Safe Drinking Water State Revolving Fund
SEP	Supplement Environmental Program
SHE	Self-Help Enterprises
SRF	State Revolving Fund
SSWS	State Small Water System
SV	Salinas Valley
t	Ton (U.S. short ton, about 907 kilograms)
TLB	Tulare Lake Basin
U.S. EPA	United States Environmental Protection Agency
U.S.C.	United States Code
USDA	United States Department of Agriculture
USGS	U.S. Geological Survey
WARMF	Watershed Analysis Risk Management Framework
WDR	Waste Discharge Requirements
WEP	Water Environmental Program
WMP	Waste Management Plan
WWTP	Wastewater Treatment Plant

Executive Summary

Executive Summary

In 2008, Senate Bill SBX2 1 (Perata) was signed into law (Water Code Section 83002.5), requiring the State Water Resources Control Board (State Water Board), in consultation with other agencies, to prepare a Report to the Legislature to "improve understanding of the causes of [nitrate] groundwater contamination, identify potential remediation solutions and funding sources to recover costs expended by the State… to clean up or treat groundwater, and ensure the provision of safe drinking water to all communities." The University of California prepared this Report under contract with the State Water Board as it prepares its Report to the Legislature.

This executive summary focuses on major findings and promising actions. Details can be found in the Main Report and eight accompanying Technical Reports.

Key Issues

Groundwater is essential to California, and nitrate is one of the state's most widespread groundwater contaminants. Nitrate in groundwater is principally a by-product of nitrogen use, a key input to agricultural production. However, too much intake of nitrate through drinking water can harm human health.

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 milligrams per liter (as nitrate). Nitrate concentrations in public drinking water supplies exceeding the MCL require water system actions to provide safe drinking water.

For this study, the four-county **Tulare Lake Basin and the Monterey County portion of the Salinas Valley are examined**. About 2.6 million people in these regions rely on groundwater for drinking water. The study area includes four of the nation's five counties with the largest agricultural production. It represents about 40% of California's irrigated cropland (including 80 different crops) and over half of California's dairy herd. Many communities in the area are among the poorest in California and have limited economic means or technical capacity to maintain safe drinking water given threats from nitrate and other contaminants.

Summary of Key Findings

1. **Nitrate problems will likely worsen for several decades. For more than half a century, nitrate from fertilizer and animal waste have infiltrated into Tulare Lake Basin and Salinas Valley aquifers. Most nitrate in drinking water wells today was applied to the surface decades ago.**

2. **Agricultural fertilizers and animal wastes applied to cropland are by far the largest regional sources of nitrate in groundwater. Other sources can be locally relevant.**

3. **Nitrate loading reductions are possible, some at modest cost. Large reductions of nitrate loads to groundwater can have substantial economic cost.**

4. **Direct remediation to remove nitrate from large groundwater basins is extremely costly and not technically feasible. Instead, "pump-and-fertilize" and improved groundwater recharge management are less costly long-term alternatives.**

5. **Drinking water supply actions such as blending, treatment, and alternative water supplies are most cost-effective. Blending will become less available in many cases as nitrate pollution continues to spread.**

6. **Many small communities cannot afford safe drinking water treatment and supply actions. High fixed costs affect small systems disproportionately.**

7. **The most promising revenue source is a fee on nitrogen fertilizer use in these basins. A nitrogen fertilizer use fee could compensate affected small communities for mitigation expenses and effects of nitrate pollution.**

8. **Inconsistency and inaccessibility of data prevent effective and continuous assessment. A statewide effort is needed to integrate diverse water-related data collection activities by many state and local agencies.**

Nitrate in groundwater poses two major problems and risks:

- **Public health concerns** for those exposed to nitrate contamination in drinking water; in California's Tulare Lake Basin and Salinas Valley, roughly 254,000 people are currently at risk for nitrate contamination of their drinking water. Of these, 220,000 are connected to community public (>14 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.
- **Financial costs of nitrate contamination** include additional drinking water treatment, new wells, monitoring, or other safe drinking water actions; over 1.3 million people are financially susceptible because nitrate in raw source water exceeds the MCL, requiring actions by drinking water systems. Nitrate contamination of drinking water sources will continue to increase as nitrogen from fertilizer, manure, and other sources applied in the last half century continues to percolate downward and flow toward drinking water wells.

Findings: Sources of Nitrate Pollution

Within the study area, human-generated nitrate sources to groundwater include (Figure ES-1):

- cropland (96% of total), where nitrogen applied to crops, but not removed by harvest, air emission, or runoff, is leached from the root zone to groundwater. Nitrogen intentionally or incidentally applied to cropland includes synthetic fertilizer (54%), animal manure (33%), irrigation source water (8%), atmospheric deposition (3%), and wastewater treatment and food processing facility effluent and associated solids (2%) (Figure ES-2);
- percolation of wastewater treatment plant (WWTP) and food processing (FP) wastes (1.5% of total);
- leachate from septic system drainfields (1% of total);
- urban parks, lawns, golf courses, and leaky sewer systems (less than 1% of total); and
- recharge from animal corrals and manure storage lagoons (less than 1% of total);
- downward migration of nitrate-contaminated water via wells (less than 1% of total).

Findings: Reducing Nitrate Pollution

Options for reducing nitrate pollution were identified for all sources. For cropland, where less than 40% of applied nitrogen is removed by crop harvest, 10 management measures (and 50 practices and technologies to achieve these management objectives) were reviewed that can reduce—but not eliminate—nitrate leaching to groundwater. These fall into four categories:

1. Design and operate irrigation and drainage systems to reduce deep percolation.
2. Manage crop plants to capture more nitrogen and decrease deep percolation.
3. Manage nitrogen fertilizer and manure to increase crop nitrogen use efficiency.
4. Improve storage and handling of fertilizers and manure to decrease off-target discharge.

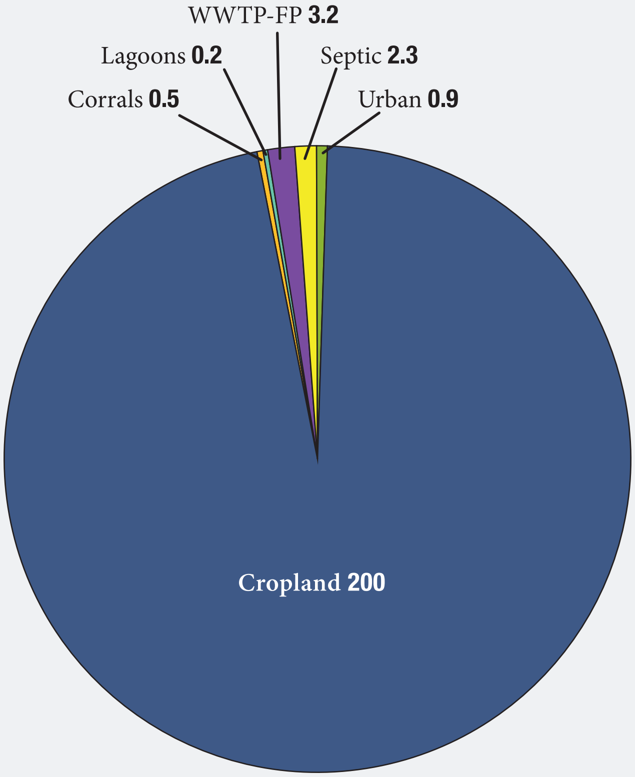
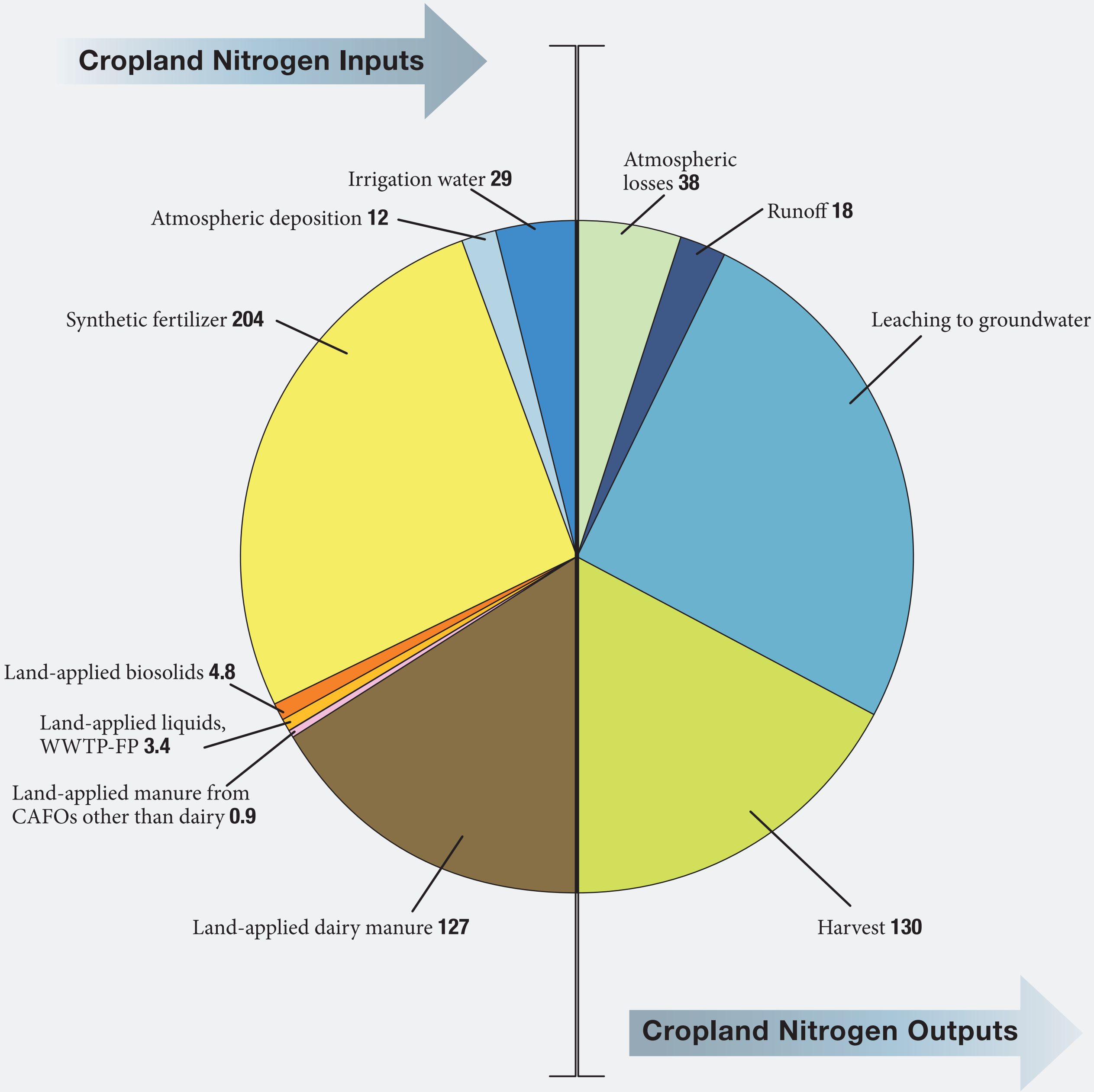


Figure ES-1. Estimated groundwater nitrate loading from major sources within the Tulare Lake Basin and Salinas Valley, in Gg nitrogen per year (1 Gg = 1,100 t).



Note: No mass balance was performed on 0.17 million ha (0.4 million ac) of nitrogen-fixing alfalfa, which is estimated to contribute an additional 5 Gg N/yr to groundwater. Groundwater nitrate loading from all non-cropland sources is about 8 Gg N/yr.

Figure ES-2. Overview of cropland input and output (Gg N/yr) in the study area (Tulare Lake Basin and Salinas Valley) in 2005. The left half of the pie chart represents total nitrogen inputs to 1.27 million ha (3.12 million ac) of cropland, not including alfalfa. The right half of the pie chart represents total nitrogen outputs with leaching to groundwater estimated by difference between the known inputs and the known outputs. Source: Viers et al. 2012.

Some of the needed improvements in nitrogen use efficiency by crops will require increased operating costs, capital improvements, and education. For some cropland, the high economic costs of nitrate source reduction sufficient to prevent groundwater degradation will likely hinder strict compliance with the state's current anti-degradation policy for groundwater (State Water Board Resolution 68-16).

Findings: Groundwater Nitrate Pollution

Groundwater nitrate data were assembled from nearly two dozen agencies and other sources (100,000 samples from nearly 20,000 wells). Of the 20,000 wells, 2,500 are frequently sampled public water supply wells (over 60,000 samples). In these public supply wells, about 1 in 10 raw water samples exceed the nitrate MCL. Apart from the recently established Central Valley dairy regulatory program in the Tulare Lake Basin, there are no existing regular well sampling programs for domestic and other private wells.

The largest percentages of groundwater nitrate MCL exceedances are in the eastern Tulare Lake Basin and in the northern, eastern, and central Salinas Valley, where about one-third of tested domestic and irrigation wells exceed the MCL. These same areas have seen a significant increase in nitrate concentrations over the past half century, although local conditions and short-term trends vary widely.

Travel times of nitrate from source to wells range from a few years to decades in domestic wells, and from years to many decades and even centuries in deeper production wells. This means that nitrate source reduction actions made today may not affect sources of drinking water for years to many decades.

Findings: Groundwater Remediation

Groundwater remediation is the cleanup of contaminated groundwater to within regulatory limits. Traditional pump-and-treat and in-place approaches to remediation, common for localized industrial contamination plumes, would cost billions of dollars over many decades to remove nitrate from groundwater in the Tulare Lake Basin and Salinas Valley. Timely cleanup of basin-scale nitrate contamination is not technically feasible.

Instead, long-term remediation by "pump-and-fertilize" would use existing agricultural wells to gradually remove nitrate-contaminated groundwater and treat the water by ensuring nitrate uptake by crops through appropriate nutrient and irrigation water management. Improved groundwater recharge management would provide clean groundwater recharge to mix with irrigation water recharge and partially mitigate nitrate levels in groundwater regionally.

Removal or reduction of contamination sources must accompany any successful remediation effort. Combining "pump-and-fertilize" with improved groundwater recharge management is more technically feasible and cost-effective.

Findings: Safe Drinking Water Supply

Nitrate contamination is widespread and increasing. Groundwater data show that 57% of the current population in the study area use a community public water system with recorded raw (untreated) nitrate concentrations that have exceeded the MCL at least once between 2006 and 2010. Continued basin-wide trends in nitrate groundwater concentration may raise the affected population to nearly 80% by 2050. Most of this population is protected by water system treatment, or alternative wells, at additional cost. But about 10% of the current population is at risk of nitrate contamination in their delivered drinking water, primarily in small systems and self-supplied households.

No single solution will fit every community affected by nitrate in groundwater. Each affected water system requires individual engineering and financial analyses.

Communities served by small systems vulnerable to nitrate contamination can (a) consolidate with a larger system that can provide safe drinking water to more customers; (b) consolidate with nearby small systems into a new single larger system that has a larger ratepayer base and economies of scale; (c) treat the contaminated water source; (d) switch to surface water; (e) use interim bottled water or point-of-use treatment until an approved long-term solution can be implemented; (f) drill a new well; or (g) blend contaminated wells with cleaner sources, at least temporarily.

There is significant engineering and economic potential for consolidating some systems. Consolidation can often permanently address nitrate problems, as well as many other problems faced by small water systems.

Solutions for self-supplied households (domestic well) or local small water systems (2–4 connections) affected by nitrate contamination are point-of-use (POU) or point-of-entry (POE) treatment and drilling a new or deeper well, albeit with no guarantee for safe drinking water.

Additional costs for safe drinking water solutions to nitrate contamination in the Tulare Lake Basin and Salinas Valley are roughly $20 and $36 million per year for the short- and long-term solutions, respectively. About $17 to $34 million per year will be needed to provide safe drinking water for 85 identified community public and state small water systems in the study area that exceed the nitrate drinking water MCL (serving an estimated 220,000 people). The annualized cost of providing nitrate-compliant drinking water to an estimated 10,000 affected rural households (34,000 people) using private domestic wells or local small water systems is estimated to be at least $2.5 million for point-of-use treatment for drinking use only. The total cost for alternative solutions translates to $80 to $142 per affected person per year, $5 to $9 per irrigated acre per year, or $100 to $180 per ton of fertilizer nitrogen applied in these groundwater basins.

Findings: Regulatory, Funding, and Policy Options

To date, regulatory actions have been insufficient to control nitrate contamination of groundwater. Many options exist to regulate nitrate loading to groundwater, with no ideal solution. Nitrate source reductions will improve drinking water quality only after years to decades. Fertilizer regulations have lower monitoring and enforcement costs and information requirements than do nitrate leachate regulations, but they achieve nitrate reduction targets less directly. Costs to farmers can be lower with fertilizer fees or market-based regulations than with technology mandates or prescriptive standards. Market-based approaches may also encourage the development and adoption of new technologies to reduce fertilizer use.

Current funding programs cannot ensure safe drinking water in the Salinas Valley and Tulare Lake Basin. Small water system costs are high, and some of these systems already face chronic financial problems. Most current state funding for nitrate contamination problems is short term. Little funding is provided for regionalization and consolidation of drinking water systems. Policy options exist for long-term funding of safe drinking water, but all existing and potential options will require someone to bear the costs.

Promising Actions

Addressing groundwater nitrate contamination 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. Promising actions for legislative and state agency consideration in these areas appear below (see also Table ES-1). Starred (*) actions do not appear to require legislative action, but might benefit from it.

Safe Drinking Water Actions (D)

Safe drinking water actions are the most effective and economical short- and long-term approach to address nitrate contamination problems in the Tulare Lake Basin and Salinas Valley. These actions apply especially to small and self-supplied household water systems, which face the greatest financial and public health problems from nitrate groundwater contamination.

D1: Point-of-Use (POU) Treatment Option. CDPH reports on how to make economical household and point-of-use treatment for nitrate contamination an available and permanent solution for small water systems.*

D2: Small Water System Task Force. CalEPA and CDPH convene an independently led Task Force on Small Water Systems that would report on problems and solutions of small water and wastewater systems statewide as well as the efficacy of various state, county, and federal programs to aid small water and wastewater systems. Many nitrate contamination problems are symptomatic of the broad problems of small water and wastewater systems.*

D3: Regional Consolidation. CDPH and counties provide more legal, technical, and funding support for preparing consolidation of small water systems with nearby larger systems and creating new, regional safe drinking water solutions for groups of small water systems, where cost-effective.*

D4: Domestic Well Testing. In areas identified as being at risk for nitrate contamination by the California Water Boards, as a public health requirement, CDPH (a) mandates periodic nitrate testing for private domestic wells and local and state small systems and (b) requires disclosure of recent well tests for nitrate contamination on sales of residential property. County health departments also might impose such requirements.

D5: Stable Small System Funds. CDPH receives more stable funding to help support capital and operation and maintenance costs for new, cost-effective and sustainable safe drinking water solutions, particularly for disadvantaged communities (DACs).

Source Reduction Actions (S)

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. Within the framework of Porter-Cologne, 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. The following options seem most promising to reduce nitrate loading.

S1: Education and Research. California Department of Food and Agriculture (CDFA), in cooperation with the University of California and other organizations, develops and delivers a comprehensive educational and technical program to help farmers improve efficiency in nitrogen use (including manure) and reduce nitrate loading to groundwater. This could include a groundwater nitrate–focused element for the existing CDFA Fertilizer Research and Education Program, including "pump-and-fertilize" remediation and improved recharge options for groundwater cleanup.*

S2: Nitrogen Mass Accounting Task Force. CalEPA establishes a Task Force, including CDFA, to explore nitrogen mass balance accounting methods for regulating agricultural land uses in areas at risk for nitrate contamination, and to compare three long-term nitrogen source control approaches: (a) a cap and trade system; (b) farm-level nutrient management plans, standards, and penalties; and (c) nitrogen fertilizer fees.*

S3: Fertilizer Excise Fee. Significantly raising the cost of commercial fertilizer through a fee or excise tax would fund safe drinking water actions and monitoring and give further incentive to farmers for reducing nitrate contamination. An equivalent fee or excise tax could be considered for organic fertilizer sources (manure, green waste, wastewater effluent, biosolids, etc.).

S4: Higher Fertilizer Fee in Areas at Risk. Areas declared to be at risk for nitrate contamination might be authorized to maintain a higher set of excise fees on nitrogen fertilizer applications (including synthetic fertilizer, manure, waste effluent, biosolids, and organic amendments), perhaps as part of a local safe drinking water compensation agreement.

Monitoring and Assessment (M)

Monitoring and assessment is needed to better assess the evolving nitrate pollution problem and the effectiveness of safe drinking water and nitrate source loading reduction actions. Such activities should be integrated with other state agricultural, environmental, and land use management; groundwater data; and assessment programs (source loading reduction actions)—along with other drinking water, treatment, and wastewater management programs (safe drinking water actions).

M1: Define Areas at Risk. Regional Water Boards designate areas where groundwater sources of drinking water are at risk of being contaminated by nitrate.*

M2: Monitor at-Risk Population. CDPH and the State Water Board, in coordination with DWR and CDFA, issue a report every 5 years to identify populations at risk of contaminated drinking water and to monitor long-term trends of the state's success in providing safe drinking water as a supplement to the California Water Plan Update.*

M3: Learn from Department of Pesticide Regulation Programs. CalEPA and CDFA examine successful DPR data collection, analysis, education, and enforcement programs for lessons in managing nitrogen and other agricultural contaminants, and consider expanding or building upon the existing DPR program to include comprehensive nitrogen use reporting to support nitrate discharge management.*

M4: Groundwater Data Task Force. CalEPA , in coordination with CalNRA and CDPH, convenes an independently led State Groundwater Data Task Force to examine the efficacy of current state and local efforts to collect, maintain, report, and use groundwater data for California's groundwater quality and quantity problems.

M5: Groundwater Task Force. CalEPA, CalNRA, and CDPH maintain a joint, permanent, and independently led State Groundwater Task Force to periodically assess and coordinate state technical and regulatory groundwater programs in terms of effectiveness at addressing California's groundwater quality and quantity problems. These reports would be incorporated into each California Water Plan Update.*

Funding (F)

Little effective action can occur without funding. Four funding options seem most promising, individually or in combination. State funding from fees on nitrogen or water use, which directly affect nitrate groundwater contamination, seem particularly promising and appropriate.

F1: Mill Fee. Increase the mill assessment rate on nitrogen fertilizer to the full authorized amount (CAL. FAC Code Section 14611). This would raise roughly $1 million/year statewide and is authorized for fertilizer use research and education.*

F2: Local Compensation Agreements. Regional Water Boards can require and arrange for local compensation of affected drinking water users under Porter-Cologne Act Water Code Section 13304. Strengthening existing authority, the Legislature could require that a Regional Water Board finding that an area is at risk of groundwater nitrate contamination for drinking water be accompanied by a cleanup and abatement order requiring overlying, current sources of nitrate to financially support safe drinking water actions acceptable to the local County Health Department. This might take the form of a local "liability district."*

F3: Fertilizer Excise Fee. Introduce a substantial fee on nitrogen fertilizer sales or use, statewide or regionally, to fund safe drinking water actions, nitrate source load reduction efforts, and nitrate monitoring and assessment programs.

F4: Water Use Fee. A more comprehensive statewide fee on water use could support many beneficial activities. Some of such revenues could fund management and safe drinking water actions in areas affected by nitrate contamination, including short-term emergency drinking water measures for disadvantaged communities.

Table ES-1. Likely performance of promising state and agency actions for nitrate groundwater contamination.

Action	Safe Drinking Water	Groundwater Degradation	Economic Cost
No Legislation Required			
Safe Drinking Water Actions			
D1: Point-of-Use Treatment Option for Small Systems +	◆◆		low
D2: Small Water Systems Task Force +	◆		low
D3: Regionalization and Consolidation of Small Systems +	◆◆		low
Source Reduction Actions			
S1: Nitrogen/Nitrate Education and Research +		◆◆◆	low–moderate
S2: Nitrogen Accounting Task Force +		◆◆	low
Monitoring and Assessment			
M1: Regional Boards Define Areas at Risk +	◆◆◆	◆◆◆	low
M2: CDPH Monitors At-Risk Population +	◆	◆	low
M3: Implement Nitrogen Use Reporting +		◆◆	low
M4: Groundwater Data Task Force +	◆	◆	low
M5: Groundwater Task Force +	◆	◆	low
Funding			
F1: Nitrogen Fertilizer Mill Fee		◆◆◆	low
F2: Local Compensation Agreements for Water +	◆◆	◆	moderate
New Legislation Required			
D4: Domestic Well Testing *	◆◆		low
D5: Stable Small System Funds	◆		moderate
Non-tax legislation could also strengthen and augment existing authority.			
Fiscal Legislation Required			
Source Reduction			
S3: Fertilizer Excise Fee	◆◆	◆	moderate
S4: Higher Fertilizer Fee in Areas at Risk	◆	◆	moderate
Funding Options			
F3: Fertilizer Excise Fee	◆◆	◆◆	moderate
F4: Water Use Fee	◆◆	◆◆	moderate

◆ Helpful
◆◆ Effective
◆◆◆ Essential
+ Legislation would strengthen.
* County health departments may have authority; CDPH requires legislation.

1 Introduction

The development of California's tremendous economy has not been without environmental costs. Since early in the twentieth century, nitrate from agricultural and urban activities has slowly infiltrated into groundwater. Nitrate has accumulated and spread and will continue to make its way into drinking water supplies. The time lag between the application of nitrogen to the landscape and its withdrawal at household and community public water supply wells, after percolating through soils and groundwater, commonly extends over decades.

This Report is an overview of groundwater contamination by nitrate in the Tulare Lake Basin and Salinas Valley. We examine the extent, causes, consequences, and costs of this contamination, as well as how it will likely develop over time. We also examine management and policy actions available for this problem, including possible nitrate source reduction, provisions for safe drinking water, monitoring and assessment, and aquifer remediation actions. The costs and institutional complexities of these options, and how they might be funded, also are addressed.

Addressing nitrate contamination problems in the Tulare Lake Basin and Salinas Valley will require decades to resolve, driven by the pace of groundwater flow and the response times of humans and institutions on the surface. Nitrate in drinking water today is a legacy contaminant, but years and decades from now the nitrate in drinking water will be from today's discharges. Assistance and management to improve drinking water supplies in response to nitrate contamination is a central and urgent policy issue for the State of California. Another major policy issue is the inevitability of widespread groundwater degradation for decades to come, despite even heroic (and ultimately expensive) efforts to reduce nitrate loading into aquifers. This introduction attempts to put the issue in a larger context.

Groundwater is essential to California. Groundwater is vital for California's agricultural, industrial, urban, and drinking water uses. Depending on drought conditions, groundwater provides between one-third and nearly one-half of the state's water supplies. As a source of drinking water, groundwater serves people from highly dispersed rural communities to densely populated cities. More than 85% of community public water systems in California (serving 30 million residents) rely on groundwater for at least part of their drinking water supply. In addition, approximately 2 million residents rely on groundwater from either a private domestic well or a smaller water system not regulated by the state (State Water Board 2011). Intensive agricultural production, population growth, and—indirectly—partial restoration of environmental instream flows have led to groundwater overdraft (Hanak et al. 2011). More protective health-based water quality standards for naturally occurring water quality constituents and groundwater contamination from urban and agricultural activities pose serious challenges to managing the state's drinking water supply.

Nitrate is one of California's most widespread groundwater contaminants. Nitrate is among the most frequently detected contaminants in groundwater systems around the world, including the extensively tapped aquifers in California's Central Valley and Salinas Valley (Figure 1) (Spalding and Exner 1993; Burow et al. 2010; Dubrovsky et al. 2010; MCWRA 2010; Sutton et al. 2011). Nitrate contamination poses an environmental health risk because many rural areas obtain drinking water from wells that are often shallow and vulnerable to contamination (Guillette and Edwards 2005; Fan and Steinberg 1996).

High levels of nitrate affect human health. Infants who drink water (often mixed with baby formula) containing nitrate in excess of the maximum contaminant level (MCL) for drinking water may quickly become seriously ill and, if untreated, may die because high nitrate levels can decrease the capacity of an infant's blood to carry oxygen (methemoglobinemia, or "blue baby syndrome"). High nitrate levels may also affect pregnant women and adults with hereditary cytochrome b5 reductase deficiency. In addition, nitrate and nitrite ingestion in humans has been linked to goitrogenic (anti-thyroid) actions on the thyroid gland (similar to perchlorate), fatigue and reduced cognitive functioning due to chronic hypoxia, maternal reproductive complications including spontaneous abortion, and a variety of carcinogenic outcomes deriving from N-nitrosamines formed via gastric nitrate conversion in the presence of amines (Ward et al. 2005).

Nitrate is part of the natural nitrogen cycle in the environment. Groundwater nitrate is part of the global nitrogen cycle. Like other key elements essential for life, nitrogen flows through the environment in a dynamic cycle that supports organisms ranging from microbes to plants to animals. Plants require nitrogen for growth, and scarcity of fixed soil nitrogen often limits plant growth. Specialized microorganisms can fix atmospheric elemental nitrogen and make it available for plants to use for photosynthesis and growth. The natural nitrogen cycle is a dynamic balance between elemental nitrogen in the atmosphere and reactive forms of nitrogen moving through the soil-plant-animal-water-atmosphere cycle of ecosystems globally. Production of synthetic nitrogen fertilizer has disrupted this balance.

Nitrogen is key to global food production. Modern agricultural practices, using synthetically produced nitrogen fertilizer, have supplied the nitrogen uses of plants to increase food, fiber, feed, and fuel production for consumption by humans and livestock. Agricultural production is driven by continued global growth in population and wealth, which increases demand for agricultural products, particularly high-value agricultural products such as those produced in California. Global food, feed, and fiber demands are anticipated to increase by over 70% over the next 40 years (Tilman et al. 2002; De Fraiture et al. 2010).

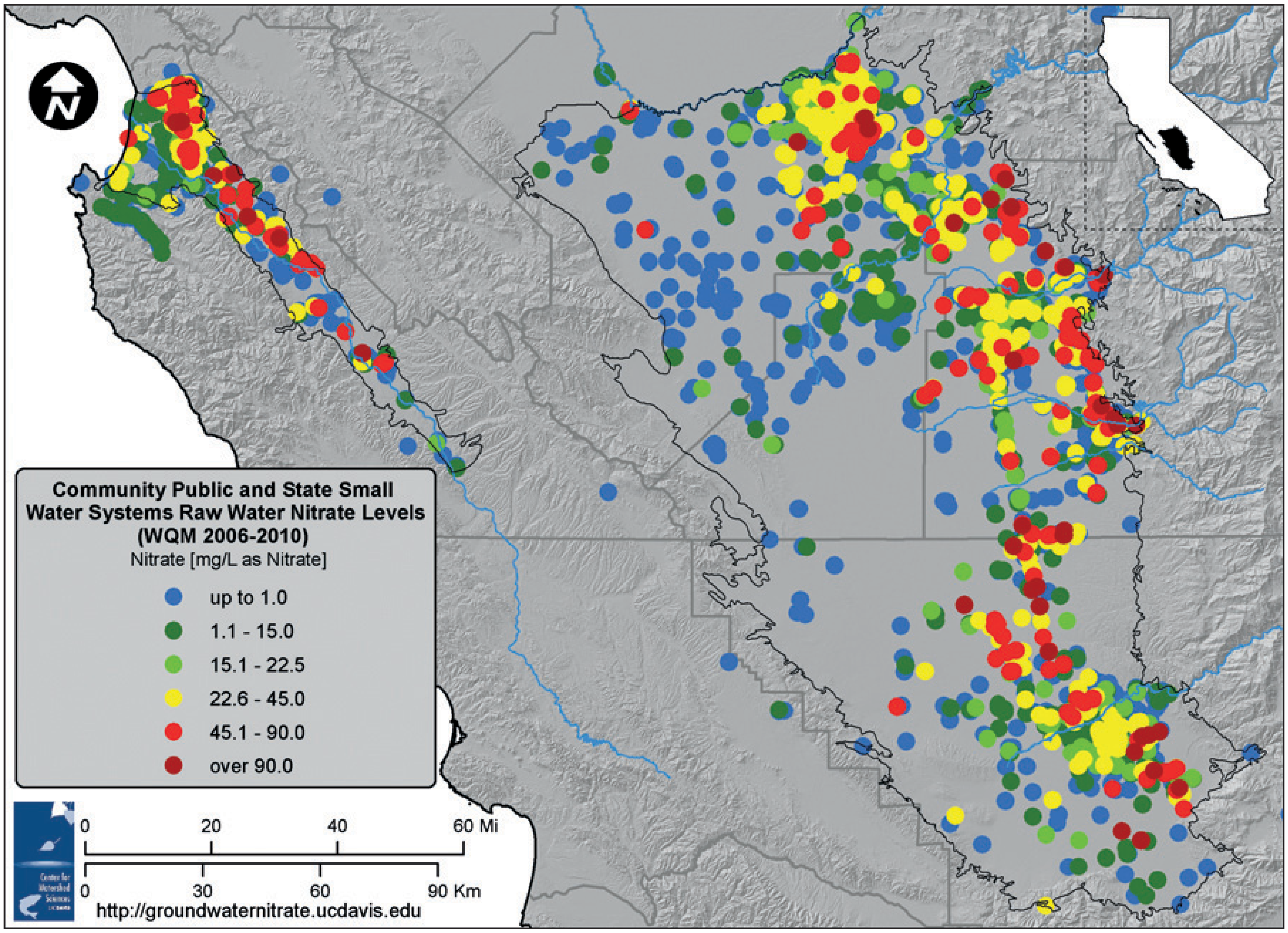


Figure 1. Maximum reported raw-level nitrate concentration in community public water systems and state-documented state small water systems, 2006–2010. Source: CDPH PICME WQM Database (see Honeycutt et al. 2011).

Intensive agriculture and human activities have increased nitrate concentrations in the environment. Greater use of nitrogen-based fertilizers, soil amendments such as manure, and nitrogen-fixing cover crops add nitrogen to deficient soils and dramatically raise crop yields. Technological advances in agriculture, manufacturing, and urban practices have increased levels of reactive forms of nitrogen, including nitrate, released into the atmosphere, into surface water, and into groundwater. The nearly 10-fold increase of reactive nitrogen creation related to human activities over the past 100 years (Galloway and Cowling 2002) has caused a wide range of adverse ecological and environmental impacts (Davidson et al. 2012).

The most remarkable impacts globally include the leaching of nitrate to groundwater; the eutrophication of surface waters and resultant marine "dead zones"; atmospheric deposition that acidifies ecosystems; and the emission of nitrogen oxides (NOx) that deplete stratospheric ozone (Keeney and Hatfield 2007; Beever et al. 2007; Foley et al. 2005). These widespread environmental changes also can threaten human health (Galloway et al. 2008; Guillette and Edwards 2005; Galloway et al. 2004; Townsend et al. 2003; Vitousek et al. 1997; Fan and Steinberg 1996; Jordan and Weller 1996).

California has decentralized regulatory responsibility for groundwater nitrate contamination. Nitrate contamination of groundwater affects two state agencies most directly. Sources of groundwater nitrate are regulated under California's Porter-Cologne Water Quality Control Act (Porter-Cologne) administered through the State Water Resources Control Board (State Water Board) and the Regional Water Quality Control Boards (Regional Water Boards). State Water Board Resolution 88-63 designates drinking water as a beneficial use in nearly all of California's major aquifers. Under the Porter-Cologne Act, dischargers to groundwater are responsible, first, for preventing adverse effects on groundwater as a source of drinking water, and second, for cleaning up groundwater when it becomes contaminated.

Drinking water in public water systems (systems with at least 15 connections or serving at least 25 people for 60 or more days per year) is regulated by CDPH under the federal Safe Drinking Water Act of 1972 (SWDA). CDPH has set the nitrate MCL in drinking water at 45 mg/L (10 mg/L as nitrate-N). If nitrate levels in public drinking water supplies exceed the MCL standard, mitigation measures must be employed by water purveyors to provide a safe supply of drinking water to the population at risk.

The California Department of Food and Agriculture (CDFA) and the Department of Water Resources (DWR) also have roles in nitrate management. The DWR is charged with statewide planning and funding efforts for water supply and water quality protection, including the funding of Integrated Regional Water Management Plans and DWR's management of urban and agricultural water use efficiency. CDFA collects data, funds research, and promotes education regarding the use of nitrogen fertilizers and other nutrients in agriculture.

SBX2 1 Nitrate in Groundwater Report to Legislature. In 2008, the California legislature enacted Senate Bill SBX2 1 (Perata), which created California Water Code Section 83002.5. The bill requires the State Water Board to prepare a Report to the Legislature (within 2 years of receiving funding) to "improve understanding of the causes of [nitrate] groundwater contamination, identify potential remediation solutions and funding sources to recover costs expended by the state for the purposes of this section to clean up or treat groundwater, and ensure the provision of safe drinking water to all communities." Specifically, the bill directs the State Water Board to

> identify sources, by category of discharger, of groundwater contamination due to nitrate in the pilot project basins; to estimate proportionate contributions to groundwater contamination by source and category of discharger; to identify and analyze options within the board's current authority to reduce current nitrate levels and prevent continuing nitrate contamination of these basins and estimate the costs associated with exercising existing authority; to identify methods and costs associated with the treatment of nitrate contaminated groundwater for use as drinking water; to identify methods and costs to provide an alternative water supply to groundwater reliant communities in each pilot project basin; to identify all potential funding sources to provide resources for the cleanup of nitrate, groundwater treatment for nitrate, and the provision of alternative drinking water supply, including, but not limited to, State bond funding, federal funds, water rates, and fees or fines on polluters; and to develop recommendations for developing a groundwater cleanup program for the Central Valley Water Quality Control Region and the Central Coast Water Quality Control Region based upon pilot project results.

The bill designates the groundwater basins of the Tulare Lake Basin region and the Monterey County portion of the Salinas Valley as the selected pilot project areas. In June 2010, the State Water Board contracted with the University of California, Davis, to prepare this Report for the Board as background for its Report to the Legislature.

Project area is relevant to all of California. The project area encompasses all DWR Bulletin 118 designated groundwater sub-basins of the Salinas River watershed that are fully contained within Monterey County, and the Pleasant Valley, Westside, Tulare Lake Bed, Kern, Tule River, Kaweah River, and Kings River groundwater sub-basins of the Tulare Lake Basin. The study area—2.3 million ha (5.7 million ac) in size—is home to approximately 2.65 million people, almost all of whom rely on groundwater as a source of drinking water. The study area includes four of the nation's five counties with the largest agricultural production; 1.5 million ha (3.7 million ac) of irrigated cropland, representing about 40% of California's irrigated cropland; and more than half of California's dairy herd. More than 80 different crops are grown in the study area (Figure 2). This is also one of California's poorest regions: many census blocks with significant population belong to the category of severely disadvantaged communities (less than 60% of the state's median household income), and many of the remaining populated areas are disadvantaged communities (less than 80% of the state's median household income). These communities have little economic means and technical capacity to maintain safe public drinking water systems given contamination from nitrate and other contaminants in their drinking water sources.

Report excludes assessment of public health standards for nitrate. Public health and appropriateness of the drinking water limits are prescribed by CDPH and by U.S. EPA under SDWA. The scope of SBX2 1 precluded a review of the public health aspects or a review of the appropriateness of the nitrate MCL, although this is recognized as an important and complex aspect of the nitrate contamination issue (Ward et al. 2005).

"Report for the State Water Resources Control Board Report to the Legislature" and supporting Technical Reports. This Report for the State Water Board Report to the Legislature ("Report") has been provided in fulfillment of the University of California, Davis, contract with the State Water Board. This Report provides an overview of the goals of the research, methods, and key findings of our work, and is supported by eight related Technical Reports (Harter et al. 2012; Viers et al. 2012; Dzurella et al. 2012; Boyle et al. 2012; King et al. 2012; Jensen et al. 2012; Honeycutt et al. 2012; and Canada et al. 2012). The Technical Reports provide detailed information on research methods, research results, data summaries, and accompanying research analyses that are important for evaluating our results and findings and for applying our approach and results to other groundwater basins.

The Report takes a broad yet quantitative view of the groundwater nitrate problem and solutions for this area and reflects collaboration among a diverse, interdisciplinary team of experts. In its assessment, the Report spans institutional and governmental boundaries. The Report quantifies the diverse range of sources of groundwater nitrate. It reviews the current groundwater quality status in the project area by compiling and analyzing all available data from a variety of institutions. It then identifies source reduction, groundwater remediation, drinking water treatment, and alternative drinking water supply alternatives, along with the costs of these options. Descriptions and summaries are also included of current and potential future funding options and regulatory measures to control source loading and provide safe drinking water, along with their advantages, disadvantages, and potential effectiveness.

This set of Reports is the latest in a series of reports on nitrate contamination in groundwater beginning in the 1970s (Schmidt 1972; Report to Legislature 1988; Dubrovsky et al. 2010; U.S. EPA 2011). This Report has some of the same conclusions as previous reports but takes a much broader perspective, contains more analysis, and perhaps provides a wider range of promising actions.

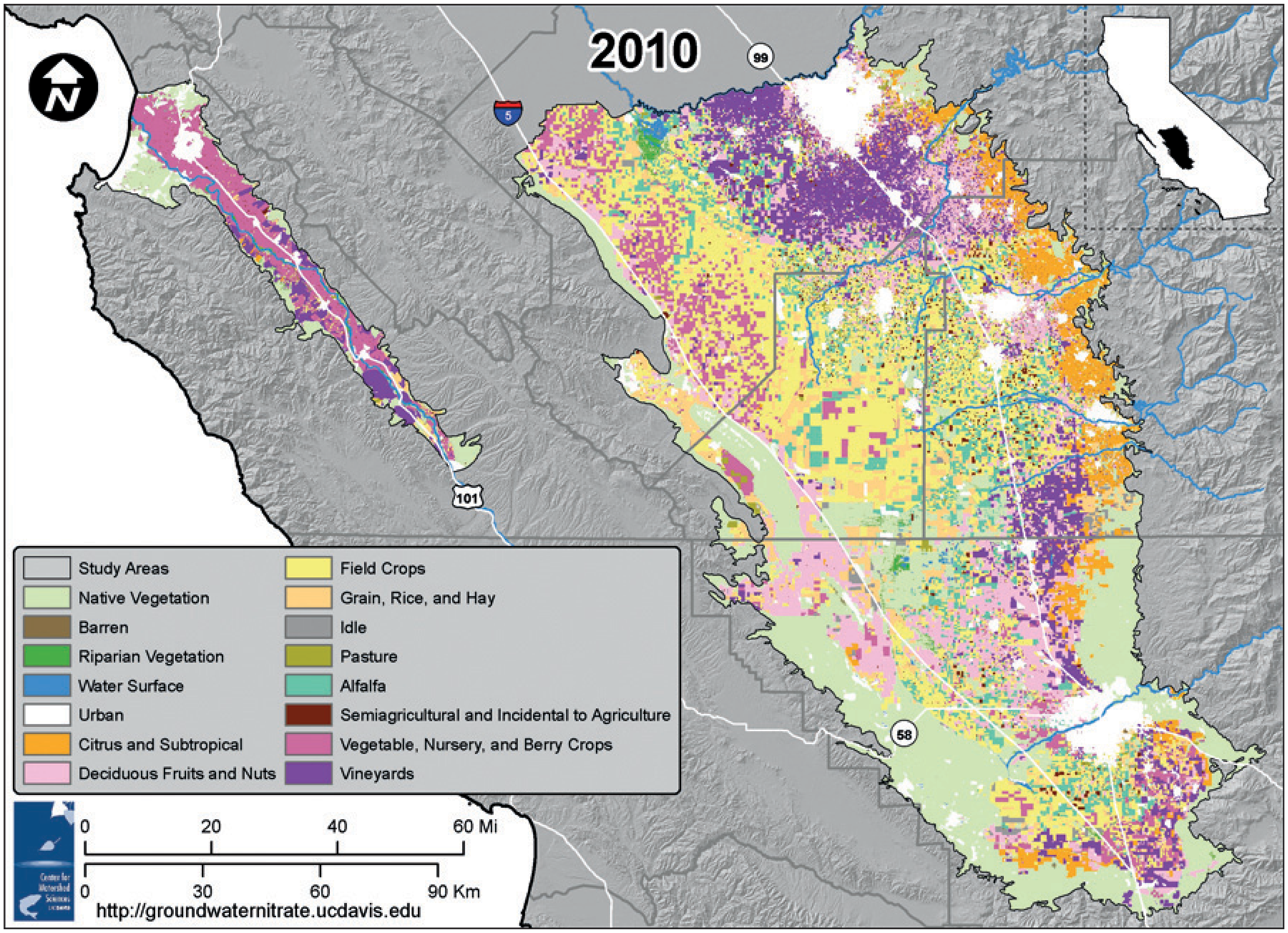
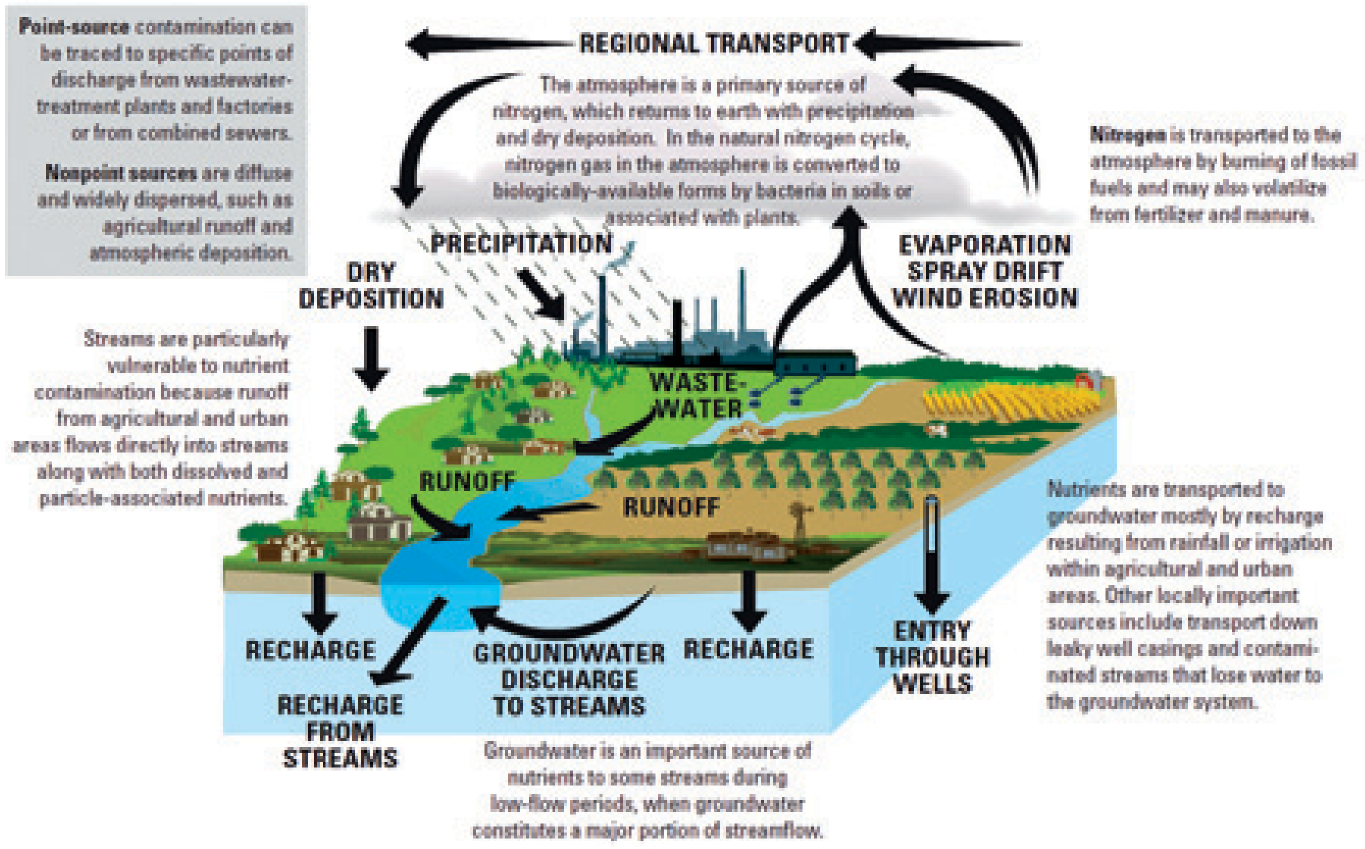


Figure 2. The Tulare Lake Basin (TLB) and Salinas Valley (SV) are the focus of this study. The study area represents 40% of California's diverse irrigated agriculture and more than half of its confined animal farming industry. It is home to 2.6 million people, with a significant rural population in economically disadvantaged communities. Source: Viers et al. 2012.



Point-source contamination can be traced to specific points of discharge from wastewater-treatment plants and factories or from combined sewers.

Nonpoint sources are diffuse and widely dispersed, such as agricultural runoff and atmospheric deposition.

The atmosphere is a primary source of nitrogen, which returns to earth with precipitation and dry deposition. In the natural nitrogen cycle, nitrogen gas in the atmosphere is converted to biologically-available forms by bacteria in soils or associated with plants.

Nitrogen is transported to the atmosphere by burning of fossil fuels and may also volatilize from fertilizer and manure.

Streams are particularly vulnerable to nutrient contamination because runoff from agricultural and urban areas flows directly into streams along with both dissolved and particle-associated nutrients.

Nutrients are transported to groundwater mostly by recharge resulting from rainfall or irrigation within agricultural and urban areas. Other locally important sources include transport down leaky well casings and contaminated streams that lose water to the groundwater system.

Groundwater is an important source of nutrients to some streams during low-flow periods, when groundwater constitutes a major portion of streamflow.

Source: Dubrovsky et al. 2010.

2 Sources of Groundwater Nitrate

2.1 Nitrogen Cycle: Basic Concepts

Nitrogen is an essential element for all living organisms. Nitrogen cycles through the atmosphere, hydrosphere, and biosphere. The dominant gas (78%) in the atmosphere is highly stable (inert) N_2 gas. Biological nitrogen fixation transforms N_2 gas into ammonia (NH_3), which is rapidly converted to the forms of nitrogen needed for plant growth. Nitrogen fixation is performed only by specialized soil and aquatic microbes. Other living organisms cannot use inert atmospheric N_2 directly but rely on accumulated soil organic matter, plants, animals, and microbial communities for nitrogen.

Soil nitrogen is most abundant in the organic form (N_{org}). Mineralization is a suite of processes performed by soil microbes that converts organic nitrogen to inorganic forms of nitrogen. The rates of mineralization depend on the environmental conditions such as temperature, moisture, pH, and oxygen content, as well as the type of organic matter available. The first product of mineralization is ammonium (NH_4^+), but under aerobic conditions, microbes can convert ammonium (NH_4^+) first to nitrite (NO_2^-) and then to nitrate (NO_3^-). Most plants use nitrate or ammonium as their preferred source of nitrogen (White 2006). Immobilization is the reverse of mineralization in that soil ammonium and nitrate are taken up by soil organisms and plants and converted into N_{org}.

The ultimate fate of "reactive" nitrogen (organic nitrogen, ammonium, nitrate, ammonia, nitrous oxide, etc.) is to return back to the atmosphere as N_2. For nitrate, this is a microbially mediated process ("denitrification") that requires an anoxic (i.e., oxygen-free) environment.

Groundwater is becoming a growing component of the global nitrogen cycle because of the increased nitrogen inflows and because of long groundwater residence times. Nitrate does not significantly adhere to or react with sediments or other geologic materials, and it moves with groundwater flow. Other forms of reactive nitrogen in groundwater are less significant and much less mobile: ammonia occurs under some groundwater conditions, but it is subject to sorption and rapidly converts to nitrate under oxidizing conditions. Dissolved organic nitrogen (DON) concentrations are generally much less than those of nitrate, except near wastewater sources, due to the high adsorption of DON to aquifer materials.

Groundwater nitrate inputs may come from natural, urban, industrial, and agricultural sources. Groundwater nitrate outputs occur through wells or via discharge to springs, streams, and wetlands. Discharge to surface water sometimes involves denitrification or reduction of nitrate to ammonium when oxygen-depleted conditions exist beneath wetlands and in the soils immediately below streams.

2.2 Sources of Nitrate Discharge to Groundwater

Nitrogen enters groundwater at varying concentrations and in varying forms (organic nitrogen, ammonium, nitrate) with practically all sources of recharge: diffuse recharge from precipitation and irrigation; focused recharge from streams, rivers, and lakes; focused recharge from recharge basins and storage lagoons; and focused recharge from septic system drainfields. Across major groundwater basins in California, diffuse recharge from irrigation, stream recharge, and intentional recharge are the major contributors to groundwater. Since groundwater is an important reservoir for long-term water storage, recharge is extremely important and desirable in many areas. Controlling nitrate in recharge and managing recharge are therefore key to nitrate source control.

Current groundwater nitrate, its spatial distribution, and its changes over time are the result of recent as well as historical nitrate loading. To understand current and future groundwater conditions requires knowledge of historical, current, and anticipated changes in land use patterns, recharge rates, and nitrate loading rates (Viers et al. 2012).

Natural Nitrate Sources

Nitrate occurs naturally in many groundwaters but at levels far below the MCL for drinking water (Mueller and Helsel 1996). The main potential sources of naturally occurring nitrate are bedrock nitrogen and nitrogen leached from natural soils. Surface water nitrate concentrations can be elevated in areas with significant bedrock nitrogen (Holloway et al. 1998), but they are not high enough to be a drinking water concern. During the early twentieth century, conversion of the study area's semiarid and arid natural landscape to irrigated agriculture may have mobilized two additional, naturally occurring sources of nitrate. First, nitrate was released from drained wetlands at the time of land conversion due to increased microbial activity in agricultural soils; stable organic forms of nitrogen that had accumulated in soils over millennia were converted to mobile nitrate. Second, nitrate salts that had accumulated over thousands of years in the unsaturated zone below the grassland and desert soil root zone due to lack of significant natural recharge were mobilized by irrigation (Dyer 1965; Stadler et al. 2008; Walvoord et al. 2003). However, the magnitude of these sources (Scanlon 2008) is considered to have negligible effects on regional groundwater nitrate given the magnitude of human sources.

Human Nitrate Sources

Anthropogenic groundwater nitrate sources in the study area include agricultural cropland, animal corrals, animal manure storage lagoons, wastewater percolation basins at municipal wastewater treatment plants (WWTPs) and food processors (FPs), septic system drainfields (onsite sewage systems), leaky urban sewer lines, lawns, parks, golf courses, and dry wells or percolation basins that collect and recharge stormwater runoff. Incidental leakage of nitrate may also occur directly via poorly constructed wells. Croplands receive nitrogen from multiple inputs: synthetic fertilizer, animal manure, WWTP and FP effluent, WWTP biosolids, atmospheric deposition, and nitrate in irrigation water sources.

Source categories. For this Report, we estimated the groundwater nitrate contributions for 58 individual agricultural cropland categories, for animal corrals, for manure lagoons, for each individual WWTP and FP within the study area, for dairies and other animal farming operations, for septic system drainfields, and for urban sources. Contributions from dry wells and incidental leakage through existing wells were estimated at the basin scale. Groundwater nitrate contributions were estimated for five time periods, each consisting of 5 years: 1943–1947 (“1945”), 1958–1962 (“1960”), 1973–1977 (“1975”), 1988–1992 (“1990”), and 2003–2007 (“2005”); the latter is considered to be current. Future year 2050 loading was estimated based on anticipated land use changes (primarily urbanization). These categorical or individual estimates of nitrate leaching lead to maps that show nitrate discharge at a resolution of 0.25 ha (less than 1 ac) for the entire study area and its changes over a period of 105 years (1945–2050) (Viers et al. 2012; Boyle et al. 2012).

Separately, we also aggregated nitrate loads to groundwater

- by crop categories (e.g., olives, persimmons, lettuce, strawberries) and crop groups (e.g., “subtropicals,” “vegetables and berries”) averaged or summed over the entire study area;
- by county, totaled across all cropland, all WWTPs and FPs, all dairies, all septic drains, and all municipal areas; and
- summed or averaged for the study area.

Higher levels of aggregation provide more accurate estimates but are less descriptive of actual conditions at any given location. Aggregated totals are most useful for policy and planning.

We report nitrate loading to groundwater in two ways:

- Total annual nitrate leached to groundwater, measured in gigagrams of nitrate-nitrogen per year (Gg N/yr).[1] As a practical measure, 1 gigagram is roughly equivalent to $1 million of nitrogen fertilizer at 2011 prices.
- Intensity of the nitrate leaching to groundwater, measured in kilograms of nitrate-nitrogen per ha of use per year (kg N/ha/yr) [lb per acre per year, lb/ac/yr], which represents the intensity of the source at its location (field, pond, corral, census block, city) and its potential for local groundwater pollution.

How much nitrate loading to groundwater is acceptable? To provide a broad reference point of what the source loading numbers mean with respect to potential groundwater pollution, it is useful to introduce an operational benchmark that indicates whether nitrate leached in recharge to groundwater exceeds the nitrate drinking water standard. This operational benchmark considers that nearly all relevant anthropogenic nitrate sources provide significant groundwater recharge and therefore remain essentially undiluted when

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[1] One gigagram is equal to 1 million kilograms (kg), 1,000 metric tons, 2.2 million pounds (lb), or 1,100 tons (t). In this report, nitrogen application to land refers to total nitrogen (organic nitrogen, ammonium-nitrogen, and nitrate-nitrogen). For consistency and comparison, total nitrate loading and the intensity of nitrate loading from the root zone to groundwater are also provided in units of nitrogen, not as nitrate. However, concentrations of nitrate in groundwater or leachate are always stated as nitrate (MCL: 45 mg/L) unless noted otherwise.

reaching groundwater. Our benchmark for "low" intensity versus "high" intensity of nitrate leaching is 35 kg N/ha/yr (31 lb N/ac/yr).[2] Aggregated across the 1.5 million ha (3.7 million ac) of cropland, the benchmark for total annual nitrate loading in the study area is 50 Gg N/yr (55,000 t N/yr). Total nitrate loading to groundwater above this benchmark indicates a high potential for regional groundwater degradation.

Estimating nitrate loading by source category. We used two methods to assess nitrate loading:

- a mass balance approach was used to estimate nitrate loading from all categories of cropland except alfalfa;
- alfalfa cropland and nitrate sources other than cropland were assessed by reviewing permit records, literature sources, and by conducting surveys to estimate groundwater nitrate loading (Viers et al. 2012).

Groundwater Nitrate Contributions by Source Category

Cropland is by far the largest nitrate source, contributing an estimated 96% of all nitrate leached to groundwater (Table 1). The total nitrate leached to groundwater (200 Gg N/yr [220,000 t N/yr]) is four times the benchmark amount, which suggests large and widespread degradation of groundwater quality. Wastewater treatment plants and food processor waste percolation basins are also substantial, high-intensity sources.[3] Septic systems, manure storage lagoons, and corrals are relatively small sources basin-wide, but since their discharge intensity significantly exceeds the operational benchmark of 35 kg N/ha/yr (31 lb N/ac/yr), these source categories can be locally important. The magnitude and intensity of urban sources (other than septic systems) does not suggest widespread impact to groundwater (Viers et al. 2012). The following sections provide further detail on these sources.

Agricultural Sources

Cropland sources: Overview. The five counties in the study area include 1.5 million ha (3.7 million ac) of cropland, about 40% of California's irrigated cropland. Agricultural production involves many crops and significant year-to-year changes in crops grown and crop yields. The dominant crop groups in the project area include subtropical crops (citrus and olives), tree fruits and nuts, field crops including corn and cotton, grain crops, alfalfa, vegetables and strawberries, and grapes (see Figure 2). The study area also supports 1 million dairy cows. These produce one-tenth of the nation's milk supply as well as large amounts of manure.

Cropland sources: Alfalfa. The mass balance approach is not applied to alfalfa because it does not receive significant amounts of fertilizer, yet alfalfa fixes large amounts of nitrogen from the atmosphere. Little is known about nitrate leaching from alfalfa; we used a reported value of 30 kg N/ha/yr (27 lb N/ac/yr) (Viers et al. 2012). In total, 170,000 ha (420,000 ac) of alfalfa fields are estimated to contribute about 5 Gg N/yr (5,500 t N/yr) in the study area. Alfalfa harvest exceeds 400 kg N/ha/yr (360 lb N/ac/yr), or 74 Gg N/yr (82,000 t N/yr), in the study area.

Cropland sources other than alfalfa. Unlike other groundwater nitrate source categories, cropland has many sources of nitrogen application, all of which can contribute to nitrate leaching. Principally, crops are managed for optimal harvest. Synthetic nitrogen is the fertilizer of choice to achieve this goal, except in alfalfa. Other sources of nitrogen are also applied to cropland, providing additional fertilizer, serving as soil amendments, or providing a means of waste disposal. These additional nitrogen sources include animal manure and effluent and biosolids from WWTPs, FPs, and other urban sources. Often do they replace synthetic fertilizer as the main source of nitrogen for a crop. Atmospheric deposition of nitrogen and nitrate in irrigation water are mostly incidental but ubiquitous.

For the mass balance analysis, external nitrogen inputs to cropland are considered to be balanced over the long run (5 years and more) by nitrogen leaving the field in crop harvest, atmospheric losses (volatilization, denitrification), runoff to streams, or groundwater leaching. Hence, cropland nitrate leaching to groundwater is estimated by summing nitrogen inputs to a field (fertilizer, effluent, biosolids,

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[2] A typical groundwater recharge rate in the study area is roughly 300 mm/yr (1 AF/ac/yr). If that recharge contains nitrate at the MCL, the annual nitrate loading rate is 30 kg N/ha/yr (27 lb N/ac/yr). We allow an additional 5 kg N/ha/yr (4.5 lb N/ac/yr) to account for potential denitrification in the deep vadose zone or in shallow groundwater.

[3] The benchmark of 35 kg N/ha (31 lb N/ac) is not adequate for percolation basins, as their recharge rate is much more than 1 AF/ac. Instead, we consider actual average concentration (by county) of nitrogen in FP and WWTP discharges to percolation basins, which range from 2 to 10 times the MCL and 1 to 2 times the MCL, respectively (Viers et al. 2012).

manure, atmospheric deposition, irrigation water) and then subtracting the three other nitrogen outputs (harvest, atmospheric losses, and runoff).

In total, the 1.27 million ha (3.1 million ac) of cropland, not including 0.17 million ha (0.4 million ac) of alfalfa, receive 380 Gg N/yr (419,000 t N/yr) from all sources. Synthetic fertilizer, at 204 Gg N/yr (225,000 t N/yr), is more than half of these inputs (Figure 3). Manure applied on dairy forages or exported for cropland applications off-dairy (but not leaving the study area) is one-third of all nitrogen inputs. Atmospheric deposition and nitrate-nitrogen in groundwater used as irrigation water are approximately one-tenth of all nitrogen input. Urban effluent and biosolids application are small portions of the overall nitrogen input in the study area, but they are locally significant.

Table 1. Major sources of groundwater nitrate, their estimated total contribution in the study area, their percent of total contribution, and their estimated average local intensity, which indicates local pollution potential (actual total nitrate loading from these source categories is very likely within the range provided in parentheses)

	Total Nitrate Loading to Groundwater Gg N/yr* (range) [1,000 t N/yr (range)]	Percent Contribution to Total Nitrate Leaching in the Study Area	Average Intensity of Nitrate Loading to Groundwater kg N/ha/yr [lb N/ac/yr]
Cropland	195 (135–255) [215 (150–280)]	93.7%	154 [137]
Alfalfa cropland	5 (<1–10) [5 (<1–10)]	2.4%	30 [27]
Animal corrals	1.5 (0.5–8) [1.7 (0.5–9)]	0.7%	183 [163]
Manure storage lagoons	0.23 (0.2–2) [0.25 (0.2–2)]	0.1%	183 [163]
WWTP and FP[†] percolation basins	3.2 (2–4) [3.5 (2–4)]	1.5%	1,200[‡] [1,070]
Septic systems	2.3 (1–4) [2.5 (1–4)]	1.1%	<10 – >50 [<8.8 – >45]
Urban (leaky sewers, lawns, parks, golf courses)	0.88 (0.1–2) [0.97 (0.1–2)]	0.5%	10 [8.8]
Surface leakage to wells	<0.4 [<0.4]	—	[§]

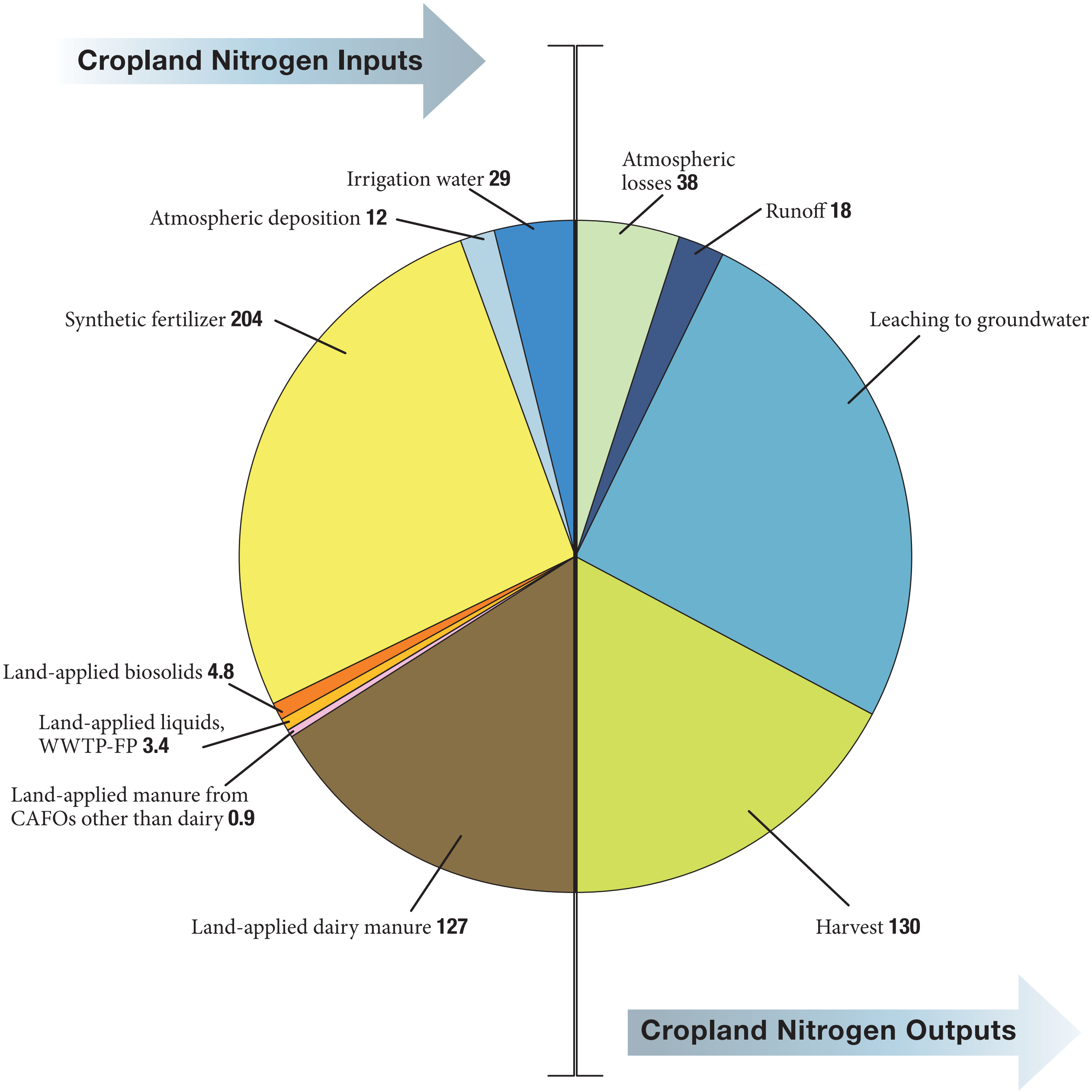
Source: Viers et al. 2012.

*At 2011 prices, 1 Gg N (1,100 t N) is roughly equivalent to $1 million in fertilizer nitrogen.

[†] WWTP = wastewater treatment plant; FP = food processor.

[‡] The benchmark of 35 kg N/ha/yr does not apply to WWTP and FP percolation basins, which may recharge significantly more water than other sources. Their nitrate loading may be high even if nitrate concentrations are below the MCL (Viers et al. 2012).

[§] Surface leakage through improperly constructed wells is based on hypothetical estimates and represents an upper limit.



Note: No mass balance was performed on 0.17 million ha (0.4 million ac) of nitrogen-fixing alfalfa, which is estimated to contribute an additional 5 Gg N/yr to groundwater. Groundwater nitrate loading from all non-cropland sources is about 8 Gg N/yr.

Figure 3. Overview of cropland input and output (Gg N/yr) in the study area (Tulare Lake Basin and Salinas Valley) in 2005. The left half of the pie chart represents total nitrogen inputs to 1.27 million ha (3.12 million ac) of cropland, not including alfalfa. The right half of the pie chart represents total nitrogen outputs with leaching to groundwater estimated by difference between the known inputs and the known outputs. Source: Viers et al. 2012.

On the output side, the total nitrate leaching to groundwater from cropland, not including alfalfa, comprises 195 Gg N/yr (215,000 t N/yr) and is by far the largest nitrogen flux from cropland, much larger than the harvested nitrogen at 130 Gg N/yr (143,000 t N/yr). The nitrogen leached to groundwater nearly matches the amount of synthetic fertilizer applied to the same cropland, suggesting large system surpluses of nitrogen use on cropland. Other outputs are small: atmospheric losses are assumed to be one-tenth of the inputs (Viers et al. 2012), and runoff is assumed to be 14 kg N/ha/yr (12.5 lb N/ac/yr) (Beaulac and Reckhow 1982).

Applying the benchmark of 50 Gg N/yr (55,000 t N/yr), groundwater leaching losses would need to be reduced by 150 Gg N/year (165,000 t N/yr) or more area-wide to avoid further large-scale groundwater degradation. Figure 3 suggests three major options to reduce nitrate loading to groundwater from cropland: develop techniques to make manure a useful and widely used fertilizer and reduce synthetic fertilizer application in the study area by as much as 75%; drastically reduce the use of manure in the study area; or significantly increase the agricultural output (harvest) without increasing the nitrogen input. Nitrate source reduction efforts will involve a combination of these options (see Section 2.3).

The following sections further discuss individual inputs and outputs that control agricultural cropland nitrate leaching.

Cropland inputs: Synthetic fertilizer (204 Gg N/yr [225,000 t N/yr]). Synthetic fertilizer application rates are estimated by first establishing a typical nitrogen application rate for each crop, derived from the literature, United States Department of Agriculture (USDA) Chemical Usage Reports,

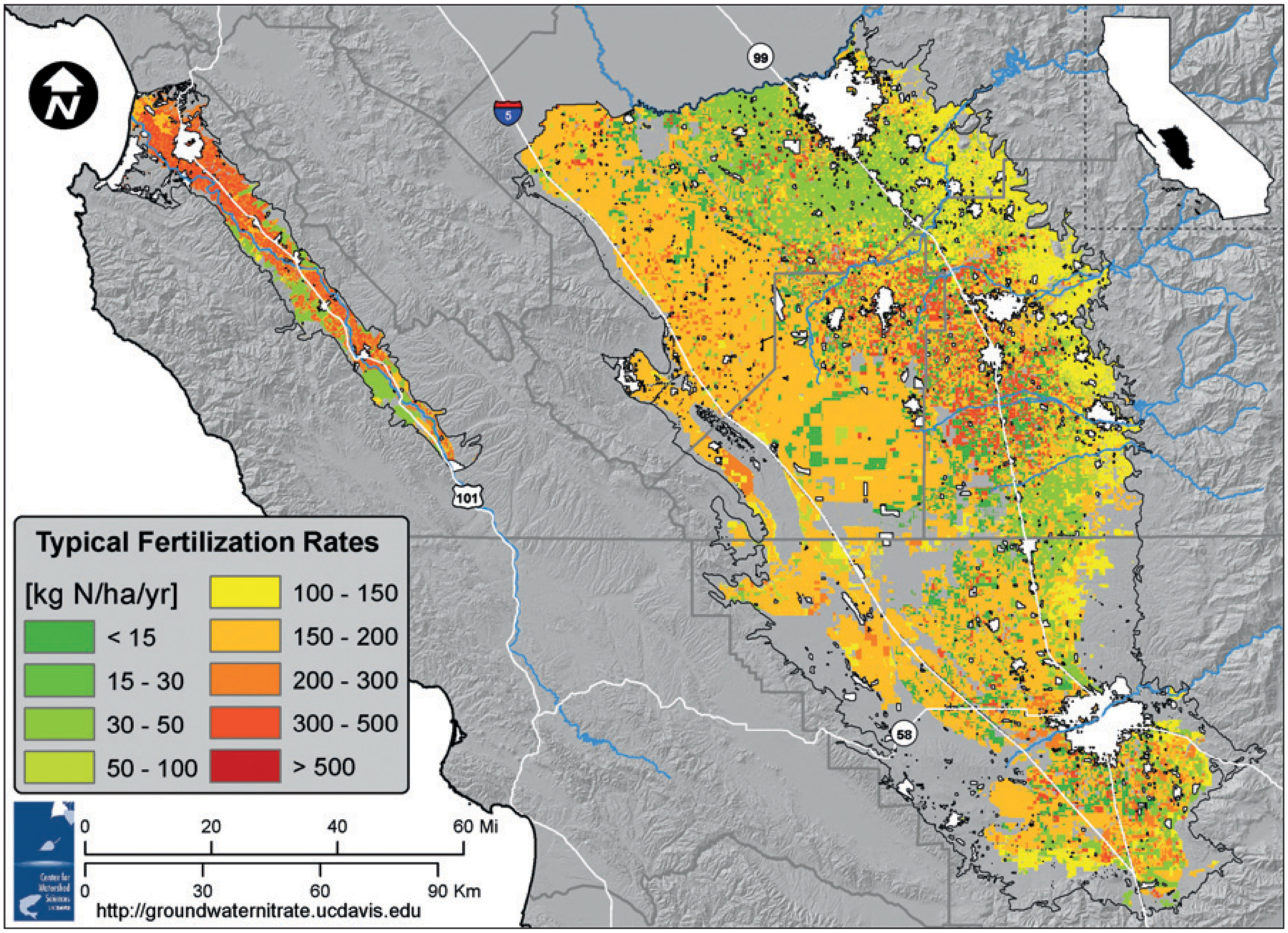


Figure 4. Current typical annual fertilization rates (1 kg/ha/yr = 1.1 lb/ac/yr) in irrigated agricultural cropland of the study area derived from the literature, USDA Chemical Usage Reports, and agricultural cost and return studies for each of 58 crop categories (does not include excess manure applications). Rates account for multi-cropping in some vegetable crops and double-cropping of corn and winter grain. Source: Viers et al. 2012.

and UC Davis ARE agricultural cost and return studies for each of 58 crop categories within 10 crop groups (Figure 4). In a second step, we assess whether some of the typical nitrogen application rate is met by other sources such as effluent, biosolids, and manure. The procedure varies with crop type, location, and aggregation level. Fertilizer needs not met by effluent, biosolids, or manure (see below) are assumed to be met by synthetic fertilizer, providing an estimate of synthetic fertilizer use at local (Figure 4), crop (see Figure 7), county (see Table 2), and study area (see Figure 3) levels. The magnitude of total estimated synthetic fertilizer use (204 Gg N/yr [225,000 t N/yr]) in the study area, on about 40% of California's irrigated land, is consistent with statewide average recorded sales of synthetic fertilizer used on cropland of 466 Gg N/yr (514,000 t N/yr) (D. Liptzin, pers. comm., 2012).

Cropland inputs: Animal manure (land-applied: 128 Gg N/yr [141,000 t N/yr]; corral and lagoon loading directly to groundwater: 1.7 Gg N/yr [1,900 t N/yr]). The Tulare Lake Basin houses 1 million adult dairy cows and their support stock (more than half of California's dairy herd), 10,000 hogs and pigs, and 15 million poultry animals. Dairy cattle are by far the largest source of land-applied manure nitrogen in the area (127 Gg N/yr [140,000 t N/yr]; see Figure 3). Manure is collected in dry and liquid forms, recycled within the animal housing area for bedding (dry manure) and as flushwater (freestall dairies), and ultimately applied to the land. Manure is applied in solid and liquid forms, typically on forage crops (e.g., summer corn, winter grain) managed by the dairy farm, or is exported to nearby farms (mostly as manure solids) and used as soil amendment. The amount of land-applied manure nitrogen is estimated based on: recently published studies of dairy cow, swine, and poultry excretion rates; animal numbers reported by the Regional Water Board and the USDA Agricultural Census; and an estimated 38% atmospheric nitrogen loss in dairy facilities before land application of the manure. Manure not exported from dairy farms is applied to portions of 130,000 ha (320,000 ac) of dairy cropland. Exported manure nitrogen is largely applied within the study area, mostly within the county of origin, on cropland nearby dairies.

Direct leaching to groundwater from animal corrals and manure lagoons is about 1.5 Gg N/yr (1,700 t N/yr) and 0.2 Gg N/yr (220 t N/yr), respectively (see Table 1).

Cropland inputs: Irrigation water (29 Gg N/yr [32,000 t N/yr]). Irrigation water is also a source of nitrogen applied to crops. Surface irrigation water is generally very low in nitrate. Nitrate in groundwater used as irrigation water is a significant source of nitrogen but varies widely with location and time. We used average nitrate concentrations measured in wells and basin-wide estimates of agricultural groundwater pumping (Faunt 2009) to estimate the total nitrogen application to agricultural lands from irrigation water, in the range of 20 Gg N/yr (22,000 t N/yr) to 33.4 Gg N/yr (36,800 t N/yr).

Cropland and general landscape inputs: Aerial deposition (12 Gg N/yr [13,000 t N/yr]). Nitrogen emissions to the atmosphere as NOx from fossil fuel combustion and ammonia from manure at confined animal feeding operations undergo transformations in the atmosphere before being redeposited, often far from the source of emissions. Nitrogen deposition estimates at broader spatial scales are typically based on modeled data. Nitrogen deposition in urban and natural areas was assumed to be retained with the ecosystem (Vitousek and Howarth 1991). In cropland, nitrogen deposition was included in the nitrogen mass balance. For the Salinas Valley, average aerial deposition is 5.6 kg N/ha/yr (0.6 Gg N/yr) (5.0 lb N/ac [660 t N/yr]). The Tulare Lake Basin receives among the highest levels in the state, averaging 9.8 kg N/ha/yr (11.3 Gg N/yr) (8.7 lb N/ac/yr [12,500 t N/yr]).

Cropland output: Harvested nitrogen (130 Gg N/yr [143,000 t N/yr]). The nitrogen harvested is the largest independently estimated nitrogen output flow from cropland. Historical and current annual County Agricultural Commissioner reports provide annual harvested acreage and yields for major crops. From the reported harvest, we estimate the nitrogen removed. For each of 58 crop categories, the study area total harvest nitrogen and total acreage used to estimate the rate of nitrogen harvested (Figure 5). All crops combined (not including alfalfa) contain a total of 130 Gg N/yr (143,000 t N/yr), with cotton (21 Gg N/yr [23,000 t N/yr]), field crops (28 Gg N/yr [31,000 t N/yr]), grain and hay crops (30 Gg N/yr [33,000 t N/yr]), and vegetable crops (30 Gg N/yr [30,000 t N/yr]) making up 85% of harvested nitrogen. Tree fruits, nuts, grapes, and subtropical crops constitute the remainder of the nitrogen export from cropland.

Historical Development of Fertilizer Use, Manure Production, Harvested Nitrogen, and Estimated Nitrate Leaching to Groundwater. Current and near-future groundwater nitrate conditions are mostly the result of past agricultural practices. So the historical development of nitrogen fluxes to and from cropland provides significant insight in the relationship between past agricultural practices, their estimated groundwater impacts, and current as well as anticipated groundwater quality. Two major inventions effectively doubled the farmland in production from the 1940s to the 1960s: the introduction of the turbine pump in the 1930s, allowing access to groundwater for irrigation in a region with very limited surface water supplies, and the invention and commercialization of the Haber-Bosch process, which made synthetic fertilizer widely and cheaply available by the 1940s.

The amount of cropland (not including alfalfa) in the study area nearly doubled in less than 20 years, from 0.6 million ha (1.5 million ac) in the mid-1940s to nearly 1.0 million ha (2.5 million ac) in 1960 (not including alfalfa) (Figure 6). Further increases occurred until the 1970s, to 1.3 million ha (3.2 million ac), but the extent of farmland has been relatively stable for the past 30 years.

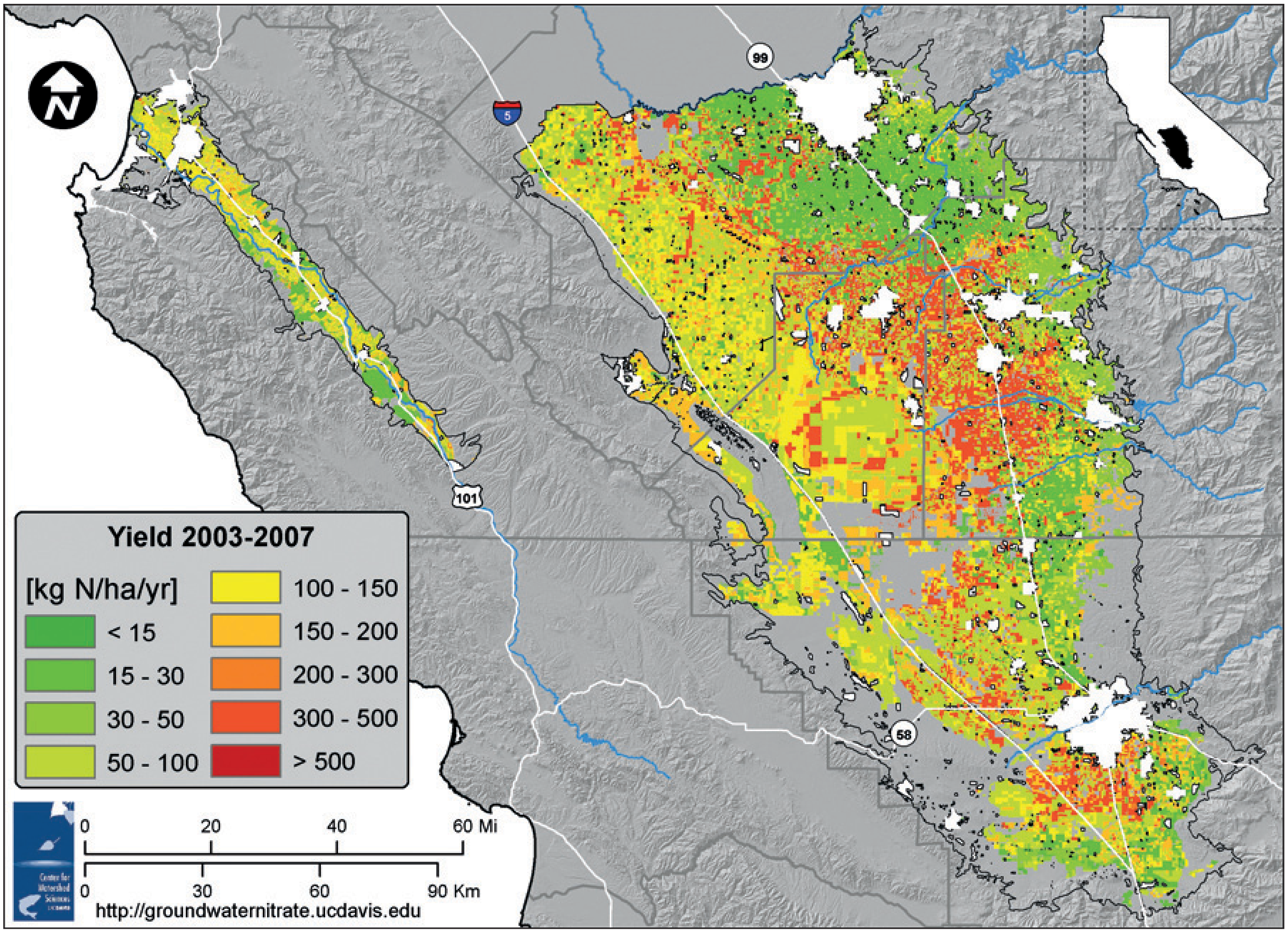


Figure 5. Current annual nitrogen removal rate in harvested materials (1 kg/ha/yr = 1.1 lb/ac/yr) derived from county reports of harvested area and harvested tonnage for each of 58 crop categories. Rates account for multi-cropping in some vegetable crops and double-cropping of corn and winter grain. Source: Viers et al. 2012.

In contrast, the harvested nitrogen has consistently increased throughout the past 60 years (see Figure 6). From 1945 to 1975, total harvested nitrogen increased twice as fast as farmland expansion, quadrupling from 20 Gg N/yr (22,000 t N/yr) to 80 Gg N/yr (88,000 t N/yr). Without further increases in farmland, harvests and harvested nitrogen increased by more than 60% in the second 30-year period, from the mid-1970s to the mid-2000s.

Synthetic fertilizer inputs also increased from the 1940s to the 1980s but have since leveled off. Between 1990 and 2005, the gap between synthetic nitrogen fertilizer applied and harvested nitrogen has significantly decreased.[4]

In contrast, dairy manure applied to land has increased exponentially, effectively doubling every 15 years (see Figure 6), from 8 Gg N/yr (9,000 t N/yr) in 1945 to 16 Gg N/yr (18,000 t N/yr) in 1960, 32 Gg N/yr (35,000 t N/yr) in 1975, 56 Gg N/yr (62,000 t N/yr) in 1990, and 127 Gg N/yr (140,000 t N/yr) in 2005, an overall 16-fold increase in manure nitrogen output. The increase in manure nitrogen is a result of increasing herd size (7-fold) and increasing milk production per cow (3-fold) and is slowed only by the increased nitrogen-use efficiency of milk production.

Until the 1960s, most dairy animals in the region were only partly confined, often grazing on irrigated pasture with

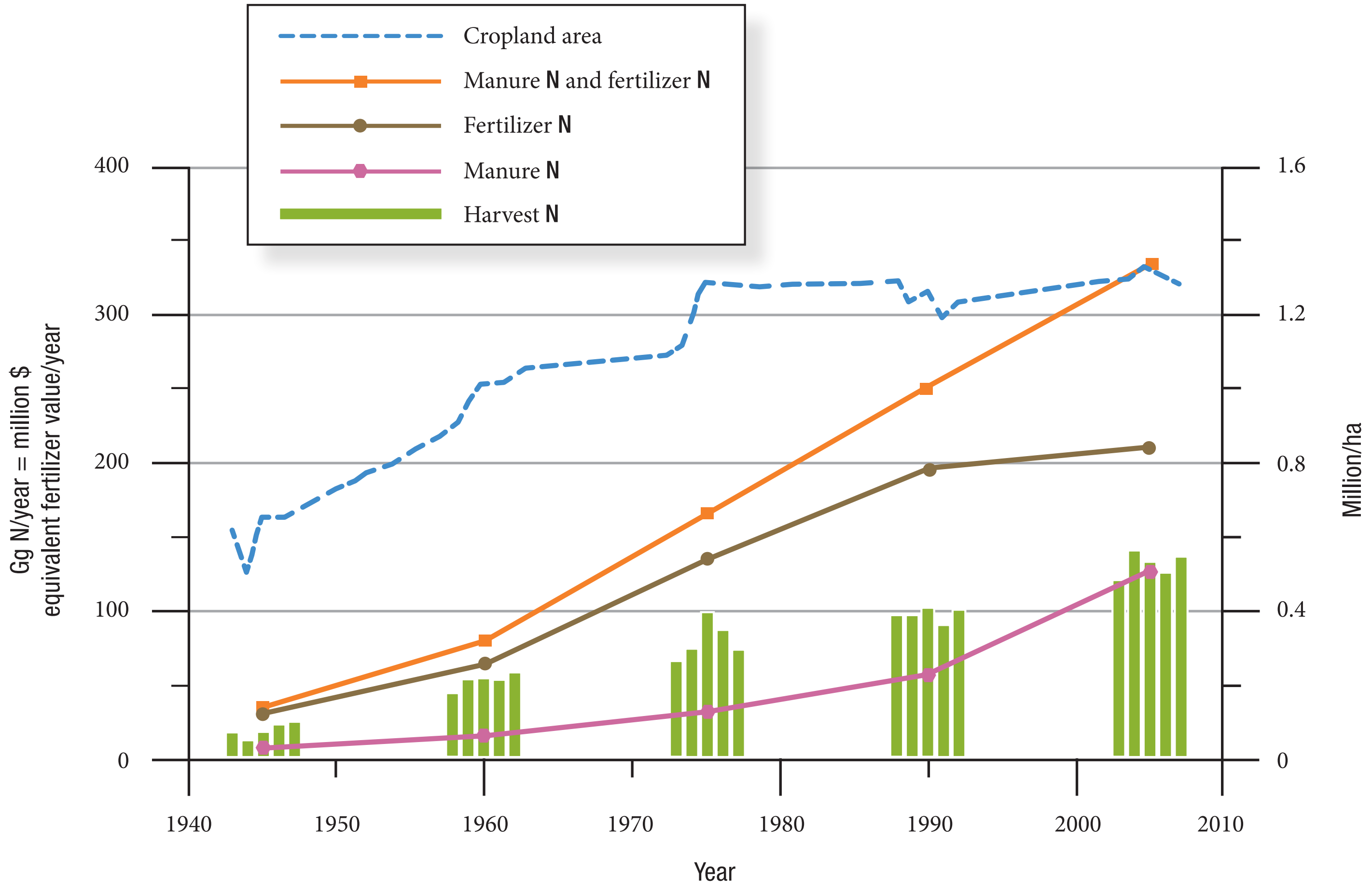


Figure 6. Estimated historical agricultural development in the study area (not including alfalfa): total harvested area, total harvested nitrogen in fertilized crops, fertilizer applied to cropland (5-year average), manure applied to cropland (5-year average), and sum of manure and fertilizer applied to cropland (5-year average). Not shown: In the study area, harvested alfalfa area grew from 0.12 million ha (0.3 million ac) in the 1940s to 0.2 million ha (0.5 million ac) around 1960, then leveled off to current levels of 0.17 million ha (0.42 million ac). Since the 1960s, nitrogen removal in alfalfa harvest has varied from 50 to 80 Gg N/yr. Note: 0.4 million ha = 1 million ac. Source: Viers et al. 2012.

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[4] Fertilizer application rates and statewide fertilizer sales have grown little since the late 1980s.

limited feed imports. Manure from dairy livestock generally matched the nitrogen needs of dairy pastures. Since the 1970s, dairies in the Tulare Lake Basin have operated mostly as confined animal facilities, growing alfalfa, corn, and grain feed on-site, importing additional feed, and housing the animals in corrals and freestalls. The growth in the dairy industry has created a nitrogen excess pool that remains unabsorbed by crops (see Figure 6). Much of the nitrogen excess is a recent phenomenon (see Figure 6). With groundwater quality impacts delayed by decades in many production wells (see Section 3), the recent increase in land applied manure nitrogen is only now beginning to affect water quality in wells of the Tulare Lake Basin, with much of the impact yet to come.

Groundwater loading from irrigated agriculture, by crop group and by county. Significant differences exist in groundwater loading intensity between crop groups.[5] The intensity of groundwater loading is least in vineyards (less than 35 kg N/ha/yr [31 lb N/ac/yr]), followed by rice and subtropical tree crops (about 60 kg N/ha/yr [54 lb N/ac/yr]), tree fruits, nuts, and cotton (90–100 kg N/ha/yr [80–90 lb N/ac/yr]), vegetables and berry crops (over 150 kg N/ha/yr [130 lb N/ac/yr]), which includes some vegetables being cropped twice per year), field crops (about 480 kg N/ha/yr [430 lb N/ac/yr]), and grain and hay crops (about 200 kg N/ha/yr [180 lb N/ac/yr]). Manure applications constitute the source of nearly all of the nitrate leaching from these latter two crops. Without manure, field crops leach less than 35 kg N/ha/yr (31 lb N/ac/yr), and grain and hay crops leach 50 kg N/ha/yr (45 lb N/ac/yr). Figure 7 shows the rate of reduction (in kg N/ha/crop) that would be needed, on average across each crop group, to reduce groundwater nitrate leaching to benchmark levels.

At the county level, we aggregate cropland area, fertilizer applications (by crop category), manure output from individual dairies, effluent and biosolid land applications from individual facilities, and crop category–specific harvest. Differences in cropping patterns between counties and the absence or presence of dairy facilities within counties drive county-by-county differences in total groundwater loading and in the average intensity of groundwater loading (Table 2). Fresno County, which has fewer mature dairy cows (133,000) than Kings (180,000), Tulare (546,000), or Kern (164,000) Counties and also has large areas of vineyards (see Figure 2), has the lowest average groundwater loading intensity (103 kg N/ha/yr [103 lb N/ac/yr]). Monterey County is dominated by vegetable and berry crops (high intensity) and grape vineyards (low intensity).

Urban and Domestic Sources

Urban and domestic sources: Overview. Urban nitrate loading to groundwater is divided into four categories: nitrate leaching from turf, nitrate from leaky sewer systems, groundwater nitrate contributions from WWTPs and FPs, and groundwater nitrate from septic systems. For all these systems, groundwater nitrate loading is estimated based on either actual data or reported data of typical nitrate leaching.

Urban and domestic sources: Wastewater treatment plants and food processors (11.4 Gg N/yr [12,600 t/yr]: 3.2 Gg N/yr [3,500 t/yr] to percolation ponds, 3.4 Gg N/yr [3,800 t/yr] in effluent applications to cropland, and 4.8 Gg N/yr [5,300 t/yr] in WWTP biosolids applications to cropland). The study area has roughly 2 million people on sewer systems that collect and treat raw sewage in WWTPs. In addition, many of the 132 food processors within the study area generate organic waste that is rich in nitrogen (Table 3). Potential sources of groundwater nitrate contamination from these facilities include effluent that is land applied on cropland or recharged directly to groundwater via percolation basins, along with waste solids and biosolids that are land applied. Typically, WWTP influent contains from 20 mg N/L to 100 mg N/L total dissolved nitrogen (organic N, ammonium N, nitrate-N), of which little is removed in standard treatment (some WWTPs add treatment beyond

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[5] Aggregated estimates were obtained from study area-wide totals for harvested area (by crop group), for typical nitrogen application, and for harvested nitrogen. The following averages were assumed: irrigation water nitrogen (24 kg N/ha/yr [21 lb N/ac/yr]), atmospheric nitrogen losses (10% of all N inputs), and runoff (14 kg N/ha/yr [12.5 lb N/ac/yr]). Most manure is likely land-applied to field crops, particularly corn, and to grain and hay crops. Little is known about the actual distribution prior to 2007 and the amount of synthetic fertilizer applied on fields receiving manure. As an illustrative scenario, we assume that two-thirds of dairy manure is applied to field crops and one-third of dairy manure is applied to grain and hay crops. In field crops, 50% of crop nitrogen requirements are assumed to be met with synthetic fertilizer, and in grain and hay crops 90% of their crop nitrogen requirements are assumed to be met by synthetic fertilizer. These are simplifying assumptions that neglect the nonuniform distribution of manure on field and grain crops between on-dairy, near-dairy, and away-from-dairy regions. However, corn constitutes most (106,000 ha [262,000 ac]) of the 130,000 ha (321,000 ac) in field crops, with at least 40,000 ha (99,000 ac) grown directly on dairies. Grain crops are harvested from 220,000 ha (544,000 ac). For further detail, see Viers et al. 2012.

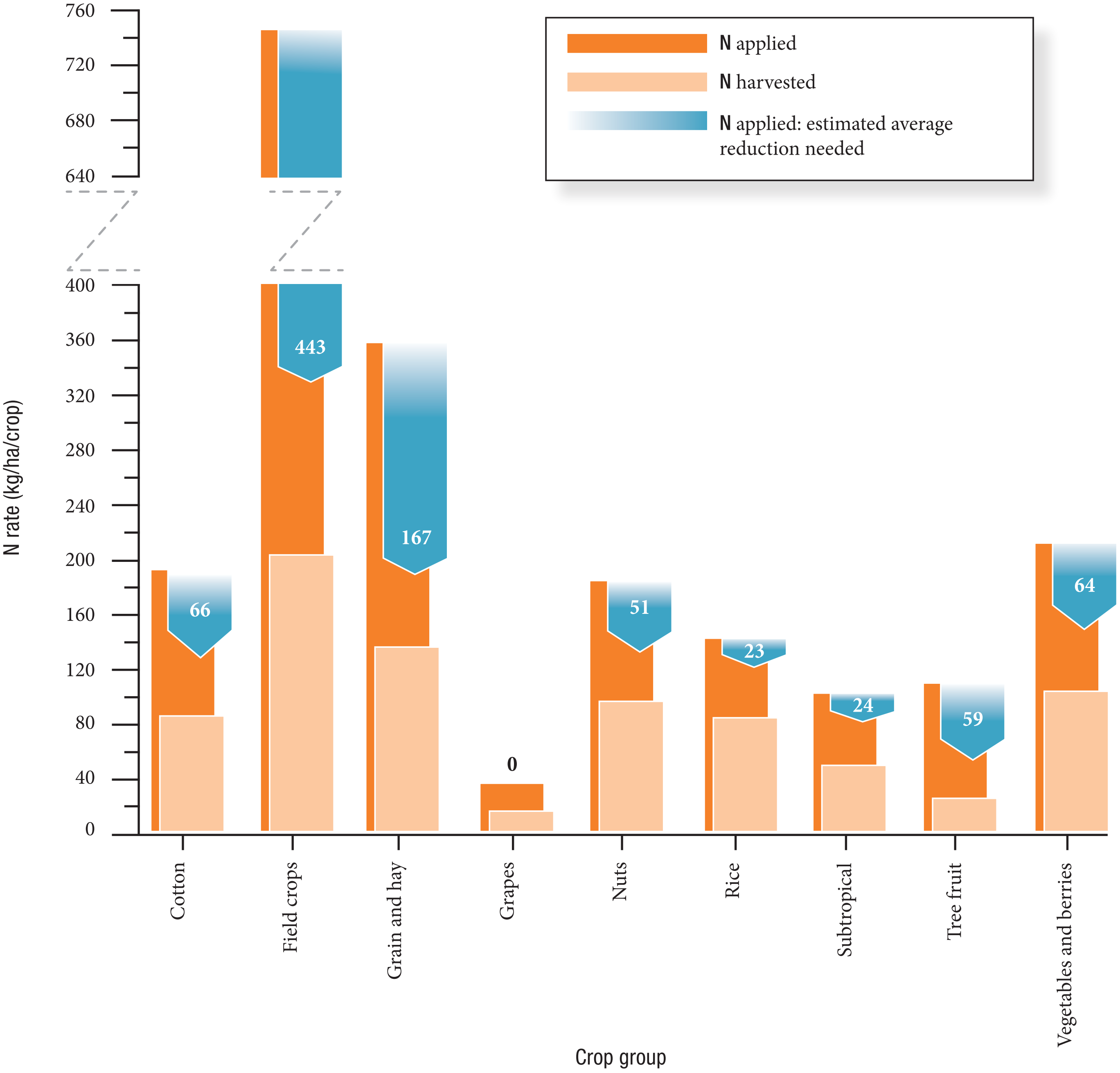

Figure 7. Nitrogen application reduction needed to reduce groundwater nitrate loading to less than 35 kg N/ha/crop, compared with average nitrogen applied (synthetic fertilizer and manure) and nitrogen harvested (all units in kg N/ha/crop). Rates are given per crop, and the required reduction does not account for double-cropping. Some vegetables and some field crops are harvested more than once per year. In that case, additional reductions in fertilizer applications would be necessary to reduce nitrate loading to less than 35 kg N/ha. Large reductions needed in field crops and grain and hay crops are due to the operational assumption that manure generated in the study area is applied to only these crop groups. Typical amounts of synthetic fertilizer applied ("N applied") to these crops, without excess manure, are 220 kg N/ha/crop for field crops and 190 kg N/ha/crop for grain and hay crops. Thus, without excess manure, average field crops and grain and hay crops may require relatively small reductions in nitrogen application. Source: Viers et al. 2012.

Table 2. Major nitrogen fluxes to and from cropland in the study area, by county (not including alfalfa)

	Synthetic Fertilizer Application Gg N/yr [1,000 t N/yr]	Manure Application Gg N/yr [1,000 t N/yr]	Land Applied Effluent and Biosolids, Gg N/yr [1,000 t N/yr]	Harvest Gg N/yr [1,000 t N/yr]	PNB* %	PNB_0† %	Groundwater Loading Gg N/yr [1,000 t N/yr]	Groundwater Loading Intensity kg N/ha/yr [lb N/ac/yr]
By County								
Fresno	62.1 [68.3]	16.6 [18.3]	0.8 [0.88]	35.5 [39.1]	44.7	54.4	42.4 [46.7]	103 [92]
Kern	50.3 [55.4]	20.4 [22.5]	4.6 [5.0]	29.6 [32.6]	39.3	56.4	42.8 [47.2]	141 [123]
Kings	27.5 [30.3]	22.0 [24.3]	1.9 [2.1]	19.6 [21.6]	38.1	62.7	29.2 [32.2]	179 [160]
Tulare	36.0 [39.7]	67.3 [74.2]	0.7 [0.77]	32.7 [36.0]	31.4	72.5	65.1 [71.8]	236 [210]
Monterey	28.1 [30.9]	1.4 [1.54]	0.1 [0.11]	12.4 [13.6]	41.9	43.5	15.6 [17.2]	138 [123]
By Basin								
TLB	176 [194]	127 [140]	8.1 [8.9]	118 [130]	37.8	60.5	179 [197]	155 [138]
SV	28 [30.8]	1 [1.1]	0.1 [0.11]	12 [13]	41.9	43.5	16 [18]	138 [123]
Overall	**204 [225]**	**128 [141]**	**8.2 [9]**	**130 [143]**	**38.2**	**58.3**	**195 [215]**	**154 [137]**

Source: Viers et al. 2012.

Manure applications include non-dairy manure nitrogen (0.9 Gg N/yr [(990 t N/yr)] for the entire study area). Groundwater loading accounts for atmospheric deposition (9.8 and 5.6 kg N/ha/yr [(8.7 and 5 t N/yr)] in TLB and SV, respectively), atmospheric losses (10% of all inputs), irrigation water quality (22.8 kg N/ha/yr [20 lb N/ac/yr]), and runoff (14 kg N/ha/yr [12.5 lb N/ac/yr]) to and from agricultural cropland, in addition to fertilizer and manure application, and harvested nitrogen. Synthetic fertilizer application on field crops is assumed to meet 50% of typical application rates; on grain and hay crops, 90% of typical applications, with the remainder met by manure.

* PNB = partial nutrient balance, here defined as Harvest N divided by (Synthetic + Manure + Effluent + Biosolids Fertilizer N).

† PNB_0 = hypothetical PNB, if no manure/effluent/biosolids overage was applied above typical fertilizer rates.

conventional processes to remove nutrients including nitrate and other forms of nitrogen). Across the study area, WWTP effluent nitrogen levels average 16 mg N/L. Within the study area, 40 WWTPs treat 90% of the urban sewage. FP effluent nitrogen levels to percolation basins and irrigated agriculture average 42 mg N/L and 69 mg N/L, respectively.

Urban and domestic sources: Septic systems (2.3 Gg N/yr [2,500 t N/yr]). Crites and Tchobanoglous (1998) estimated that the daily nitrogen excretion per adult is 13.3 g. Approximately 15% of that nitrogen is assumed to either stay in the septic tank, volatilize from the tank, or volatilize from the septic leachfield (Siegrist et al. 2000). Based on census data, the number of people on septic systems in the study areas is about 509,000 for the Tulare Lake Basin and 48,300 for Salinas Valley. Total nitrate loading from septic leaching is 2.1 Gg N/yr (2,300 t N/yr) in the Tulare Lake Basin and 0.2 Gg N/yr (220 t N/yr) in the Salinas Valley. The distribution of septic systems varies greatly. The highest density of septic systems is

Table 3. Total nitrogen discharge to land application and average total nitrogen concentration (as nitrate-N, MCL: 10 mg N/L) in discharge to percolation basins from WWTPs and FPs, based on our surveys of WWTPs and the FP survey of Rubin et al. (2007)

	Biosolids Gg N/yr [1,000 t N/yr]	WWTP Land Application Gg N/yr [1,000 t N/yr]	WWTP Percolation Concentration mg N/L	FP Land Application Gg N/yr [1,000 t N/yr]	FP Percolation Concentration mg N/L
By County					
Fresno	0.006 [0.006]	0.40 [0.40]	18.5	0.42 [0.46]	56.2
Kern	3.1 [3.4]	0.92 [0.92]	17.7	0.56 [0.62]	43.9
Kings	1.6 [1.7]	0.09 [0.09]	11.2	0.26 [0.29]	2.1
Tulare	0.038 [0.044]	0.50 [0.50]	14.9	0.13 [0.14]	34.2
Monterey	0 [0]	0.09 [0.09]	13.9	0.05 [0.05]	22.1
By Basin					
Tulare Lake Basin	4.8 [5.3]	1.9 [2.1]	16.3	1.37 [1.51]	43.3
Salinas Valley	0 [0]	0.09 [0.09]	13.9	0.05 [0.05]	22.1
Overall	**4.8** **[5.3]**	**2.0** **[2.2]**	**16**	**1.4** **[1.5]**	**42**

in peri-urban (rural sub-urban) areas near cities but outside the service areas of the wastewater systems that serve those cities (Figure 8). In the Tulare Lake Basin and Salinas Valley, 7.9% and 12.6%, respectively, of the land area exceeds the EPA-recommended threshold of 40 septic systems per square mile (0.154 systems per ha). Nearly 1.5% of the study area has a septic system density of over 256 systems per square mile (1 system/ha, or 1 system/2.5 ac). In those areas, groundwater leaching can significantly exceed our operational benchmark rate of 35 kg N/ha/yr (31 lb N/ac/yr).

Urban and domestic sources: Fertilizer and leaky sewer lines (0.88 Gg N/yr [970 t N/yr]). Fertilizer is used in urban areas for lawns, parks, and recreational facilities such as sports fields and golf courses. These land uses differ in their recommended fertilizer use, and there is almost no evidence of actual fertilization rates. Based on the most comprehensive survey of turfgrass leaching, only about 2% of applied nitrogen fertilizer was found to leach below the rooting zone (Petrovic 1990). For our nitrogen flow calculations, we assume a net groundwater loss of 10 kg N/ha/yr (8.9 lb N/ac/yr) from lawns and golf courses in urban areas (0.35 Gg N/yr [380 t N/yr]).

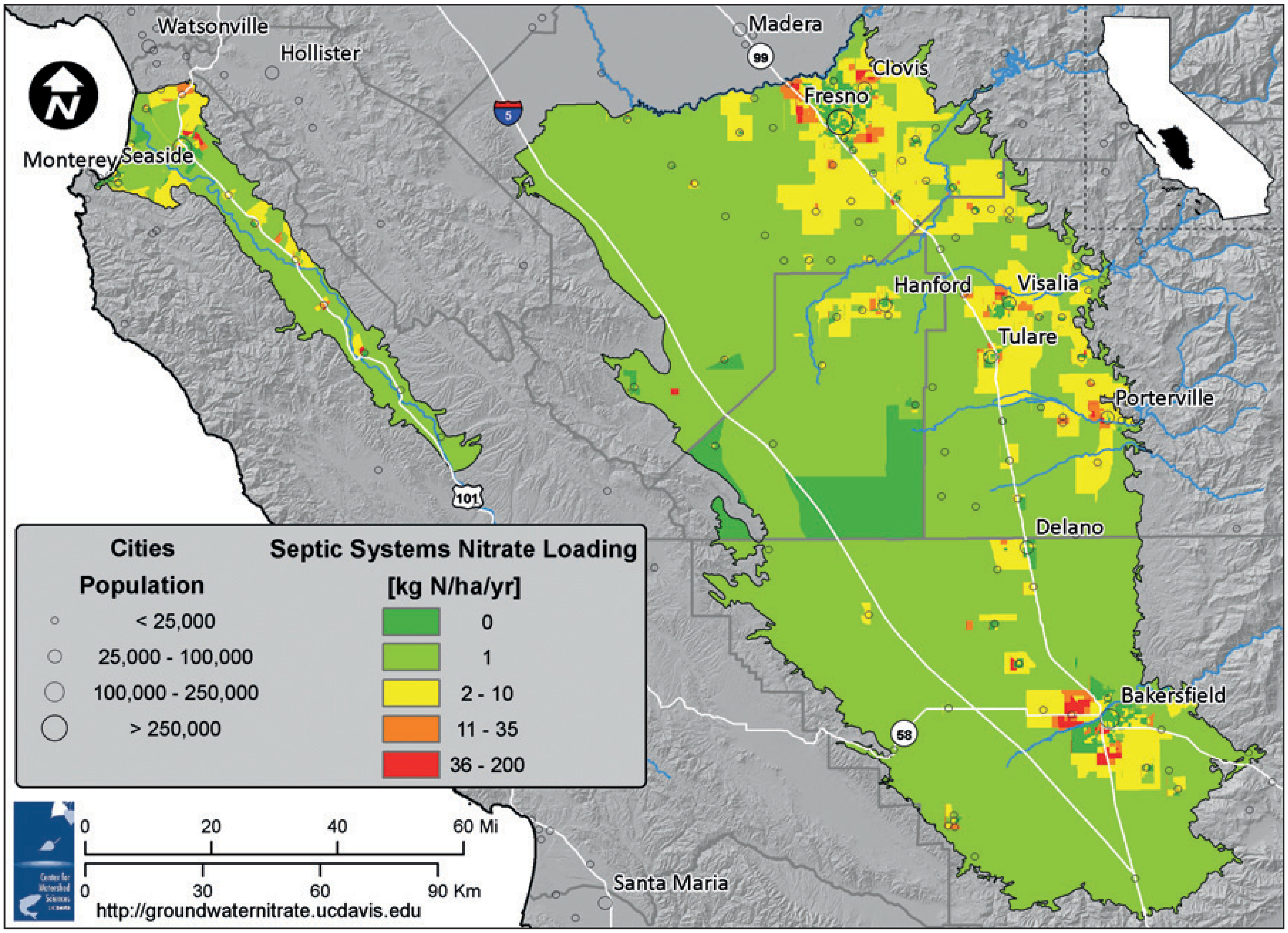

Figure 8. Septic-derived nitrate leaching rates within the study area. Source: Viers et al. 2012.

Sewer systems in urban areas can be a locally significant source of nitrogen. We use both reported sewer nitrogen flows and per capita nitrogen excretion rates to obtain total nitrogen losses via leaky sewer lines in urban areas. Nationally, estimated municipal sewer system leakage rates range from 1% to 25% of the total sewage generated. Given that much of the urban area within the study region is relatively young, we consider that the leakage rate is low, roughly 5% or less (0.53 Gg N/yr).

General Sources

General sources: Wells, dry wells, and abandoned wells (<0.4 Gg N/yr [<440 t N/yr]). Wells contribute to groundwater nitrate pollution through several potential pathways. Lack of or poor construction of the seal between the well casing and the borehole wall can lead to rapid transport of nitrate-laden irrigation water from the surface into the aquifer. In an inactive or abandoned production well, long well screens (several hundred feet) extending from relatively shallow depth to greater depth, traversing multiple aquifers, may cause water from nitrate-contaminated shallow aquifer layers to pollute deeper aquifer layers, at least in the vicinity of wells. Dry wells, which are large-diameter gravel-filled open wells, were historically designed to capture stormwater runoff or irrigation tailwater for rapid recharge to groundwater. Abandoned wells also allow surface water leakage to groundwater (spills) and cross-aquifer contamination. Lack of backflow prevention devices can lead to direct introduction of fertilizer chemicals into the aquifer via a supply well. Few data are available on these types of nitrate transfer in the Tulare Lake Basin or Salinas Valley. In a worst-case situation, as much as 0.4 Gg N/yr (440 t N/yr) may leak from the surface to groundwater via improperly constructed, abandoned, or dry wells, and as much as 6.7 Gg N/yr (7,400 t N/yr) are transferred within wells from shallow to deeper aquifers. Actual leakage rates are likely much lower than these worst-case estimates.

Groundwater Nitrate Loading: Uncertainty. The analyses above provide specific numbers for the average amount and intensity of nitrate loading from various categories of sources. However, discharges of nitrate to groundwater may vary widely between individual fields, farms, or facilities of the same category due to differences in operations, management practices, and environmental conditions. Also, average annual nitrate loading estimates for specific categories are based on many assumptions and are based on (limited) data with varying degrees of accuracy; the numbers given represent a best, albeit rough, approximation of the actual nitrate loading from specific sources. These estimates have inherent uncertainty. Very likely, though, the actual groundwater nitrate loading from source categories falls within the ranges shown in Table 1.

2.3 Reducing Nitrate Source Emissions to Groundwater

Although reduction of anthropogenic loading of nitrate to groundwater aquifers will not reduce well contamination in the short term (due to long travel times), reduction efforts are essential for any long-term improvement of drinking water sources. Technologies for reducing nitrate contributions to groundwater involve (a) reducing nitrogen quantity discharged or applied to the land and (b) controlling the quantity of water applied to land, which carries nitrate to groundwater (Dzurella et al. 2012).

Many source control methods require changes in land management practices and upgrading of infrastructure. Costs for mitigation or abatement vary widely and can be difficult to estimate. In particular, the quantity of nitrate leached from irrigated fields (the largest source) is determined by a complex interaction of nitrogen cycle processes, soil properties, and farm management decisions. Only broad estimates of the cost of mitigation per unit of decrease in the nitrate load are possible.

Reducing Nitrate Loading from Irrigated Cropland and Livestock Operations

Reduction of nitrate leaching from cropland, livestock, and poultry operations can come from changes in farm management that improve crop nitrogen use efficiency and proper storage and handling of manure and fertilizer. A common measure of cropland nitrogen use efficiency is the partial nitrogen balance (PNB), which is the ratio of harvested nitrogen to applied (synthetic, manure, or other organic) fertilizer nitrogen (Table 2).

We reviewed technical and scientific literature to compile a list of practices known or theorized to improve crop nitrogen use efficiency. Crop-specific expert panels reviewed and revised this list of practices. Input from these panel members also helped to estimate the current extent of use of each practice in the study area and to identify barriers to expanded adoption.

PNB can be increased by optimizing the timing and application rates of fertilizer nitrogen, animal manure, and irrigation water to better match crop needs, and to a lesser extent by modifying crop rotation. Improving the storage and handling of manure, livestock facility wastewater, and fertilizer also helps reduce nitrate leaching. A suite of improved management practices is generally required to reduce nitrate leachate most effectively, and these must be chosen locally for each unique field situation. No single set of management practices will be effective in protecting groundwater quality everywhere. The best approach depends on the crop grown, soil characteristics of the field, and other specific factors. As summarized in Table 4, ten key farm management measures for increasing crop nitrogen use efficiency (and PNB) are identified and reviewed (Dzurella et al. 2012).

Although PNBs as low as 33% have been reported, a recent EPA report estimated that with the adoption of best management practices, PNB could increase by up to 25% of current average values (U.S. EPA 2011). Improvements in PNB are possible, but a practical upper limit is about 80% crop recovery of applied nitrogen (U.S. EPA 2011; Raun and Schepers 2008). This limit is due to the unpredictability of rainfall, the difficulty in predicting the rate of mineralization of organic nitrogen in the soil, spatial variability and nonuniformity in soil properties, and the need to leach salts from the soil.

Table 4. Management measures for improving nitrogen use efficiency and decreasing nitrate leaching from agriculture (local conditions determine which specific practices will be most effective and appropriate)

Basic Principle	Management Measure	Number of Recommended Practices
Design and operate irrigation and drainage systems to decrease deep percolation.	MM 1. Perform irrigation system evaluation and monitoring.	3
	MM 2. Improve irrigation scheduling.	4
	MM 3. Improve surface gravity system design and operation.	6
	MM 4. Improve sprinkler system design and operation.	5
	MM 5. Improve microirrigation system design and operation.	2
	MM 6. Make other irrigation infrastructure improvements.	2
Manage crop plants to capture more N and decrease deep percolation.	MM 7. Modify crop rotation.	4
Manage N fertilizer and manure to increase crop N use efficiency.	MM 8. Improve rate, timing, placement of N fertilizers.	9
	MM 9. Improve rate, timing, placement of animal manure applications.	6
Improve storage and handling of fertilizer materials and manure to decrease off-target discharges.	MM 10. Avoid fertilizer material and manure spills during transport, storage, and application.	9
		Total: 50

Source: Dzurella et al. 2012.

Based on expert panel commentary, several farm management practices that reduce nitrate leaching have been widely adopted in recent years in the study area, representing a positive change from past practices that have contributed to current groundwater nitrate concentrations. High PNB can sometimes increase yields and decrease costs to the producer (by decreasing costs for fertilizer and water). Alas, field data that document improvements in nitrate leaching from these actions are largely unavailable.

Significant barriers to increased adoption of improved practices exist. These include higher operating or capital costs, risks to crop quality or yield, conflicting farm logistics, and constraints from land tenure. Lack of access to adequate education, extension, and outreach activities is another primary barrier, especially for the adoption of many of the currently underused practices, highlighting the importance of efforts such as those offered by the University of California Cooperative Extension. The future success of leaching reductions through improved crop and livestock facility management will require a significant investment in crop-specific research that links specific management practices with groundwater nitrate contamination. Additional investments in farmer (and farm labor) education and extension opportunities are needed, as well as increased support for farm infrastructure improvements. Monitoring and assessment programs need to be developed to evaluate management practices being implemented and their relative efficacy.

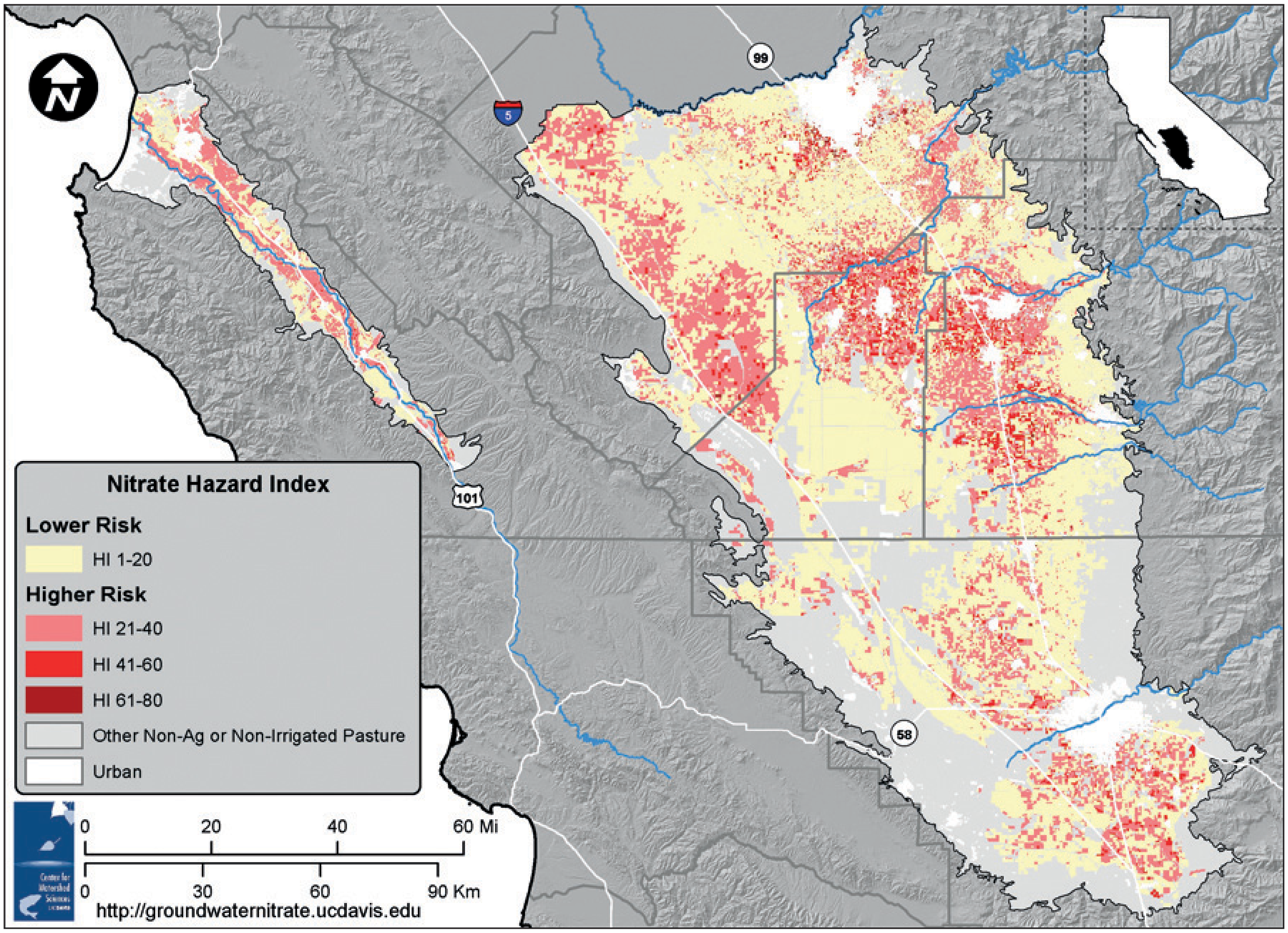

Figure 9. Overall nitrate hazard index calculated for the study area fields. Index values over 20 indicate increased potential for nitrate leaching from the crop root zone, benefiting most from implementation of improved management practices. Comparison between values in the higher-risk categories is not necessarily an indication of further risk differentiation, but it may indicate that multiple variables are involved in risk. Less-vulnerable areas still require vigilance in exercising good farm management practices. Source: Dzurella et al. 2012.

To establish the areas that would benefit most from improved management practices, we conducted a vulnerability assessment. Management-specific vulnerability was mapped using the UC Nitrate Hazard Index (Wu et al. 2005), which calculates the potential of nitrate leaching as a function of the crop grown, the irrigation system type in use, and the soil characteristics of each individual field. Based on this information, approximately 52% of irrigated cropland in the Salinas Valley and 35% of such land in the Tulare Lake Basin would most benefit from broad implementation of improved management practices (Figure 9).

A maximum net benefit modeling approach was developed to estimate relative costs of policies to improve PNB while maintaining constant crop yields for selected crop groups in the study area. Net revenue losses from limiting nitrate load to groundwater increase at an increasing rate (Table 5 and Figure 10). Our modeling results, although preliminary due to the lack of data on the cost of improving nitrogen use efficiency, suggest that reductions of 25% in total nitrate load to groundwater from crops will slightly increase production costs but are unlikely to affect total irrigated crop area, as summarized in Table 5. Smaller reductions (<10%) can be achieved at low costs, assuming adequate farmer education is in place (see Figure 10).

Greater reductions in total nitrate loading (>50%) are much more costly to implement, as capital and management investments in efficient use of nitrogen are required. Achieving such high load reductions may ultimately shift cropping toward more profitable and nitrogen-efficient crops or fallowing, as lower-value field crops and low-PNB crops lose

Table 5. Summary of how two groundwater nitrate load reduction scenarios may affect total applied water, annual net revenues, total crop area, and nitrogen applications, according to our estimative models for each basin*

Region	Scenario	Applied Water km^3/yr [million AF/yr]	Net Revenues $M/yr (2008)	Irrigated Land 1,000 ha [ac]	Applied Nitrogen Gg N/yr (%) [1,000 t/yr]
Tulare Lake Basin	base load	10.5 [8.5]	4,415 (0%)	1,293 [3,194]	200 (0%) [221]
	25% load reduction	10.0 [8.1]	4,259 (–3.5%)	1,240 [3,064]	181 (–9%) [199]
	50% load reduction	7.9 [6.4]	3,783 (–14%)	952 [2,352]	135 (–32%) [149]
Salinas Valley	base load	0.37 [0.30]	309 (0%)	92 [227]	18 (0%) [19]
	25% load reduction	0.33 [0.27]	285 (–7.5%)	83 [205]	15 (–16%) [16]
	50% load reduction	0.25 [0.20]	239 (–22%)	62 [153]	10 (–46%) [11]

Source: Dzurella et al. 2012.

* Irrigated land area and applied nitrogen in base load vary slightly from those reported in Section 2.2 due to land use data being based on Figure 2 (derived from DWR data) instead of County Agricultural Commissioner Reports (Figure 6).

favor economically. The average net revenue loss of reducing nitrate loading to groundwater is estimated to be $16 per kilogram of nitrogen at this 50% reduction level. Modeling a 7.5% sales fee on nitrogen fertilizer indicated an estimated reduction in total applied nitrogen by roughly 1.6%, with a 0.6% loss in net farm revenues.

Agricultural source reduction: Promising actions. Expanded efforts to promote nitrogen-efficient practices are needed. Educational and outreach activities could assist farmers in applying best management practices (BMPs) and nutrient management. Research should focus on demonstrating the value of practices on PNB and on adapting practices to local conditions for crop rotations and soils with the greatest risk of nitrate leaching. This especially includes row crops receiving high rates of nitrogen and/or manure that are surface- or sprinkler-irrigated. Research on the costs of increasing nitrogen use efficiency in crops would greatly benefit the capacity to estimate the economic costs of reductions in agricultural nitrate loading to groundwater. Research and education programs are needed to promote conversion of solid and liquid dairy manure into forms that meet food safety and production requirements for a wider range of crops.

We suggest that a working group develop crop-specific technical standards on nitrogen mass balance metrics for regulatory and assessment purposes. This nitrogen-driven metric would reduce the need for more expensive direct measurement of nitrate leaching to groundwater. Such

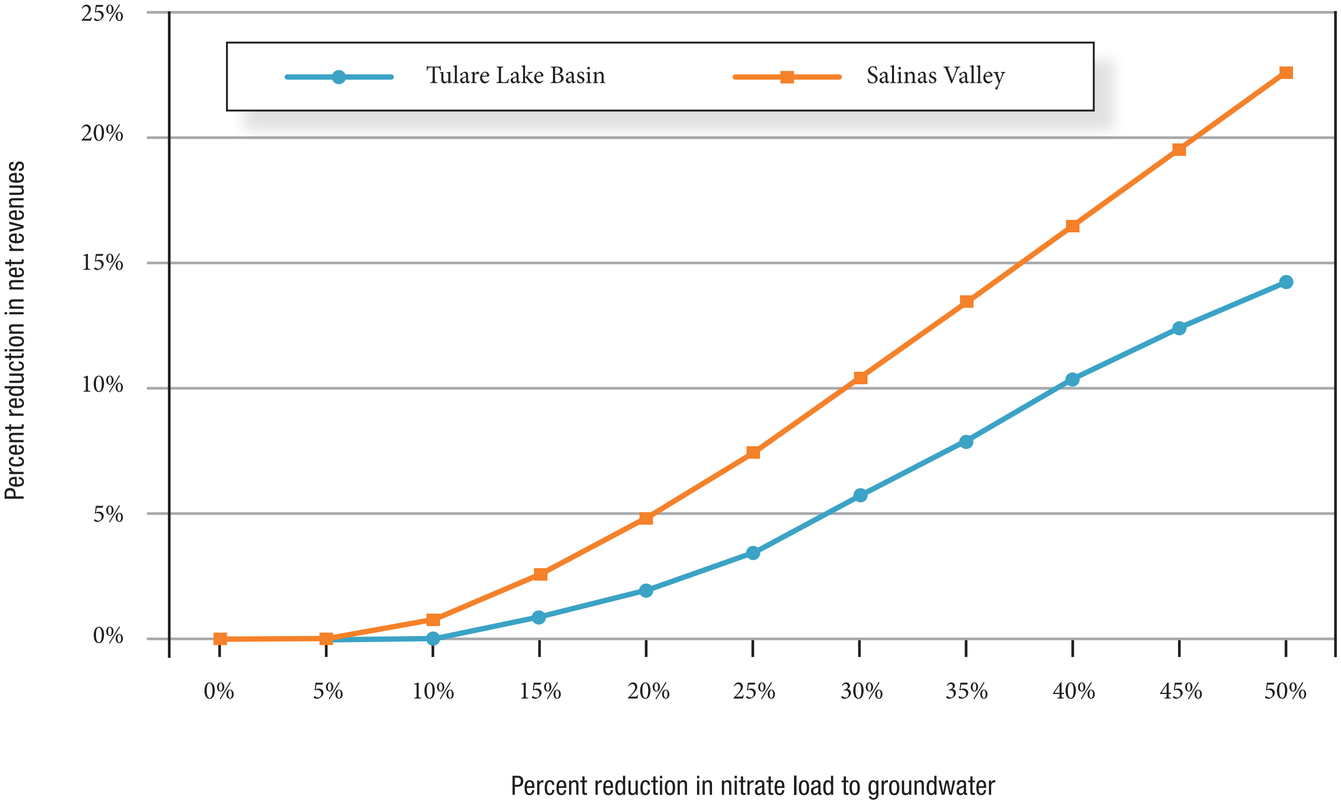

Figure 10. Percent reduction in net revenues estimated from different levels of reduction in nitrate loading to groundwater. Source: Dzurella et al. 2012.

metrics would also serve as a starting point to assist farmers in assessing their crop nitrogen use efficiency and be useful for nitrogen management. Finally, we recommend that a task force review and further develop methods to identify croplands most in need of improved management practices. Such a method should include consideration of soil characteristics (as in the UC Nitrate Hazard Index), as well as possible monitoring requirements.

Reducing Nitrate Leaching from Municipal Wastewater Treatment and Food Processing Plants

Implementation of nitrogen control options for WWTP and FP sources is feasible and useful. Nitrogen removal from wastewater can be accomplished using a variety of technologies and configurations; both biological and physical or chemical processes are effective. The selection of the most appropriate treatment option depends on many factors.

Estimated capital costs for nutrient removal from all wastewater (FPs and WWTPs) for facilities categorized as "at-risk" range from $70 to $266 million. Cropland application of wastewater treatment and food processing effluents can reduce direct groundwater contamination and total fertilizer application requirements of such fields, as the water and nutrients are effectively treated and recycled. These wastes should be managed in an agronomic manner rather than applied to land for disposal or land treatment purposes so that the nutrients are included in the overall nitrogen management plan for the receiving crops.

Optimizing wastewater treatment plant and food processing plant operations is another way to reduce nitrogen and total discharge volume. Facility process modifications may be sufficient in some cases. Groundwater monitoring is required for many facilities, but the data are largely unavailable since they are not in a digital format. To improve monitoring, enforcement, and abatement efforts related to these facilities, groundwater data need to be more centrally managed and organized digitally.

Reducing Nitrate Contributions from Leaking Sewer Pipes and Septic Systems

Retrofitting of septic system components and sewer pipes is the main way to diminish loading from these sources. Replacing aging sewer system infrastructure and ensuring proper maintenance are required to reduce risks to human health; such infrastructure upgrades also reduce nitrate leaching.

Loading from septic systems, significant locally, can be reduced significantly by two approaches where connection to a sewer system is not possible. Source separation technology can reduce nitrate loading to wastewater treatment systems by about 50%. Costs include separating toilets ($300–$1,100), dual plumbing systems ($2,000–$15,000), storage tank costs, and maintenance, pumping, heating, and transport costs (where applicable). Post-septic tank biological nitrification and denitrification treatment reduces nitrate concentrations below levels achieved via source separation technology but does not result in a reusable resource. Wood chip bioreactors have reduced influent nitrate by 74% to 91%, with costs ranging from $10,000 to $20,000 to retrofit existing septic systems.

Reducing Nitrate Leaching from Turfgrass in Urban Areas

Nitrate leaching from urban turfgrass, including golf courses, is often negligible due to the dense plant canopy and perennial growth habit of turf, which results in continuous plant nitrogen uptake over a large portion of the year. However, poor management can lead to a discontinuous canopy and weed presence, wherein nitrate leaching risk increases, especially if the turf is grown on permeable soils, is overirrigated, or is fertilized at high rates during dormant periods. The UCCE and UC IPM publish guidelines on proper fertilizer use in turfgrass. The knowledge and willingness of homeowners and groundskeepers to apply guidelines depend on funding for outreach efforts.

Reducing Nitrate Transfer and Loading from Wells

Backflow prevention devices should be required on agricultural and other wells used to mix fertilizer with water. Furthermore, local or state programs and associated funding to identify and properly destroy abandoned and dry wells are needed to prevent them from becoming nitrate transfer conduits. However, many well owners may not be able to afford the high costs of retrofitting long-screened wells to seal contaminated groundwater layers. As such, enforcement of proper well construction standards for future wells may be more feasible. Expenditures on retrofitting of existing dry and abandoned wells should be based on the contamination risks of individual wells. The nitrate contamination potential of wells needs to be identified as a basis for developing and enforcing improved, appropriate well construction standards that avoid the large-scale transfer of nitrate to deep groundwater in all newly constructed wells.

3 Impact: Groundwater Nitrate Occurrence

3.1 Current Groundwater Quality Status

We assembled groundwater quality data from nearly two dozen local, state, and federal agencies and other sources into a dataset, here referred to as the (Central) California Spatio-Temporal Information on Nitrate in Groundwater (CASTING) dataset (see Table 6 for information about data sources, Boyle et al. 2012). The dataset combines nitrate concentrations from 16,709 individual samples taken at 1,890 wells in the Salinas Valley and from 83,375 individual samples taken at 17,205 wells in the Tulare Lake Basin collected from the 1940s to 2011, a total of 100,084 samples from 19,095 wells. Almost 70% of these samples were collected from 2000 to 2010; only 15% of the samples were collected prior to 1990. Half of all wells sampled had no recorded samples prior to 2000 (Boyle et al. 2012).

Of the nearly 20,000 wells, 2,500 are frequently sampled public water supply wells (over 60,000 samples). Apart from the recently established Central Valley dairy regulatory program, which now monitors about 4,000 domestic and irrigation wells in the Tulare Lake Basin, there are no existing regular well sampling programs for domestic and other private wells.

From 2000 to 2011, the median nitrate concentration in the Tulare Lake Basin and Salinas Valley public water supply well samples was 23 mg/L and 21 mg/L,[6] respectively, and in all reported non-public well samples, 23 mg/L and 20 mg/L, respectively. In public supply wells, about one in ten raw water samples exceeds the nitrate MCL. Nitrate concentrations in wells vary widely with location and well depth. More domestic wells and unregulated small system wells have high nitrate concentrations due to their shallow depth (Table 6). Highest nitrate concentrations are found in wells of the alluvial fans in the eastern Tulare Lake Basin and in wells of unconfined to semi-confined aquifers in the northern, eastern, and central Salinas Valley (Figure 11). In the Kings, Kaweah, and Tule River groundwater sub-basins of Fresno and Kings County, and in the Eastside and Forebay sub-basins of Monterey County, one-third of domestic or irrigation wells exceed the nitrate MCL. Consistent with these findings, the maximum nitrate level, measured in any given land section (1 square mile) for which nitrate data exist between 2000 and 2009, exceeds the MCL across wide portions of these areas (Figure 12). Low nitrate concentrations tend to occur in the deeper, confined aquifer in the western and central Tulare Lake Basin (Boyle et al. 2012).

Nitrate levels have not always been this high. While no significant trend is observed in some areas with low nitrate (e.g., areas of the western TLB), USGS research indicates significant long-term increases in the higher-nitrate areas of the Tulare Lake Basin (Burow et al. 2008), which is consistent with the CASTING dataset. Average nitrate concentrations in public supply wells of the Tulare Lake Basin and Salinas Valley have increased by 2.5 mg/L (±0.9 mg/L) per decade over the past three decades. Average trends of similar magnitude are observed in private wells. As a result, the number of wells with nitrate above background levels (>9 mg/L) has steadily increased over the past half century from one-third of wells in the 1950s to nearly two-thirds of wells in the 2000s (Figure 13). Due to the large increase in the number of wells tested across agencies and programs, the overall fraction of sampled wells exceeding the MCL grew significantly in the 2000s (Boyle et al. 2012).

The increase in groundwater nitrate concentration measured in domestic wells, irrigation wells, and public supply wells lags significantly behind the actual time of nitrate discharge from the land surface. The lag is due, first, to travel time between the land surface or bottom of the root zone and the water table, which ranges from less than 1 year in areas with shallow water table (<3 m [10 ft]) to several years or even decades where the water table is deep (>20 m [70 ft]). High water recharge rates shorten travel time to a deep water table, but in irrigated areas with high irrigation efficiency and low recharge rates, the transfer to a deep water table may take many decades.

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[6] Unless noted otherwise, nitrate concentration is given in mg/L as nitrate (MCL = 45 mg/L).

Once nitrate is recharged to groundwater, additional travel times to shallow domestic wells are from a few years to several decades and one to several decades and even centuries for deeper production wells.

3.2 Cleanup of Groundwater: Groundwater Remediation

Groundwater remediation is the cleanup of contaminated groundwater to levels that comply with regulatory limits. In the pump-and-treat (PAT) approach, groundwater is extracted from wells, treated on the surface, and returned to the aquifer by injection wells or surface spreading basins. In-situ treatment approaches create subsurface conditions that aid degradation of contaminants underground. In-situ remediation is not appropriate for contaminants spread over large regions or resistant to degradation. Both remediation methods typically also require removal or reduction of contamination sources and long-term groundwater monitoring.

Table 6. Data sources with the total number of samples recorded, total number of sampled wells, location of wells, type of wells, and for the last decade (2000–2010) in the Tulare Lake Basin and Salinas Valley: Number of wells measured, median nitrate concentration, and percentage of MCL exceedance for the Tulare Lake Basin and the Salinas Valley*

Data Source[†]	Total # of Wells	Total # of Samples	Location of Wells	Type of Wells	Years 2000–2010					
					# of Wells TLB	# of Wells SV	TLB Median mg/L nitrate	SV Median mg/L nitrate	TLB % > MCL	SV % > MCL
CDPH	2,421	62,153	throughout study area	public supply wells	1,769	327	12	8	6%	5%
CVRWB DAIRY	6,459	11,300	dairies in TLB	domestic, irrigation, and monitoring wells	6,459	—	22	—	31%	—
DPR	71	814	eastern Fresno and Tulare Counties	domestic wells	71	—	40	—	45%	—
DWR	26	44	Westlands Water District	irrigation wells	28	—	1	—	0%	—
DWR Bulletin 130	685	2,862	throughout study area	irrigation, domestic, and public supply wells	—	—	—	—	—	—
ENVMON	537	2,601	throughout study area	monitoring wells	357	180	—	27	52%	44%
EPA	2,860	4,946	throughout study area	—	—	—	—	—	—	—
Fresno County	368	369	Fresno County	domestic wells	349	—	18	—	15%	—
GAMA	141	141	Tulare County	domestic wells	141	—	38	—	43%	—
Kern County	2,893	3,825	Kern County	Irrigation, domestic wells	361	—	5	—	7%	—

Continued on next page

Groundwater remediation is difficult and expensive (NRC 1994, 2000). Groundwater remediation is done only very locally (less than 1 km^2 [<0.5 mi^2] to often less than 2 ha [<5 ac]). Cleanup of contaminants over a wide region is not feasible, and would require many decades and considerable expense. The success rate for cleanup of widespread groundwater contaminants is very disappointing (NRC 1994, 2000).

Because of the difficulty and poor success rates of plume remediation, an approach known as monitored natural attenuation (MNA) has become popular. MNA involves letting natural biochemical transformations and dispersion reduce and dilute contamination below cleanup goals, while monitoring to confirm whether MNA is adequately protecting groundwater quality. However, this approach is effective only for contaminants that transform to relatively harmless byproducts. The combination of circumstances that would favor denitrification of nitrate is generally lacking in California's alluvial aquifer systems (Fogg et al. 1998; Boyle et al. 2012), so MNA does not seem to be an effective way of remediating nitrate-contaminated groundwater in the study area.

The total estimated volume of groundwater exceeding the nitrate MCL in the Tulare Lake Basin and Salinas Valley is 39.7 km^3 (32.2 million acre-feet, AF) and 4.2 km^3 (3.4 million AF), respectively, more than the total groundwater

Table 6. *Continued*

Data Source†	Total # of Wells	Total # of Samples	Location of Wells	Type of Wells	Years 2000–2010					
					# of Wells TLB	# of Wells SV	TLB Median mg/L nitrate	SV Median mg/L nitrate	TLB % > MCL	SV % > MCL
Monterey County, Reports	239	1,018	Monterey County	monitoring, irrigation wells	—	98	—	14	—	36%
Monterey County, Geospatial	388	1,574	Monterey County	local small systems wells	—	431	—	18	—	15%
Monterey County, Scanned	452	5,674	Monterey County	local small systems wells	—	427	—	17	—	14%
NWIS	1,028	2,151	—	miscellaneous	76	4	35	0	36%	0%
Tulare County	444	444	Tulare County	domestic wells	438	—	22	—	27%	—
Westlands Water District	48	77	Westlands Water District	irrigation wells	31	—	4	—	0%	—

Source: Boyle et al. 2012.

* Median and percent MCL exceedance were computed based on the annual mean nitrate concentration at each well for which data were available.

† Data sources: CDPH: public supply well database; CVRWB Dairy: Central Valley RWB Dairy General Order; DWR Bulletin 130: data reports from the 1960–1970s, 1985; ENVMON: SWRCB Geotracker environmental monitoring wells with nitrate data (does not include data from the CVRWB dairy dataset); EPA: STORET dataset; Fresno County: Public Health Department; GAMA: SWRCB domestic well survey; Kern County: Water Agency; Monterey County, Reports: data published in reports by MCWRA; Monterey County, Geospatial: Health Department geospatial database; Monterey County, Scanned: Health Department scanned paper records; NWIS: USGS National Water Information System; Tulare County: Health and Human Services; Westlands Water District: district dataset. Some smaller datasets are not listed. Individual wells that are known to be monitored by multiple sources are here associated only with the data source reporting the first water quality record.

pumped from the project area aquifers between 2005 and 2010 (Table 7). This is a basin-scale groundwater cleanup problem. Annual costs of traditional remediation would be on the order of $13 to $30 billion (Dzurella et al. 2012; King et al. 2012). This explains why no attempt at remediation of a contaminated groundwater basin on the scale of the Tulare Lake Basin or Salinas Valley has ever been undertaken. Except for cleanup of hot-spot sites, traditional remediation for nitrate is not a promising option.

A more promising remediation approach is what we refer to as "pump-and-fertilize" (PAF) (Dzurella et al. 2012; King et al. 2012). This approach uses existing agricultural wells to remove nitrate-contaminated groundwater and "treat" the water by ensuring nitrate uptake into crops through proper nutrient management. A disadvantage of PAF is that many irrigation wells are drilled deep to maximize the pumping rate, but most high levels of nitrate contamination are seen at shallower depths. Shallower nitrate-contaminated groundwater is en route toward the deep intake screens of many of the irrigation wells (Viers et al. 2012). One option is to drill intermediate-depth irrigation wells to intercept contaminated groundwater before it penetrates farther into the deeper subsurface. The cost, energy, and management requirements of this approach would need to be carefully evaluated, as it requires the drilling and operation of many shallower wells with smaller capture zones and smaller pumping rates at each well. At a regional or sub-regional scale, it may be an innovative alternative, although decades of PAF operations would be needed together with large reductions in nitrate leachate from the surface.

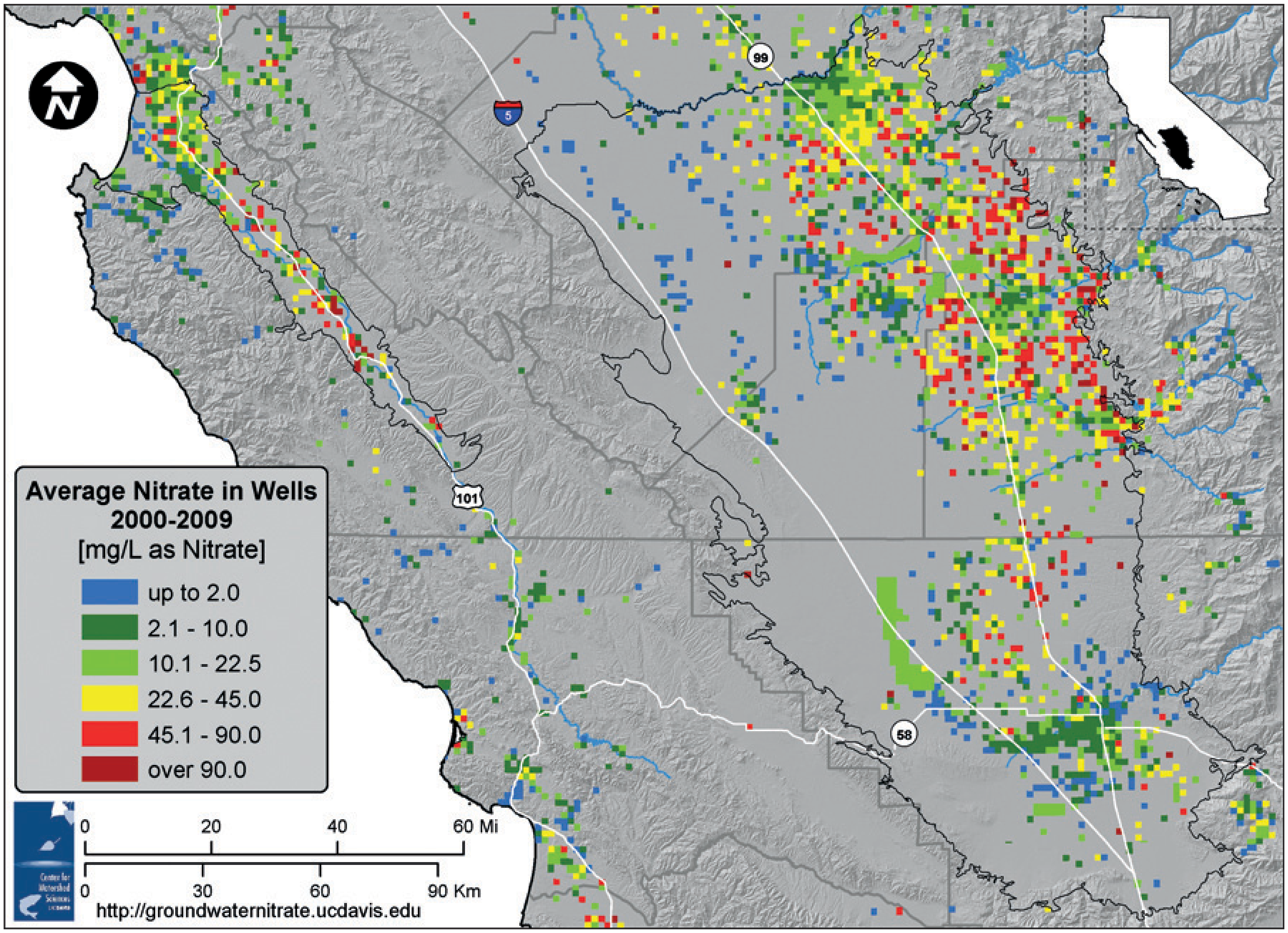

Figure 11. Mean of the time-average nitrate concentration (mg/L) in each well belonging within a square mile land section, 2000–2009. Some areas in the TLB are larger than 1 square mile. Source: Boyle et al. 2012.

Groundwater recharge operations could be managed to improve groundwater quality if the recharged water is of good quality and relatively low in nitrate (remediation by dilution). By introducing as much clean recharge water as possible, the long-term effects of contaminated agricultural recharge can be partially mitigated. But the large water volumes already affected would require decades of management.

Pump-and-fertilize along with improved groundwater recharge management are technically feasible, less costly alternatives than pump-and-treat and could help place regional groundwater quality on a more sustainable path. These alternatives should be accompanied by remediation of local nitrate contamination hot spots and long-term groundwater quality monitoring to track benefits of the strategy (for details, see King et al. 2012).

3.3 Existing Regulatory and Funding Programs for Nitrate Groundwater Contamination

Many regulatory and planning programs in the study area provide regulatory structure or technical and managerial support to water systems, communities, farmers, dairies, and others who deal with nitrate contamination in groundwater. Statutes also provide a regulatory framework for nitrate contamination of groundwater and drinking water. In the study area, there are several federal programs/statutes (Table 8a and Table 8b, blue), State programs/statutes (purple), and nongovernmental programs/agencies (orange) relevant to nitrate contamination and its effects on drinking water. Current regulatory/planning programs and statutes that have the ability to reduce groundwater nitrate contamination

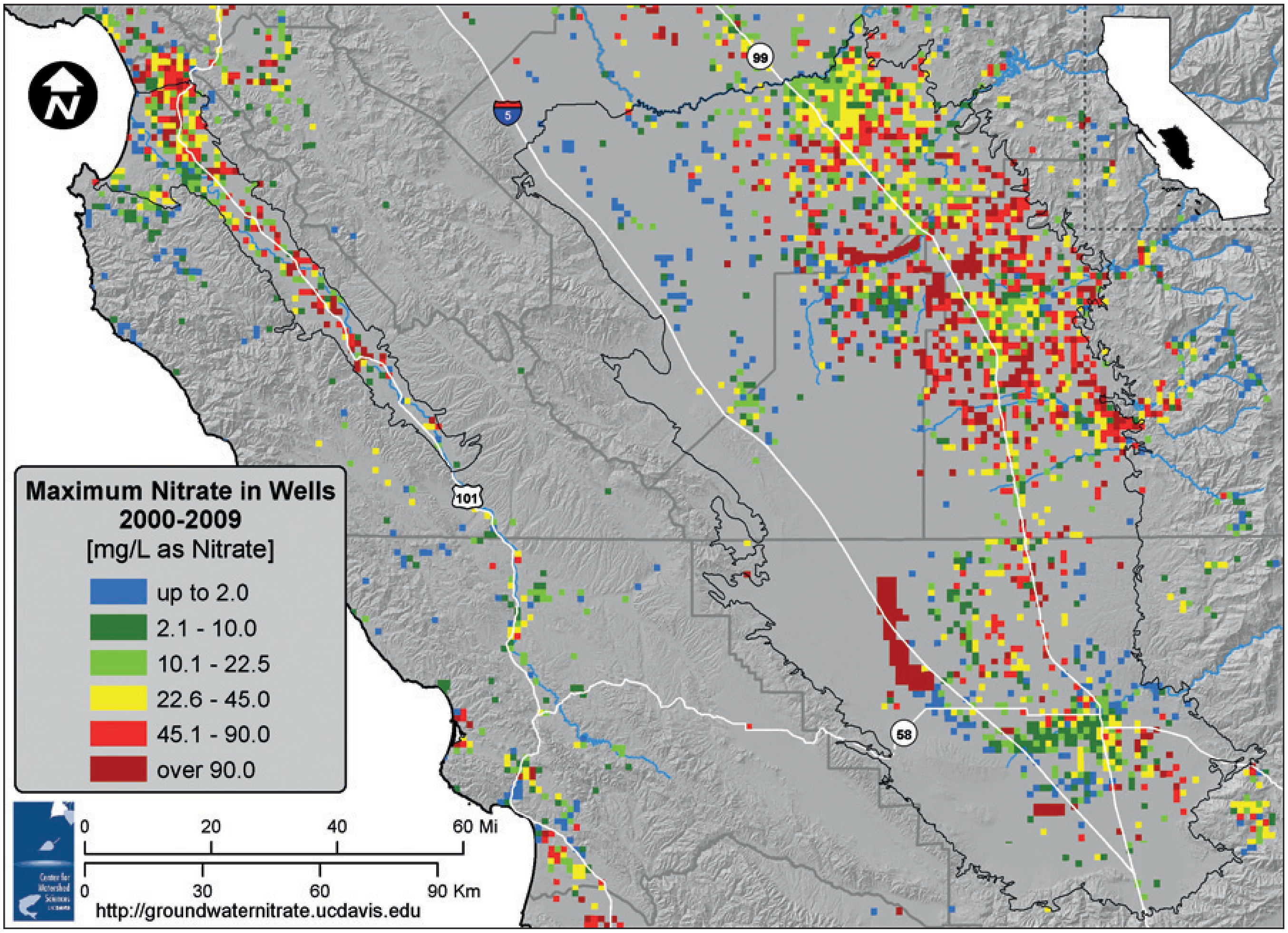

Figure 12. Maximum nitrate concentration (mg/L) measured at any time during 2000–2009 within a 1-square-mile land section. Some areas in the TLB are larger than 1 square mile. Source: Boyle et al. 2012.

are summarized in Table 8a. These programs/statutes have components that target nitrate source reduction or groundwater remediation. While providing a framework to address the groundwater nitrate issue, these programs have not been effective at preventing substantial nitrate contamination of groundwater used in drinking water supplies. Table 8b is a summary of current programs and statutes related to groundwater nitrate and drinking water. These provide for data collection, information, and education on nitrate sources and groundwater nitrate. Some of these programs regulate nitrate in drinking water.

In addition, several state, federal, and local agencies, as well as nongovernmental organizations, have established funding programs related to nitrate contamination in California's groundwater. A summary of existing funding sources to address problems related to nitrate in drinking water is shown in Table 9. In general, these programs are structured to provide assistance for activities related to alternative water supplies and nitrate load reduction. The State of California has eighteen relevant funding programs, administered by four agencies (Table 9, purple); the federal government manages an additional three funding programs (blue). Three large nongovernmental drinking water funding programs in the study area are highlighted in orange in Table 9. For a more detailed review, see Canada et al. (2012).

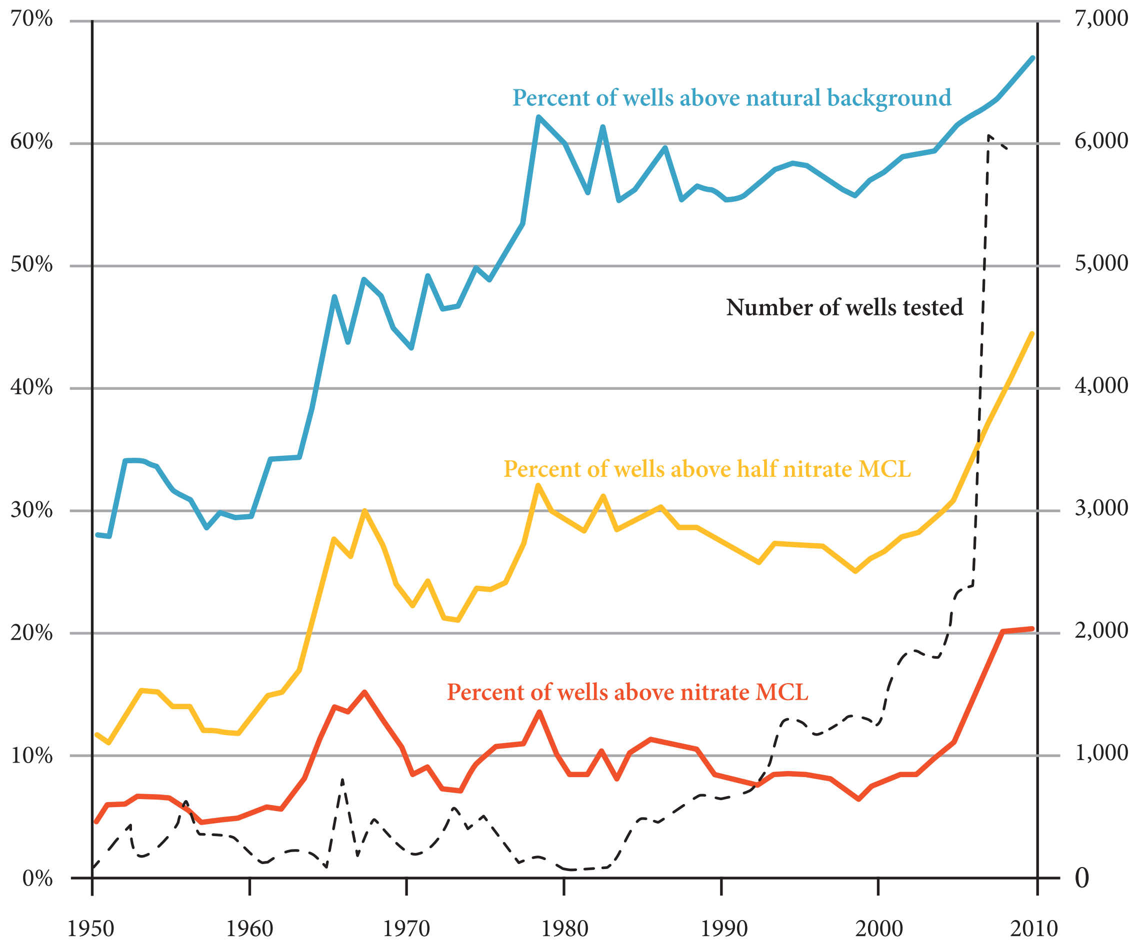

Figure 13. Five-year moving average of the percentage of wells for which the average annual measured concentration exceeded 9 mg/L (background), 22.5 mg/L (half of the MCL), and 45 mg/L (MCL) in any given year. Since the 1990s, an increasing number of wells other than public supply wells have been tested. In 2007, Central Valley dairies began testing their domestic and irrigation wells on an annual basis. Source: Boyle et al. 2012.

Table 7. Total groundwater volume* and estimated remediation volume by sub-basin

Sub-Basin	Total Groundwater Volume in Study Area km^3 [million AF]	Remediation Volume > MCL km^3 (% of total)	Remediation Volume > MCL million AF (% of total)
Tulare Lake Basin			
5-22.06–Madera	1.48 [1.2]	0.15 (10%)	0.12 (10%)
5-22.07–Delta-Mendota	3.21 [2.6]	0.16 (5%)	0.13 (5%)
5-22.08–Kings	115 [93]	12.75 (11%)	10.34 (11%)
5-22.09–Westside	64 [52]	1.67 (3%)	1.35 (3%)
5-22.10–Pleasant Valley	4.9 [4.0]	1.11 (23%)	0.90 (23%)
5-22.11–Kaweah	42 [34]	9.12 (21%)	7.39 (21%)
5-22.12–Tulare Lake	46 [37]	4.65 (10%)	3.77 (10%)
5-22.13–Tule	41 [33]	4.29 (11%)	3.48 (11%)
5-22.14–Kern	49 [40]	5.81 (12%)	4.71 (12%)
TLB TOTAL	366 [297]	39.7 (11%)	32.2 (11%)
Salinas Valley			
3-4.01–180/400 Foot Aquifer	8.46 [6.86]	0.91 (11%)	0.74 (11%)
3-4.02–Eastside	3.16 [2.56]	1.23 (39%)	1.00 (39%)
3-4.04–Forebay	5.59 [4.53]	1.37 (25%)	1.11 (25%)
3-4.05–Upper Valley	3.03 [2.46]	0.56 (19%)	0.45 (19%)
3-4.08–Seaside	0.78 [0.63]	0.07 (10%)	0.06 (10%)
3-4.09–Langley	0.44 [0.36[†]]	0.04 (9%)	0.03 (9%)
3-4.10–Corral de Tierra	0.60 [0.49[‡]]	0.002 (0.5%)	0.002 (0.5%)
SV TOTAL	22.1 [17.9]	4.19 (19%)	3.4 (19%)
Study Area Total	**315 [255]**	**43.9 (11%)**	**35.6 (11%)**

Source: King et al. 2012.

* Source: DWR 2010.

[†] Storage; actual groundwater volume not listed.

[‡] Source: Montgomery Watson Americas 1997, not listed in DWR Bulletin 118.

Table 8a. Summary of programs and statutes for reducing nitrate contamination in groundwater

Agency	Program/Statute (year created/passed)	Goal/Purpose
U.S. Environmental Protection Agency (U.S. EPA)	Supplemental Environmental Programs (SEP) (1998)	Environmentally beneficial project that a violator of environmental laws may choose to perform (under an enforcement settlement) in addition to the actions required by law to correct the violation.
State Water Resources Control Board (State Water Board)	Porter-Cologne Water Quality Control Act (1969)	Grants the State Water Board authority over state water quality policy and aims to regulate activities in California to achieve the highest reasonable water quality.
	Recycled Water Policy (2009)	Resolution No. 2009-0011: Calls for development of salt and nutrient management plans and promotes recharge of clean storm water.
Regional Water Quality Control Boards	Cleanup and Abatement Order (CAO)	CA Water Code § 13304: Allows the Regional Water Board to issue a directive to a polluter to require clean up of waste discharged into waters of the state.
Central Coast Regional Water Quality Control Board	Irrigated Lands Regulatory Program (ILRP) (2004, draft in 2011)	*General Conditional Waiver of Waste Discharge Requirements, 3-Tiered Agricultural Regulatory Program (2004):* Groundwater quality monitoring required to different degrees based on discharger's tier. Draft (2001) requires Tier 3 dischargers with high nitrate loading to meet specified Nitrogen Mass Balance Ratios or implement a solution that leads to an equivalent nitrate load reduction.
Central Valley Regional Water Quality Control Board	Irrigated Lands Regulatory Program (ILRP) (2003, draft in 2011)	*Conditional Wavier of Waste Discharge Requirements of Discharges from Irrigated Lands:* Interim program to regulate irrigated lands. Does not address groundwater. *Recommended ILRP Framework (2011):* Development of new monitoring and regulatory requirements (includes groundwater).
	CV-SALTS (2006)	Planning effort to develop and implement a basin plan amendment for comprehensive salinity and nitrate management.
	Dairy Program (2007)	*Waste Discharge Requirements General Order for Existing Milk Cow Dairies:* Confined animal facilities must comply with set statewide water quality regulations, and existing milk cow dairies must conduct nutrient and groundwater monitoring plans.
California Department of Food and Agriculture (CDFA)	Feed, Fertilizer, Livestock, Drugs, Egg Quality Control Regulatory Services (FFLDERS)	Manages licenses, registration and inspection fees, and a mill fee levied on fertilizer sales, to fund research and educational projects that improve fertilizer practices and decrease environmental impacts from fertilizer use.

Table 8b. Summary of programs and statutes related to groundwater nitrate and drinking water (data collection, information, education, or regulation of drinking water)

Agency	Program/Statute (year created/passed)	Goal/Purpose
U.S. Environmental Protection Agency (U.S. EPA)	Safe Drinking Water Act (SDWA) (1974, 1986, 1996)	Mandates EPA to set the drinking water standards and to work with states, localities, and water systems to ensure that standards are met.
	Phase II Rule (1992)	Established federal maximum contaminant level (MCL) for nitrate in public water systems.
	Enforcement Response Policy—Enforcement Targeting Tool	Focuses on high-priority systems with health-based violations or with monitoring or reporting violations that can mask acute health-based violations.
U.S. Department of Agriculture (USDA)	Rural Utilities Service: National Drinking Water Clearinghouse (1977)	Provides technical assistance and educational materials to small and rural drinking water systems.
California Department of Public Health (CDPH)	22 CCR § 64431	Established state maximum contaminant level (MCL) for nitrate in public water systems.
	Drinking Water Source Assessment and Protection (DWSAP)	Evaluation of possible contaminating activities surrounding groundwater and surface water sources for drinking water.
	Expense Reimbursement Grant Program (EPG)	Education, training, and certification for small water system (serving < 3,301 people) operators.
	Groundwater Ambient Monitoring and Assessment (GAMA)	Improves statewide groundwater monitoring and increases availability of groundwater quality information. Funded by Prop 50 and special fund fees.
Assembly Bill 3030	(1993)	Permits local agencies to adopt programs to manage groundwater and requires all water suppliers overlying useable groundwater basins to develop groundwater management plans that include technical means for monitoring and improving groundwater quality.
Kern County Water Agency (KCWA)	(1961)	Collects, interprets, and distributes groundwater quality data in Kern County.
Monterey County Health Department		Implements a tiered, regular nitrate sampling program based on increasing nitrate concentration for local small water systems and for state small water systems.
Southern San Joaquin Valley Water Quality Coalition	(2002)	Protects and preserves water quality in the Tulare Lake Basin through surface water quality monitoring and dissemination of collected data. Particular focus is on agricultural discharge areas. Does not currently focus on groundwater.
Tulare County Water Commission	(2007)	Discusses water issues impacting Tulare County and advises the Tulare County Board of Supervisors. Special focus on nitrate in groundwater and improving drinking water in small communities.
Monterey County Water Resources Agency (MCWRA)	(1947)	Provides water quality management and protection through groundwater quality monitoring (including nitrate levels) and research and outreach efforts to growers to improve fertilizer management and reduce nitrate leaching.
The Waterkeeper Alliance	Monterey Coastkeeper (2007)	Collaborates with the State Water Board to ensure effective monitoring requirements for agricultural runoff and more stringent waste discharge requirements for other nitrate sources.
Rural Community Assistance Partnership (RCAP)	(1979)	Uses publications, training, conferences, and technical assistance to help communities of less than 10,000 people access safe drinking water, treat and dispose of wastewater, finance infrastructure projects, understand regulations, and manage water facilities.
National Rural Water Association (NRWA)	(1976)	Offers drinking water system technical advice (operation, management, finance, and governance) and advocates for small/rural systems to ensure regulations are appropriate.
California Rural Water Association	(1990)	Provides online classes, onsite training, low-cost educational publications, and other forms of technical advice for rural water and wastewater systems.
Self-Help Enterprises (SHE)	Community Development Program (1965)	Provides technical advice and some seed money to small/rural/poor communities for the planning studies and funding applications associated with drinking water system projects.
Community Water Center	Association of People United for Water (AGUA) (2006)	Advocates for regional solutions to chronic local water problems in the San Joaquin Valley. Focused on securing safe drinking water, particularly from nitrate-impacted sources.

Table 9. Summary of existing funding sources for water quality investigations and safe drinking water

Agency	Program (year passed or created)	Funding Provided (in millions of dollars)
California Department of Public Health (CDPH)	Safe Drinking Water State Revolving Fund (SDWSRF) (1996) (grants and loans)	**Generally $100–$150:** Low-interest loans and some grants to support water systems with technical, managerial, and financial development and infrastructure improvements.
	Proposition 84 (2006) (grants) **(fully allocated)**	**$180:** Small community improvements. **$60:** Protection and reduction of contamination of groundwater sources. **$10:** Emergency and urgent projects.
	Proposition 50 (2002) (grants) **(fully allocated)**	**$50:** Water security for drinking water systems. **$69:** Community treatment facilities and monitoring programs. **$105:** Matching funds for federal grants for public water system infrastructure improvements.
State Water Resources Control Board (State Water Board)	Clean Water State Revolving Fund (CWSRF) (1987) (loans)	**$200–$300 per year:** Water quality protection projects, wastewater treatment, nonpoint source contamination control, and watershed management.
	Small Community Wastewater Grants (2004, amended 2007) (grants)	**$86 (fees on the CWSRF):** Loan forgiveness to small disadvantaged communities and grants to nonprofits that provide technical assistance and training to these communities in wastewater management and preparation of project applications.
	Proposition 50 (2002) (grants) **(fully allocated)**	**$100:** Drinking water source protection, water contamination prevention, and water quality blending and exchange projects.
	Agricultural Drainage Program (1986) (loans) **(fully allocated)**	**$30:** Addressing treatment, storage, conveyance or disposal of agricultural drainage.
	Dairy Water Quality Grant Program (2005) (grants) **(fully allocated)**	**$5 (Prop 50):** Regional and on-farm dairy projects to address dairy water quality impacts.
	Nonpoint Source Implementation Program (2005) (grants)	**$5.5 per year:** Projects that reduce or prevent nonpoint source contamination to ground and surface waters.
	Cleanup and Abatement Account (2009)	**$9 in 2010:** Clean up or abate a condition of contamination affecting water quality.
	Integrated Regional Water Management (IRWM) (2002) (grants) **(fully allocated)**	**$380 (Prop 50):** Planning ($15) and implementation ($365) projects related to protecting and improving water quality, and other projects to ensure sustainable water use.

continued on next page

Table 9. *Continued*

Agency	Program (year passed or created)	Funding Provided (in millions of dollars)
California Department of Water Resources (DWR)	Integrated Regional Water Management (IRWM) (2002) (grants)	**$500 remaining (Prop 84):** Regional water planning and implementation.
	Local Groundwater Assistance Grant (2008) (grants)	**$4.7 anticipated for 2011–2012 (Prop 84):** Groundwater studies, monitoring and management activities.
	Proposition 82 (1988) (loans)	**$22:** New local water supply feasibility and construction loans.
	Water Use Efficiency Grant Program (2001) (grants)	**$15 in 2011 (Prop 50):** Water use efficiency projects for agriculture, such as: wellhead rehabilitation, water and wastewater treatment, conjunctive use, water storage tanks.
	Agricultural Water Conservation Loan Program (2003) (loans)	**$28 (Prop 13):** Agricultural water conservation projects, such as: lining ditches, tailwater or spill recovery systems, and water use measurement.
	Infrastructure Rehabilitation Construction Grants (2001) (grants) **(fully allocated)**	**$57 (Prop 13):** Drinking water infrastructure rehabilitation and construction projects in poor communities.
California Infrastructure and Economic Development Bank (I-Bank)	Infrastructure State Revolving Fund (ISRF) (1994) (loans)	**$0.25 to $10 per project:** Construction or repair of publicly owned water supply, treatment, and distribution systems.
U.S. Department of Agriculture (USDA)	Rural Utilities Service—Water and Environmental Programs (RUS WEPs) (loans and grants)	**$15.5:** Development and rehabilitation of community public water systems (less than 10,000 people), including: emergency community water assistance grants, predevelopment planning grants, technical assistance, guaranteed loans, and a household well water program.
U.S. Department of Housing and Development (HUD)	Community Development Block Grant (CDBG) (grants)	**$500 in 2010 for CA:** Community development projects: feasibility studies, final plans and specs, site acquisition and construction, and grant administration.
U.S. Department of Commerce	Economic Development Administration (EDA) (grants)	**Grants up to 50% of project costs:** supports economic development, planning, and technical assistance for public works projects.
Rural Community Assistance Corporation (RCAC)	Drinking Water Technical Assistance and Training Services Project (loans)	**$1.2 per year:** Administers funds from the US EPA Office of Groundwater & Drinking Water for infrastructure projects, including water.
The Housing Assistance Council (HAC)	Small Water/Wastewater Fund (loans)	**Up to $0.25 per project:** Loans for land acquisition, site development, and construction.
Cooperative Bank (CoBank)	Water and Wastewater Loan (loans)	**$1 per project:** Water and wastewater infrastructure, system improvements, water right purchases, and system acquisitions. **$0.05–$0.5 per project:** Construction costs.

Source: Canada et al. 2012.

The Dutch Experience

In response to increasingly intensive animal production and a growing awareness of its effects on nitrate concentrations in surface water and groundwater, the European Council Nitrate Directive (ND) (Council Directive 91/67/EEC) was established in 1991 as part of the European Union (EU) Water Framework. The ND imposes a performance standard of 50 mg/L nitrate on effluent, groundwater, and surface water quality levels within all EU countries. Furthermore, each country is required to establish nitrate contamination reduction plans, monitor program effectiveness, and regularly report their findings to the European Council (EC) (EU Publications Office). Compliance with the ND is costly in terms of time, expertise, and money; however, countries that do not meet ND standards face large fines from the EC. While the ND does very little in the way of explicitly specifying how countries should act in efforts to comply with these requirements, plans that do not propose to regulate manure application at ND standards (i.e., land application rates in the range of 170–210 kg N/ha) have been historically rejected.

As an agricultural hotspot, The Netherlands has struggled to meet the ND requisites. To fulfill the obligatory ND requirements (Ondersteijn 2002), the Dutch government first created the Mineral Accounting System (MINAS) in 1998 (Henkens and Van Keulen 2001). MINAS was a farm-gate policy created to ensure the balance of nitrogen and phosphorus inputs (fertilizer and feed) and outputs (products and manure) on individual farms via balance sheets (Oenema et al. 2005). MINAS resembled a farm-gate performance standard that was enforced by a penalty tax for excess nitrogen and phosphorus inputs: farms consuming more nitrogen or phosphorus than could be accounted for via harvest outputs would be fined per kilogram of nitrogen or phosphorus lost to the environment. As of 2003, fines of € 2.27/kg N ($1.40/lb N) were enforced, more than seven times the cost of nitrogen fertilizer at the time. MINAS was popular for its simplicity, and was well supported by government aid. RIVM (Netherland's National Institute for Public Health and the Environment), which monitors nitrogen and phosphorus soil and water concentrations nationally, reports that nitrogen surpluses in agricultural areas fell substantially beginning in 1998 as a result of its implementation. Nevertheless, the EU declared the Dutch MINAS policy noncompliant with ND requirements, stating that the policy did not directly regulate water nitrate concentrations (Henkens and Van Keulen 2001).

In response to the EU's rejection of MINAS, the Netherlands implemented an additional policy in 2002: the Mineral Transfer Agreement System (MTAS). MTAS was a cap-and-trade system that prescribed manure (not inorganic fertilizer) application rates (as per ND objectives) and allowed farmers to purchase surplus application rights from those farmers applying manure to their land below legal limits. Rather than repealing MINAS, however, the Dutch increased enforceable fines under MINAS to serve as a safety net under the newly implemented MTAS (Ondersteijn 2002). Following the enactment of MTAS, water nitrate levels continued to fall at pre-MTAS rates (Henkens and Van Keulen 2001; Ondersteijn 2002; Berentsen and Tiessink 2003; Helming and Reinhard 2009), suggesting that the implementation of MTAS in addition to MINAS had little or no additional effect.

Given the apparent futility of MTAS, and following the repeated rejection of MINAS by the European court of justice in 2003, both MTAS and MINAS were abandoned by the Dutch government by 2006. The two competing regulations were replaced by a composite policy that enforces nitrogen as well as phosphorus application standards for both manure and inorganic fertilizer, thereby satisfying both ND standards and the unique challenges encountered in Dutch territory, while minimizing administrative and economic costs. The composite policy remains in effect to date.

4 Impact: Drinking Water Contamination

About 2.6 million people in the Tulare Lake Basin and Salinas Valley rely on groundwater for drinking water. This section estimates the population susceptible to nitrate contamination of groundwater, identifies safe drinking water actions available and the most promising options to address nitrate groundwater contamination, and estimates the total cost of nitrate contamination to communities and households in these areas. This discussion summarizes more detailed examinations by Jensen et al. (2012) and Honeycutt et al. (2012).

4.1 Susceptible Populations

Groundwater nitrate contamination brings two forms of susceptibility: public health risks and the economic costs of avoiding such risks through treatment, source reduction, remediation, or alternative water supplies. California's Tulare Lake Basin and Salinas Valley are particularly susceptible to public health and financial risks from nitrate contamination for the following reasons (Honeycutt et al. 2012).

- Communities in this region are unusually dependent on groundwater. Less than 3% of the area's population is served by surface water alone.
- These areas have more and larger nitrate contamination sources than most other parts of California (Viers et al. 2012).
- Of the region's 402 community public and state-documented state small water systems, 275 are very small (15–500 connections) and 58 are small (501–3,300 connections) (Figure 14). Small and very small systems are about 81% of Tulare Lake Basin water systems (serving 89,125 people, 4% of the population) and about 89% of the Salinas Valley water systems (serving 23,215 people, 6% of the population).
- Many of these small systems rely on a single well, without emergency alternatives when contamination is detected. These small water systems are inherently less reliable and face higher per capita expenses to address nitrate contamination of groundwater.
- Roughly 10.5% and 2.6% of the populations of Tulare Lake Basin and Salinas Valley, respectively, use unregulated, unmonitored domestic wells, serving 245,000 people from 74,000 wells (Figure 15).
- The area has many poor communities that cannot afford drinking water treatment or capital-intensive alternative water supplies. Over 17% of the Tulare Lake Basin and 10% of the Monterey County population lives in poverty.

We estimated the population of these basins that is susceptible to significant financial cost and public health concerns from nitrate contamination in groundwater (Honeycutt et al. 2012). The drinking water source (groundwater well or surface water), history of nitrate contamination, size, and potential for contamination were considered for each water system and self-supplied rural household well location in this region. "Vulnerability" describes the intrinsic potential for a system to deliver drinking water to users with high nitrate levels based on the type of system and based on the number of water sources within the system. Vulnerability is scored as follows:

- Lower vulnerability is assigned to community public water systems (water systems with >15 connections) having more than one water source (i.e., more than one well), regardless of whether they treat their water to remove nitrate.
- Higher vulnerability is assigned to all other water systems: community public water systems with a single source (one well) and state small (5–14 connections), local small (2–4 connections), and household self-supplied water systems (domestic well).
- No vulnerability to nitrate groundwater contamination is assigned to water systems solely supplied by surface water.

Susceptible water users could be harmed by consuming drinking water containing contaminants or by the costs for avoiding such contamination. We define "susceptible population" as those

- served by a water system with multiple sources (wells) that has reported at least one delivered water nitrate MCL exceedance in the past 5 years, or
- served by a water system with a single source (well) that has reported at least one raw water nitrate MCL exceedance in the past 5 years, or

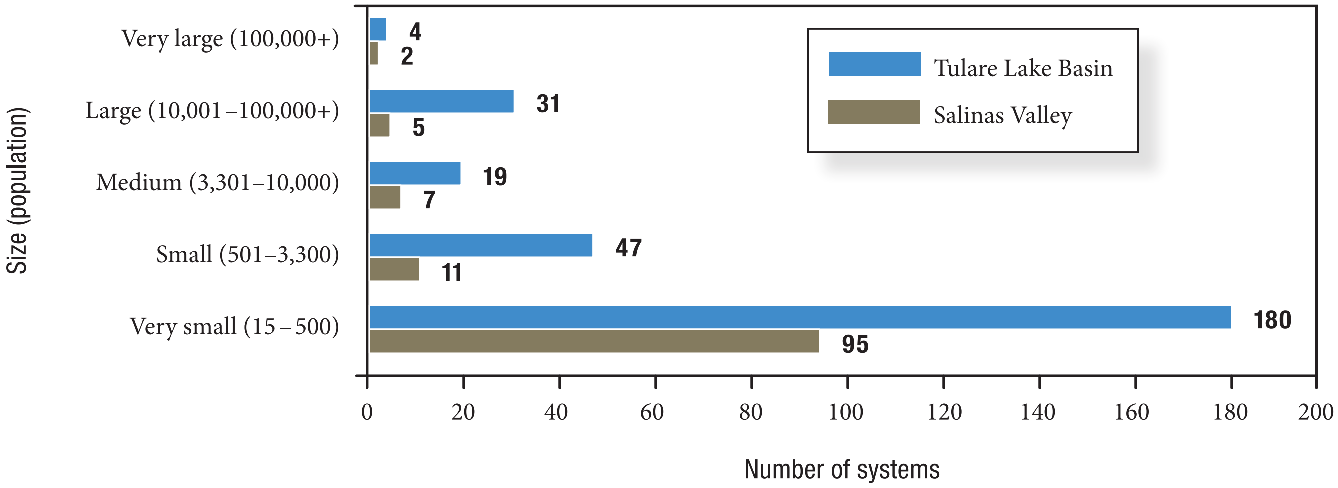

Figure 14. Community public and state-documented state small water systems of the Tulare Lake Basin and Salinas Valley. Source: CDPH 2010.

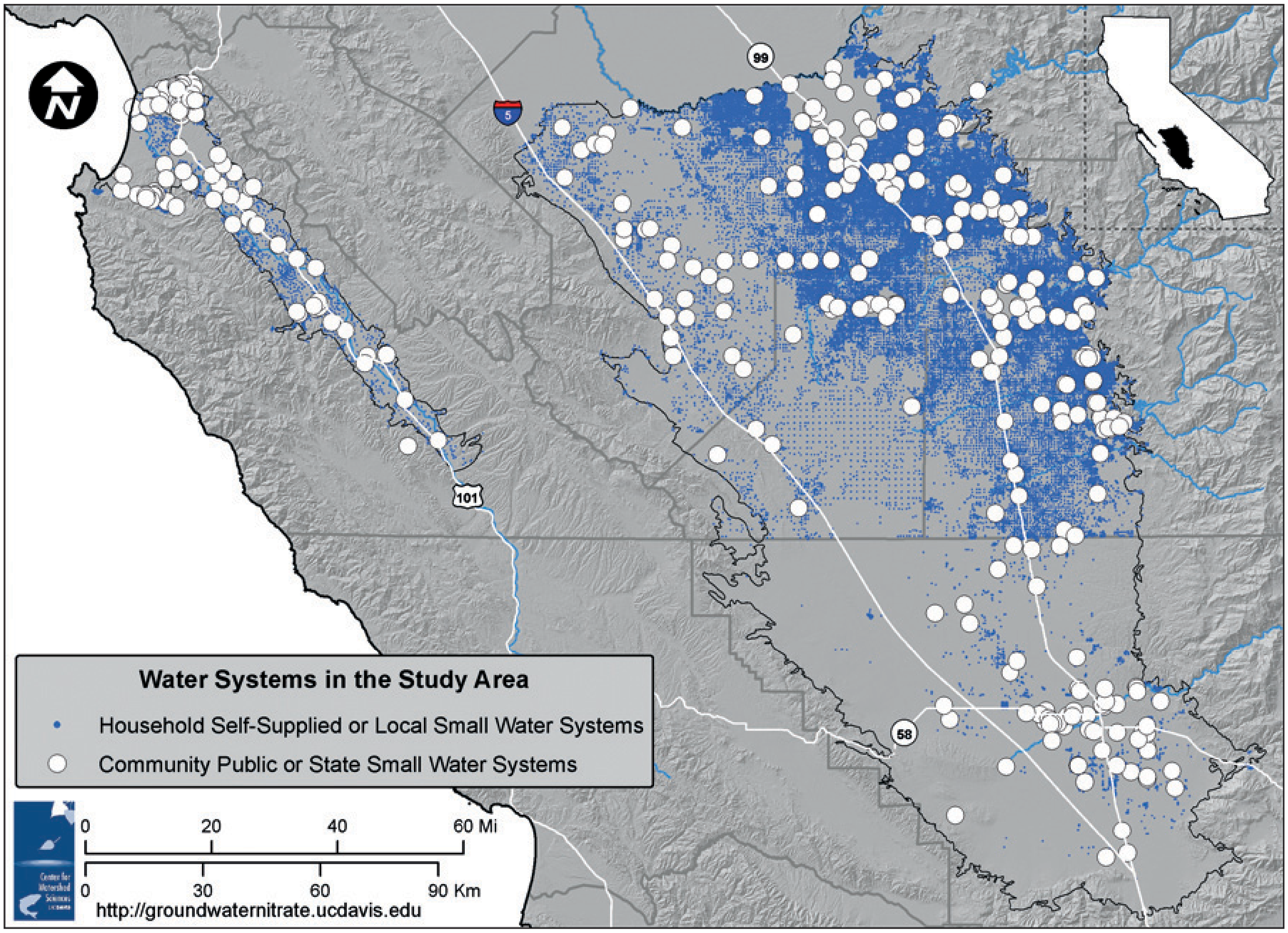

Figure 15. Estimated locations of the area's roughly 400 regulated community public and state-documented state small water systems and of 74,000 unregulated self-supplied water systems. Source: Honeycutt et al. 2012; CDPH PICME 2010.

- relying on domestic wells or local small water systems (fewer than 5 connections) in an area where shallow groundwater (<300 feet) has exceeded the nitrate MCL in the past (1989–2010), based on data from the UC Davis CASTING dataset (Boyle et al. 2012) or
- served by a water system lacking nitrate water quality data.

Figure 16 shows how these categorizations were used to classify populations and water systems. Of the 2.6 million people in the Tulare Lake Basin and Salinas Valley, 254,000 people have drinking water supplies susceptible to significant nitrate contamination. Of these, about 220,000 are connected to 85 community public or state small water systems with high or unknown susceptibility. For the majority of these systems, treatment will be expensive due to their small size (lack of economies of scale).

About 34,000 people are served by about 10,000 self-supplied household wells or local small water system wells at high risk for nitrate contamination given the known raw water quality exceedances in nearby wells (Figure 17). These systems are currently not regulated by the state or counties, and little public monitoring data exist for them.

Nine of 105 single-source small water systems in the study area exceeded the nitrate MCL at least once since 2006 and are not currently treating their water (CDPH 2010). Currently, 13 groundwater-supplied

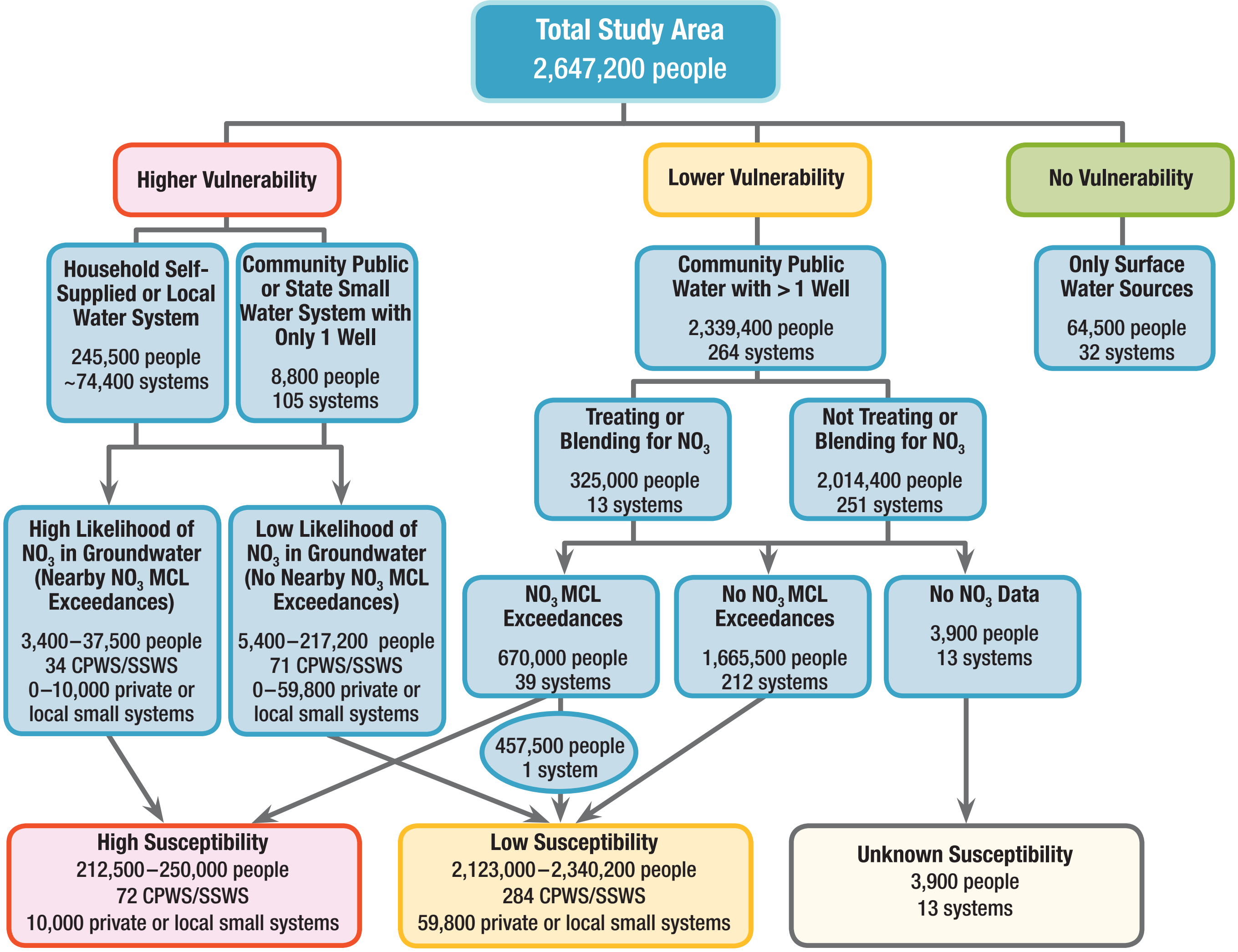

Figure 16. Classification of susceptible populations based on estimated vulnerability and water quality data for the study area. Due to different sources of data, the summation of the top row does not equal the total study area population. All population and connection information is approximate. CPWS: community public water system; SSWS: state small water system. Source: Honeycutt et al. 2012.

community public water systems and state small water systems treat for nitrate: 8 treat by blending and 5 by treatment processes (4 by ion exchange [IX] and 1 by reverse osmosis [RO]).

About 45% of the multiple-source systems that have delivered water exceeding the nitrate MCL serve severely disadvantaged and disadvantaged communities (SDACs and DACs) (Figure 18). DACs that are unincorporated, known as DUCs, often lack central water and sewer services. These DUCs are highly susceptible to nitrate contamination because they may lack a safe water source and are less financially able to resort to alternatives if their water source becomes contaminated. Since these areas have a large concentration of families with low incomes, community solutions to nitrate treatment or alternative water supply also might be difficult.

Over 2 million people in the study area are not classified as susceptible to a public health risk for nitrate contamination today. However, more than half of the study area population is considered to be at financial risk from nitrate contamination, having to potentially pay higher costs for treatment and monitoring because of regional groundwater contamination: A total of 1.3 million people (57%) in the area are served by community public water systems or state small water systems in which raw water sources have exceeded the nitrate MCL at least once between 2006 and 2010 (Figure 1 and Table 10). This includes over 457,000 people in the City of Fresno, which has nitrate exceedances in some wells but is taking measures to avoid this contamination, including significant expansion of surface water use.

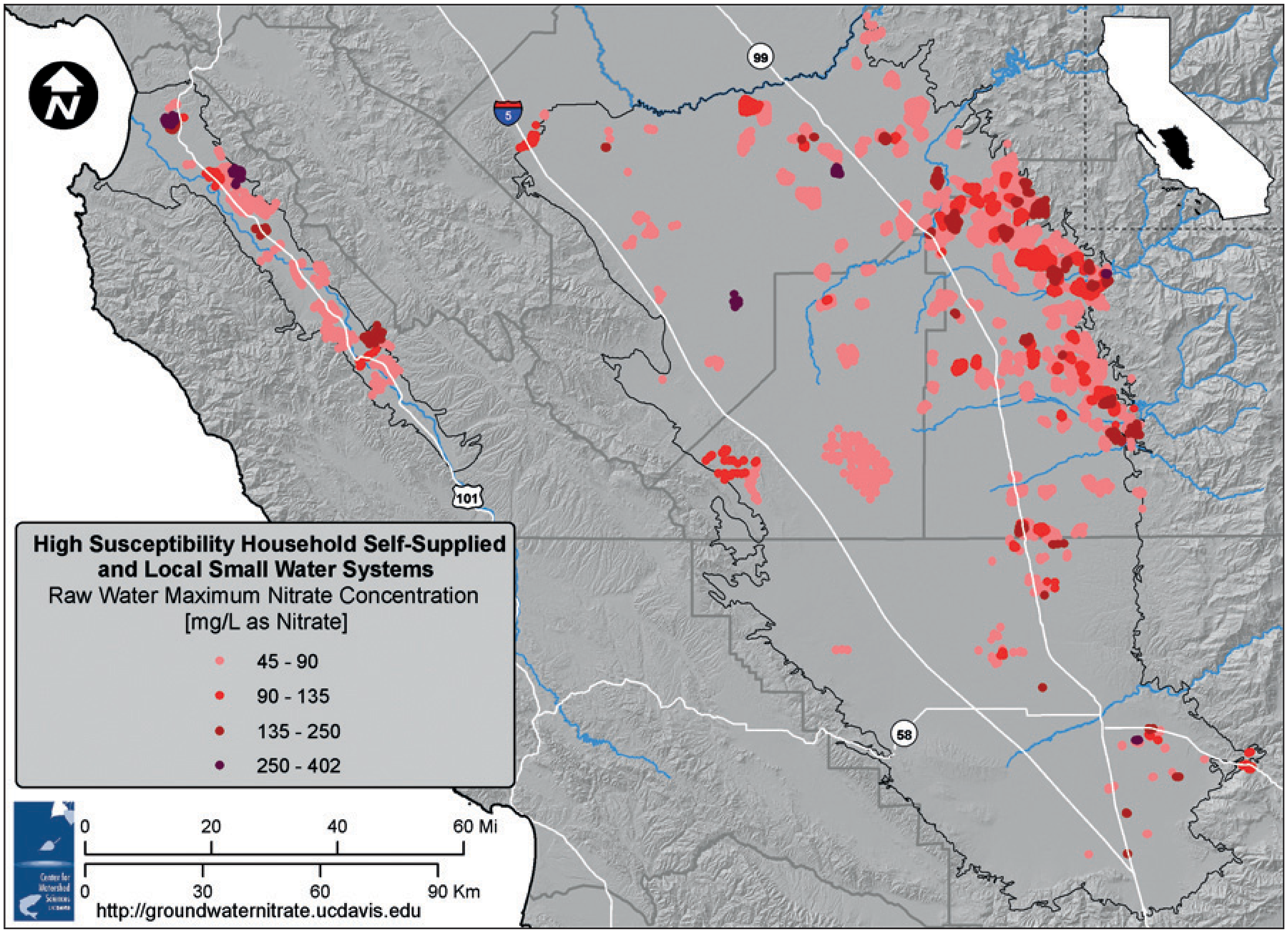

Figure 17. Household self-supplied and local small water systems located near wells having a maximum nitrate concentration value greater than the MCL. Source: 1989–2010 CASTING Database: GAMA, DWR, SWB, CDPH-CADWSAP, USGS, County Officials, Land Use Parcel Codes and DWR Land Use (see Honeycutt et al. 2012).

Severely disadvantaged communities (SDACs) are particularly vulnerable to financial costs. Of 51 community public water systems (serving about 714,000 people) in the study area with a raw source exceeding the nitrate MCL, most systems (40, serving about 379,000 people) are in a DAC. Thirteen of the 40 exceeding systems are in unincorporated areas (serving about 167,000 people), and 27 are in incorporated communities (serving about 212,000 people). They often cannot afford or organize and maintain capital-intensive solutions.

As past and current nitrogen applications migrate downward and through aquifers in the Tulare Lake Basin and Salinas Valley, populations susceptible to the costs and public health risks of nitrate contamination are likely to increase. Assuming unchanging and unabated basin-wide trends in CPWS raw nitrate groundwater levels since 1970, the financially susceptible population is estimated to increase from 57% currently to almost 80% or 1.9 million people by 2050 (not accounting for population growth, Table 10).

4.2 Alternative Water Supply and Treatment

Source reduction and aquifer remediation are insufficient to address drinking water nitrate contamination in the short- or near-term. In these cases, local water system authorities and users must select from a variety of treatment and alternative supply options. These options are summarized for community public water systems in Table 11 and for self-supplied

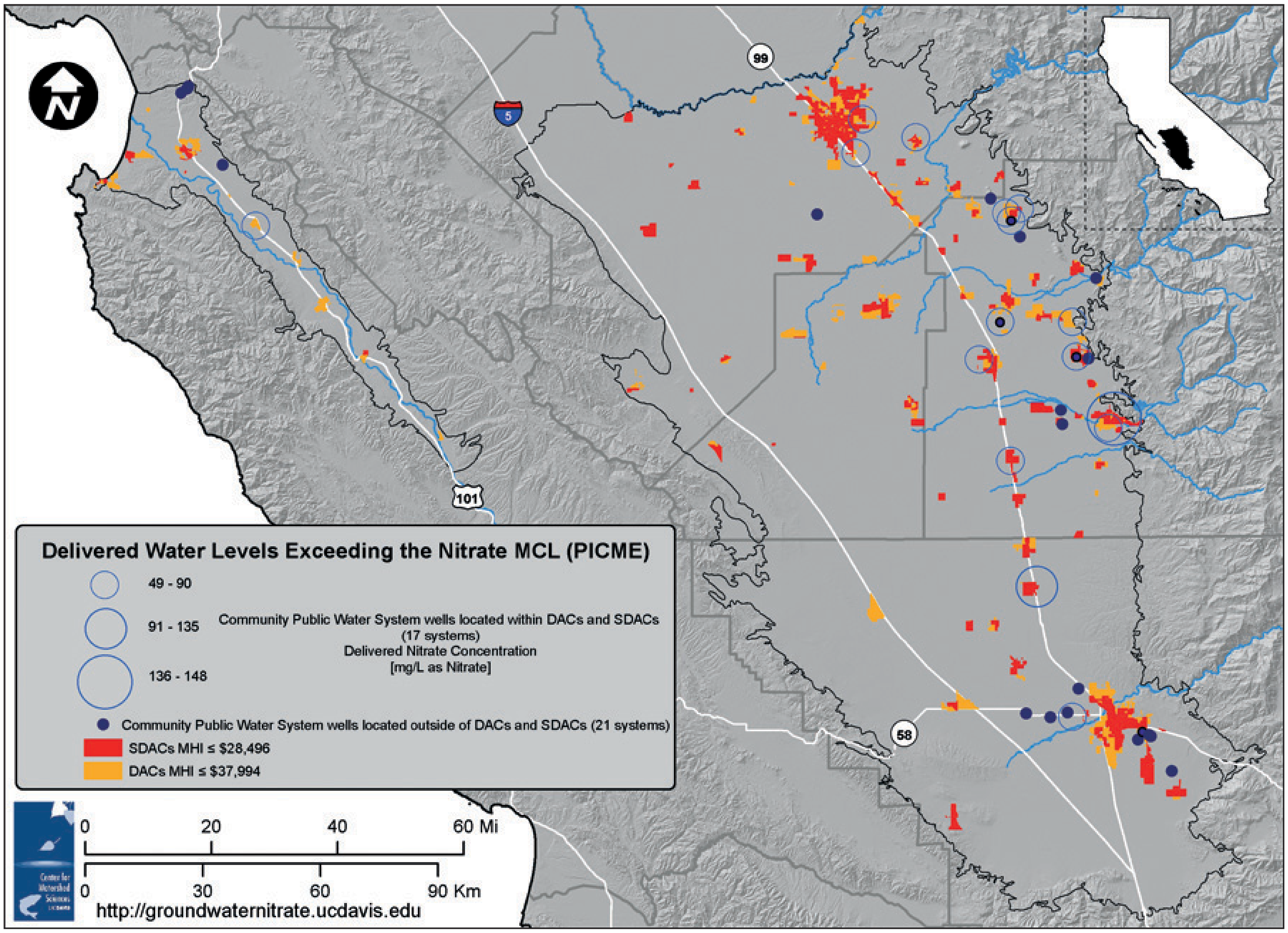

Figure 18. DACs, SDACs, and delivered water quality in multiple-source community public water systems. Source: CDPH PICME WQM 2006–2010; U.S. Census Bureau 2000, 2001 (see Honeycutt et al. 2012).

households and local small water systems in Table 12. This section further outlines these options (for details, see Honeycutt et al. 2012, and Jensen et al. 2012).

Community Public Water System Options

Each water system is unique, despite having many common problems and characteristics. No single solution will fit every community affected by nitrate in groundwater; each water system requires individual engineering and financial analysis.

The uniqueness of individual water systems is multiplied by the large number of small water systems in the Tulare Lake Basin and Salinas Valley. Small water systems have fewer and more expensive options per capita than do larger systems. They lack economies of scale and have fewer staff resources. Small water and wastewater systems also typically have disproportionately greater water quality and reliability problems and higher costs per capita (NRC 1997).

The options available for community public water systems faced with problems from nitrate contamination are summarized in Table 11. Blending is the most common approach to nitrate contamination for larger community public water systems with more than one water source. Water from the contaminated well is reduced, eliminated, or mixed with water from a safer water source. Eight community public water systems in the Tulare Lake Basin and Salinas Valley currently blend sources to comply with the nitrate MCL.[7]

Drilling a deeper or a new well is another common response to nitrate groundwater contamination. This approach can be cost-effective, but it is often only a temporary solution when nitrate contamination continues to spread locally and to deeper aquifers.

Treatment of community public water supplies is often explored and sometimes employed. A variety of treatment options are available (Jensen et al. 2012). Ion exchange and reverse osmosis are used for community public water system treatment in the basins. Additional treatment options, such as biological denitrification, may become economical and accepted in time (Jensen et al. 2012). However, treatment is expensive, especially for small systems. Under some circumstances, only a portion of extracted water is treated for nitrate because regulations can be met by blending treated water with water not treated for nitrate.

Management of waste concentrate or brine, by-products of ion exchange and reverse osmosis treatments, can also be costly. Options include discharge to a sewer or septic system, waste volume reduction using drying beds, trucking or piping for off-site disposal, deep well injection, and advanced treatment (Jensen et al. 2012).

Connecting to a larger system with reliable good-quality water can often solve many problems of small water systems, including nitrate contamination. This provides economies of scale in costs and greater access to expertise for resolving water system problems. However, connecting a small, often

Table 10. Estimated number of years until community public water supply (CPWS) sources exceed the nitrate MCL, and total affected population (not accounting for population growth)

Time for Maximum Recorded Raw Nitrate Level to Reach the MCL	Total Number of Affected CPWSs*	Total Affected Population*	Percent of Total CPWSs Population (study area)
0 years (2010)	77	1,363,700	57%
25 years (2035)	114	1,836,700	76%
40 years (2050)	127	1,903,300	79%

Source: Honeycutt et al. 2012.

* Based on raw water quality, not delivered quality susceptibility.

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[7] Jensen et al. (2012) found a total of 23 water systems, including all types of water systems, in the study area that treat or blend to address the nitrate problem (10 blending systems, 10 IX systems, and 3 RO systems).

Table 11. Options for community public water systems

Option	Advantages	Disadvantages
Blending	• Simple nontreatment alternative. • Cost-effective, given suitable wells.	• Capital investment for accessing an alternative source. • Relies on availability and consistency of low-nitrate source. • Monitoring requirements. • Rising nitrate levels may preclude ability to blend.
Drilling a deeper or new well	• Potentially more reliable water supply. • Cheaper than bottled water for households using more than 8 gal/day.	• Potential decrease in source capacity. • Capital and operational costs increase with depth. • Potentially only a temporary quick fix; longevity depends on local hydrogeologic conditions and land use. • Risk of encountering other water quality concerns at greater depths (i.e., arsenic, manganese). • Pipeline costs if source area is far from original source.
Community treatment (IX, RO and EDR)	• Multiple contaminant removal. • Feasible, safe supply.	• Disposal of waste residuals (i.e., brine waste). • High maintenance and/or energy demands. • Resin or membrane susceptibility.
Piped connection to an existing system	• Safe, reliable water supply.	• Capital cost of pipe installation. • Connection fee. • Water rights purchase (surface water).
Piped connection to a new system	• Safe, reliable water supply.	• Capital cost of pipe installation. • High treatment system capital and O&M costs. • Water rights purchase (surface water).
Regionalization and consolidation	• Often lower costs.	• High capital and O&M costs.
Trucked water	• Community-wide distribution. • No start-up capital cost.	• Temporary “emergency” solution. • Not approved for new water systems.
Relocate households	• Safe, reliable water supply.	• Socially and politically difficult, extreme option. • Loss of property value and jobs. • Social, familial dislocation.
Well water quality testing (already in place)	• Water quality awareness. • Beneficial to blending.	
Dual system	• Hybrid of options. • Treating only potable.	• Possible consumption of contaminated source. • Cost of contaminated supply plus cost for POU system or trucked/bottled water, or capital dual plumbing costs.

Source: Honeycutt et al. 2012.

substandard system to a larger system often involves substantial initial capital costs to make the connection and to upgrade the smaller distribution system. Establishing connections also can pose institutional challenges (such as water rights and governance) and financial risks to the larger system.

Connecting several smaller systems into a new larger water system has many of the same advantages and costs of connecting small systems to an existing larger system. Establishing a new system also requires additional start-up costs for infrastructure and institutional development.

Institutional consolidation of several small systems avoids the costs of hydraulically connecting small systems, and it can provide a higher level of staff expertise and administrative economies of scale. This is attractive when systems are too small to merit full-time, trained staff and too scattered to economically connect their distribution systems and sources.

Trucking uncontaminated water to supply small communities allows the servicing of small scattered water systems, usually at a high cost. Trucking in water is generally seen as a temporary or emergency solution while a more permanent high-quality drinking water source is being developed.

Relocating households to a different area with better-quality water is an extreme approach that might be suitable if a small community is unviable for a variety of reasons and can not attract additional customer investments. Relocating households is likely to be accompanied by a loss of property values and local jobs, as well as social dislocation.

Two ancillary options that can supplement some of the above options are well water quality testing and the development of dual plumbing systems. Well water testing programs provide better and more timely information for awareness of nitrate contamination and can also provide useful information for blending. Dual plumbing systems separate potable from nonpotable water distribution systems, allowing a smaller quantity of contaminated water to be treated or conveyed from a higher-quality source for potable water uses.

The least expensive option is usually to stop using a nitrate-contaminated well and switch to another existing well, if a safer well is available. Similarly, many systems with more than one well blend water from a low-nitrate source or well with more contaminated supplies.

Self-Supplied Households and Local Small Water System Options

There are approximately 74,000 self-supplied households and local small water systems in the Tulare Lake Basin and Salinas Valley. Their nitrate contamination response options are summarized in Table 12 and discussed below.

Water supply options for self-supplied households and local small water systems are are similar to the options available to community public water systems, but are are similar to the options available to community public water systems, but are applied at a much smaller scale.

Drilling a deeper or new well can provide a reliable supply where better water quality exists. This option is costly, deeper wells can be accompanied by additional forms of contamination (such as arsenic), and new wells might provide only temporary relief if the nitrate plume is spreading deeper into the aquifer.

Treatment of household water supplies for nitrate is typically by reverse osmosis (RO). RO has advantages including the ability to remove multiple contaminants (where nitrate is not the only concern). However, household treatment does require some costs as well as additional burdens for maintenance, inspection, and operation of equipment. Treatment can be either point-of-entry (treating all household water use) or point-of-use (treating only potable water at household taps, usually the kitchen). As with centralized nitrate treatment, RO units create a concentrate or brine waste that requires disposal. Dilute waste streams, characteristic of RO, can sometimes be used for irrigation.

Connection to a larger system with more reliable water quality is a promising solution where a larger system is nearby. Such a connection often has a high cost, but it may provide a net economic benefit from lower long-term costs and delegation of many water quality concerns to qualified entities.

Trucking in water to the household or local small water system can be convenient and requires little start-up cost, but it is often expensive and is commonly considered to be a temporary solution. Bottled water use is similar to trucking in water, but it often entails a greater cost.

Households or local small water systems can relocate to avoid water quality problems, but this typically would involve some loss of property value. If the household or business is prosperous, relocation is unlikely. Poorer households are likely to feel any resultant loss of jobs or social dislocation more acutely.

Well water testing can better inform self-supplied users of their risks from nitrate contamination. These tests are not expensive. Dual plumbing systems can help reduce the amount of water that is trucked in or treated, but it imposes additional costs and some risk of cross-connection of contaminated and safe water supplies.

Treatment to Remove Nitrate

Contaminated groundwater can be treated at a community treatment plant for all users, at the point-of entry-to residential or commercial buildings, or at the point of potable drinking water use (such as the kitchen sink). A variety of treatment options are available (Jensen et al. 2012). Ion exchange and reverse osmosis are used for community public water system treatment (Figures 19 and 20). RO is often used for point-of-use treatment in households and businesses. Additional treatment options, such as biological denitrification, may become economical and accepted (see Jensen et al. 2012). The effectiveness of treatment technologies across nitrate concentrations is summarized in Table 13.

Table 12. Options for self-supplied households and local small water systems

Option	Advantages	Disadvantages
Drilling a deeper or new well	• Potentially more reliable water supply. • Cheaper than bottled water for households using more than 8 gal/day.	• Potential decrease in source capacity. • Capital and operational costs increase with depth. • Potentially only a temporary quick fix; the nitrate plume follows groundwater movement. • Risk of encountering other water quality concerns at greater depths (i.e., arsenic, manganese). • Pipeline costs required if source area is far from original source.
Household treatment (RO)	• Multiple contaminant removal. • Low-nitrate water supply.	• Unless instructed, risk of improper handling or maintenance of equipment.
Regionalization and consolidation	• Cheaper treatment costs on a customer basis.	• High capital and O&M costs.
Trucked water	• Community-wide distribution. • No start-up capital cost.	• Temporary "emergency" solution. • Extra potable water storage required if a small community.
Bottled water	• Nitrate-free water supply. • No start-up cost.	• Inconvenience, monthly expenditure. • Temporary solution.
Relocate households	• Safe, reliable water supply.	• Unpleasant, extreme option. • Loss of property value and jobs. • Social, familial dislocation.
Well water quality testing	• Water quality awareness. • Beneficial to blending.	
Dual system	• Hybrid of options. • Treating only potable.	• Possible consumption of contaminated source. • Cost of contaminated supply plus cost for community treatment of potable supply and dual plumbing costs.

Source: Honeycutt et al. 2012.

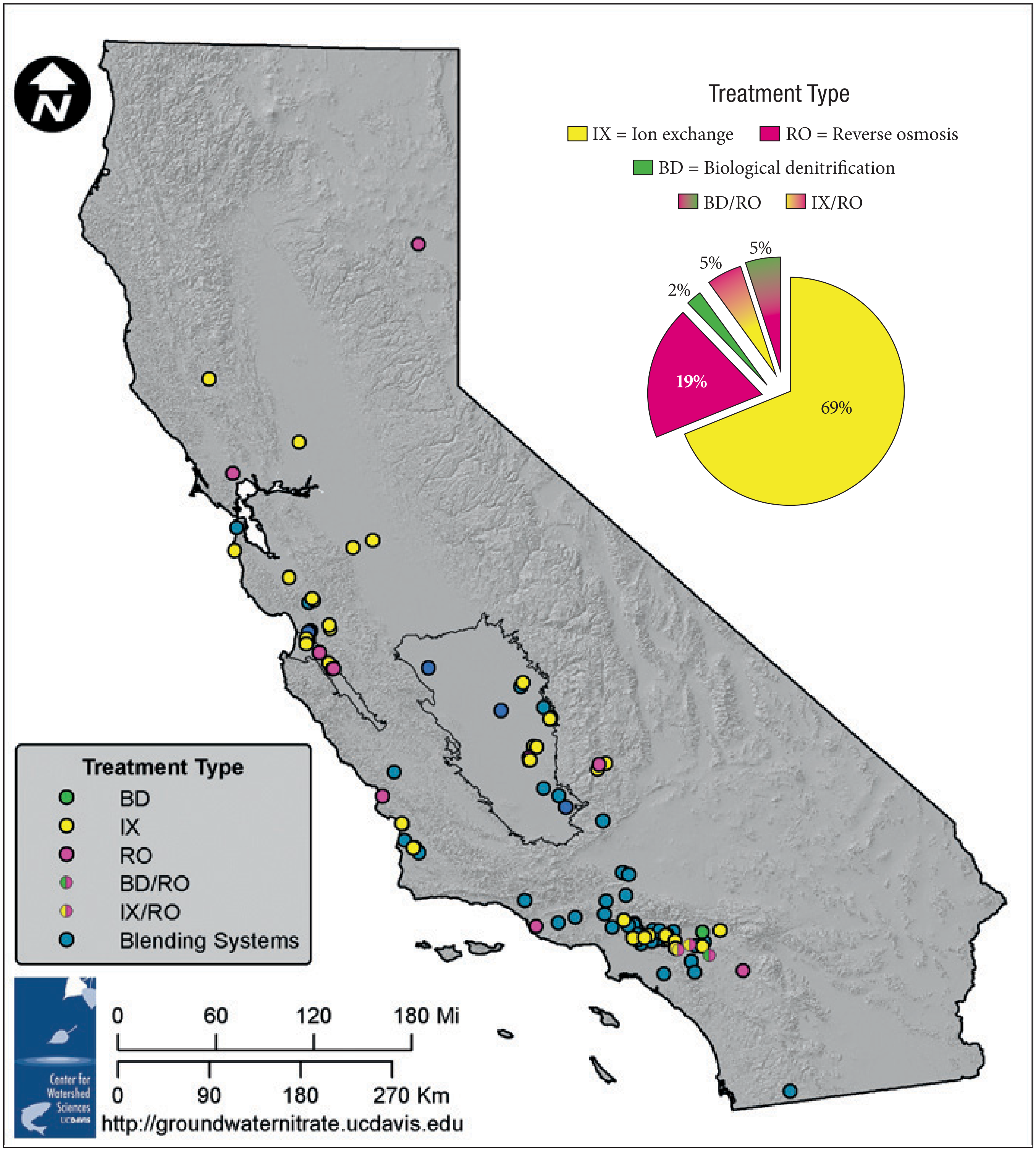

Figure 19. California drinking water systems treating or blending for nitrate, 2010. Source: Jensen et al. 2012.

However, treatment is expensive, especially for small systems. The development of treatment alternatives requires local engineering and development to accommodate local conditions. Nitrate contamination can be accompanied by other forms of groundwater contamination, including arsenic, magnesium, or pesticides, and treatment must accommodate the spectrum of water quality concerns as well as local water chemistry and distribution system conditions. Statewide, over 50% of nitrate treating systems utilize blending. Approximately 70% are using IX, and about 20% are using RO (Figure 19). In the Tulare Lake Basin and the Salinas Valley (Figure 20), 23 systems (of all types) were found to be treating and/or blending to address the nitrate problem (10 blending systems, 10 IX systems, and 3 RO systems).

Consolidation and Regionalization

Consolidation or regionalization of small systems is often suggested for addressing nitrate contamination and many other problems of small water systems. Although small systems are theoretically accountable and responsive to local customers, they often have diminished financial and technical resources that limit their ability to respond effectively or economically. Where a small system is near a larger system with superior water quality, connecting and consolidating these systems can provide a long-term remedy for the smaller system. Figure 21 shows the proximity of small systems (<10,000 people) in the Tulare Lake Basin and Salinas Valley to larger systems. Many small systems are reasonably close to potential long-term solutions.

However, the larger system may be concerned with financial and administrative burdens that may arise from upgrading the smaller system. Commonly, a smaller system must pay for the costs of connecting to a larger system as well as any distribution system upgrades needed to make the two systems compatible. This system upgrade burden on the financially weaker partner can require external financial assistance.

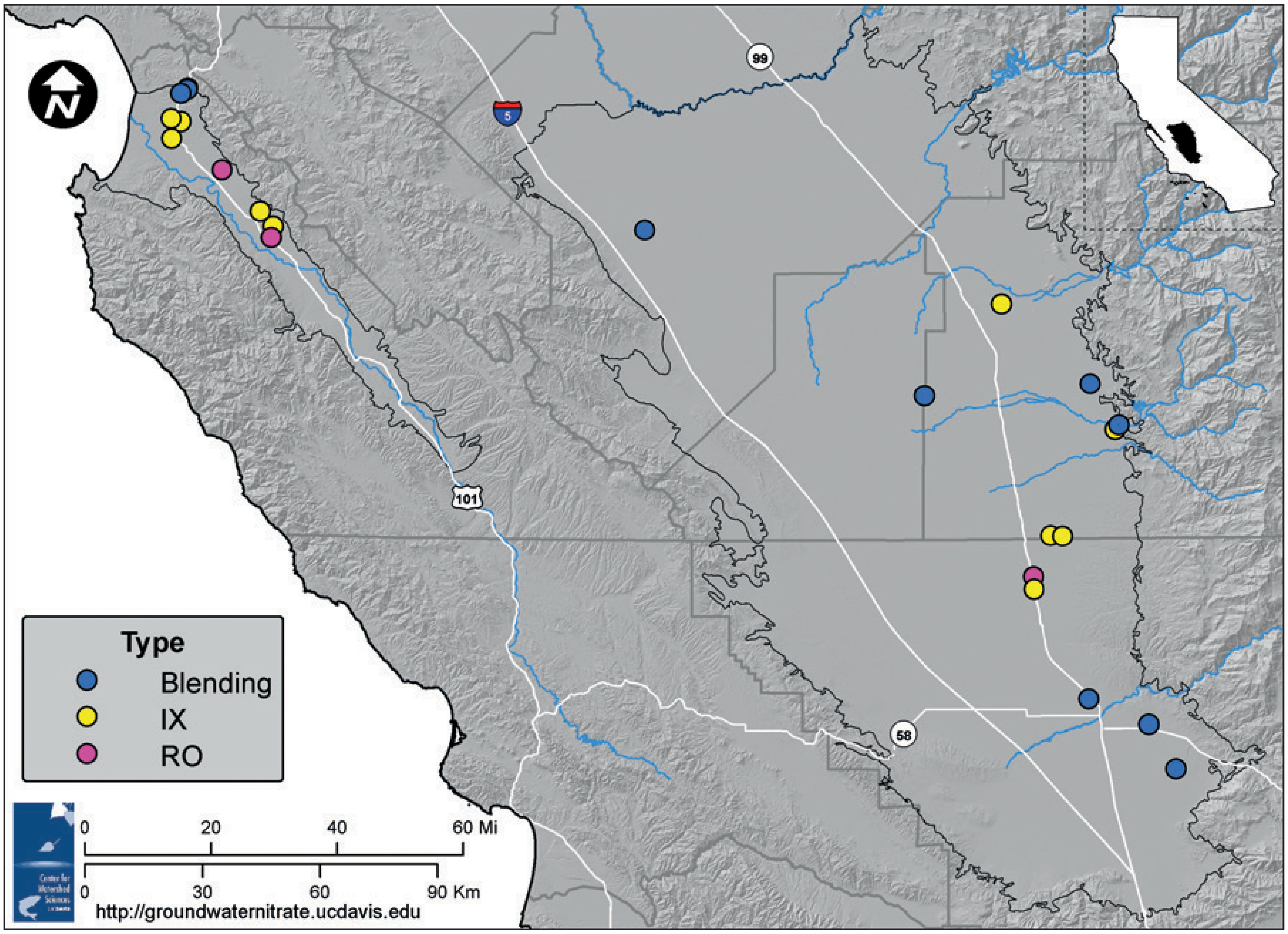

Figure 20. Utilities treating or blending for nitrate in the Salinas Valley and Tulare Lake Basin, 2010. Source: Jensen et al. 2012.

Many small systems are far from a larger system. For these cases, physical connection with a larger system is less financially attractive. However, even where systems remain hydraulically separated, consolidated operations, maintenance, and administration can sometimes have sufficient advantages to overcome financial barriers.

4.3 Comparison and Discussion

Economically promising and appropriate treatment and alternative water supply options have been identified (Honeycutt et al. 2012). These promising options give indications for state policy, and their costs are used to help estimate the overall cost of nitrate groundwater contamination in the Tulare Lake Basin and Salinas Valley.

Options for Small Community Public Water Systems

Estimated costs of options for community public water systems are compared in Table 14. Promising options for communities at risk of nitrate groundwater contamination are:

- **Consolidation to a larger system that can provide safe drinking water to more customers.** Although this option is viable for only a moderate number of systems, consolidation or regionalization of water systems can benefit a larger proportion of the vulnerable population and can help resolve many other long-term problems of small systems.
- **Consolidation of nearby small systems into a larger system** with a larger rate payer base and economies of scale. Even where small systems cannot economically connect to a large system, some opportunities exist to connect some small systems or to jointly manage several small systems to improve their overall financial condition.
- **Ion exchange treatment,** which is usually the most economical community treatment for groundwater contaminated by nitrate.
- **Interim point-of-use treatment or use of bottled water** until a more long-term and sustainable solution can be evaluated and implemented.
- **Blending of contaminated wells,** albeit temporarily if local nitrate contamination is expanding.

Table 13. Influence of nitrate concentration on treatment selection

Practical Nitrate Range	Option	Considerations
10–30% above MCL	blend	Depends on capacity and nitrate level of blending sources.
Up to 2× MCL	ion exchange	Depends on regeneration efficiency and costs of disposal and salt usage. Brine treatment, reuse, and recycling can improve feasibility at higher nitrate levels.
Up to many × MCL	reverse osmosis	Depends on availability of waste discharge options, energy use for pumping, and number of stages. May be more cost-effective than IX for addressing very high nitrate levels.
Up to many × MCL	biological denitrification	Depends on the supply of electron donor and optimal conditions for denitrifiers. Ability to operate in a start-stop mode has not yet been demonstrated in full-scale application; difficult to implement for single well systems. May be more cost-effective than IX for addressing high nitrate levels.

Source: Contact with vendors and environmental engineering consultants; Jensen et al. 2012.

A preliminary analysis was conducted to identify the short-term lowest-cost option for susceptible water systems in the project area to respond to nitrate contamination (Honeycutt et al. 2012). Results from this preliminary analysis, with and without point-of-use treatment for state small water systems, are summarized in Table 15 and Figure 22 (excluding POU). Due to public health and reliability concerns, point-of-use treatment is currently only allowed by CDPH as an interim action for very small water systems (serving <200 connections) facing nitrate pollution. In either case, drilling a new well appears to be the most economical solution for larger systems serving most of the susceptible population. In the long term, expanding nitrate contamination might reduce the viability of this option. If permanently allowed, point-of-use treatment for individual households would be economically preferred for most very small systems. Regionalization by connecting to a nearby larger system is attractive for a substantial minority of systems and about 10% of the susceptible population. The expense of groundwater treatment makes it relatively rare, but it remains important when other options are unavailable. Connection to surface water facilities was generally not found to be economical due to the high cost of surface water treatment facilities.

If expanding nitrate contamination precludes sustainable use of new wells, costs increase greatly for community public water systems to respond to nitrate contamination (Table 16). In this most constrained case, connecting to nearby larger systems (regionalization) is more common,

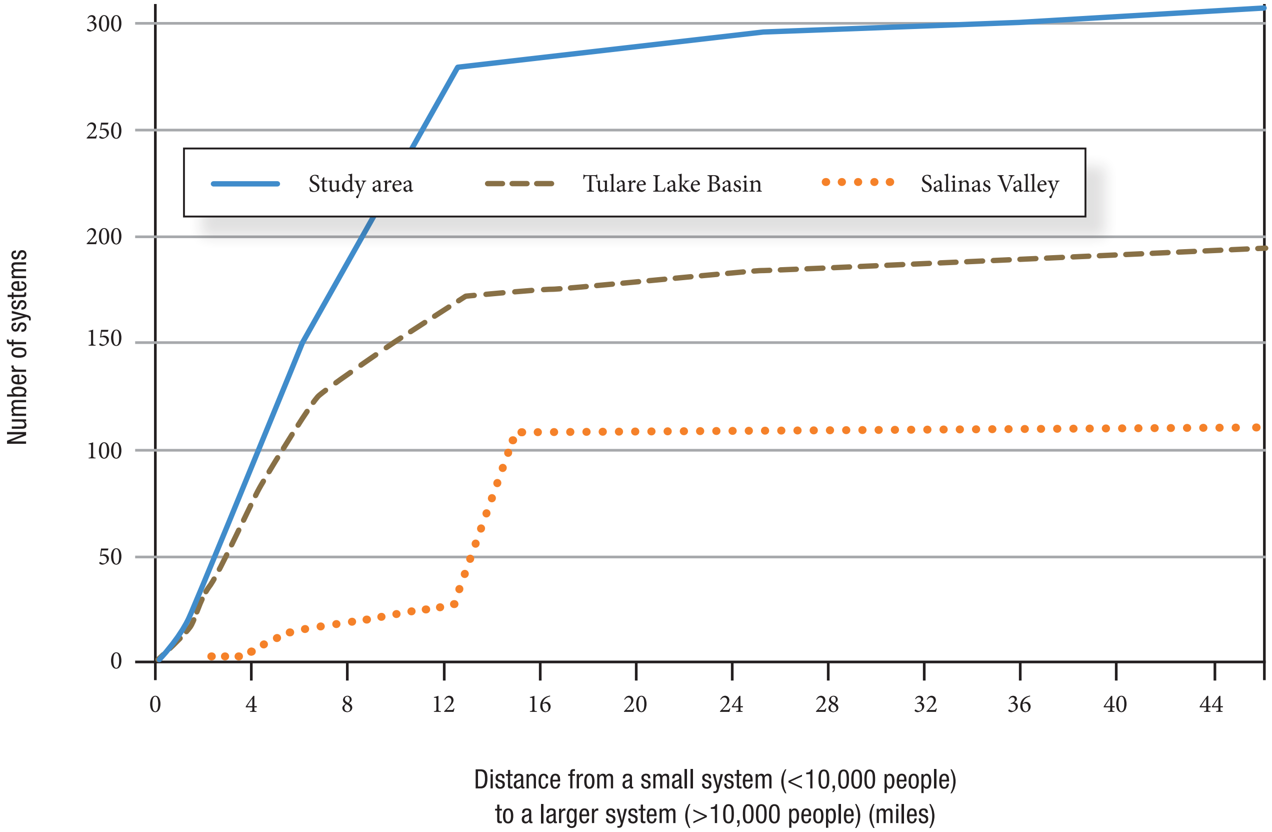

Figure 21. Cumulative distribution of the minimum distance from a small system (<10,000 people) to a larger system (>10,000 people) for the study area. Source: Honeycutt et al. 2012.

groundwater community treatment is common for small systems, and several of the largest systems (serving most of the susceptible population) switch to surface water treatment. The total estimated cost of alternative water supplies for susceptible community water systems more than doubles under this sustainable long-term scenario.

Options for Self-Supplied Households and Local Small Water Systems

Self-supplied and local small water systems have a smaller range of options (see Table 14). Point-of-use treatment is often the least-expensive option. Drilling a new well is sometimes more economical, where water use is greater and future nitrate contamination is less problematic.

Table 14. Safe drinking water option costs for self-supplied household and small community public water systems

Option	Estimated Annual Cost Range ($/year)	
	Self-Supplied Household	Small Water System (1,000 households)
Improve Existing Water Source		
Blending	N/A	$85,000–$150,000
Drill deeper well	$860–$3,300	$80,000–$100,000
Drill a new well	$2,100–$3,100	$40,000–$290,000
Community supply treatment	N/A	$135,000–$1,090,000
Household supply treatment	$250–$360	$223,000
Alternative Supplies		
Piped connection to an existing system	$52,400–$185,500	$59,700–$192,800
Trucked water	$950	$350,000
Bottled water	$1,339	$1.34 M
Relocate Households	$15,090	$15.1 M
Ancillary Activities		
Well water quality testing	$15–$50	N/A
Dual distribution system	$575–$1,580	$260,000–$900,000

Source: Honeycutt et al. 2012.

Table 15. Estimated cost of the lowest-cost short-term alternative water supply option for susceptible community public water systems and state small water systems based on system size and proximity to a larger system

Option	Number of Susceptible Water Systems		Population		Total Cost ($/year)	
	Including POU	Excluding POU	Including POU	Excluding POU	Including POU	Excluding POU
Drill new well	10	63	184,100	191,700	$10,144,000	$14,500,000
POU device for potable use	70	——	10,500	——	$1,320,000	——
Pipeline to a nearby large system (10,000+ system)	5	13	25,300	27,300	$865,000	$1,463,000
Groundwater treatment facility	0	9	0	900	$0	$450,000
Surface water treatment	0	0	0	0	$0	$0
Total	**85**	**85**	**219,900**	**219,900**	**$12,329,000**	**$16,413,000**

Source: Honeycutt et al. 2012.

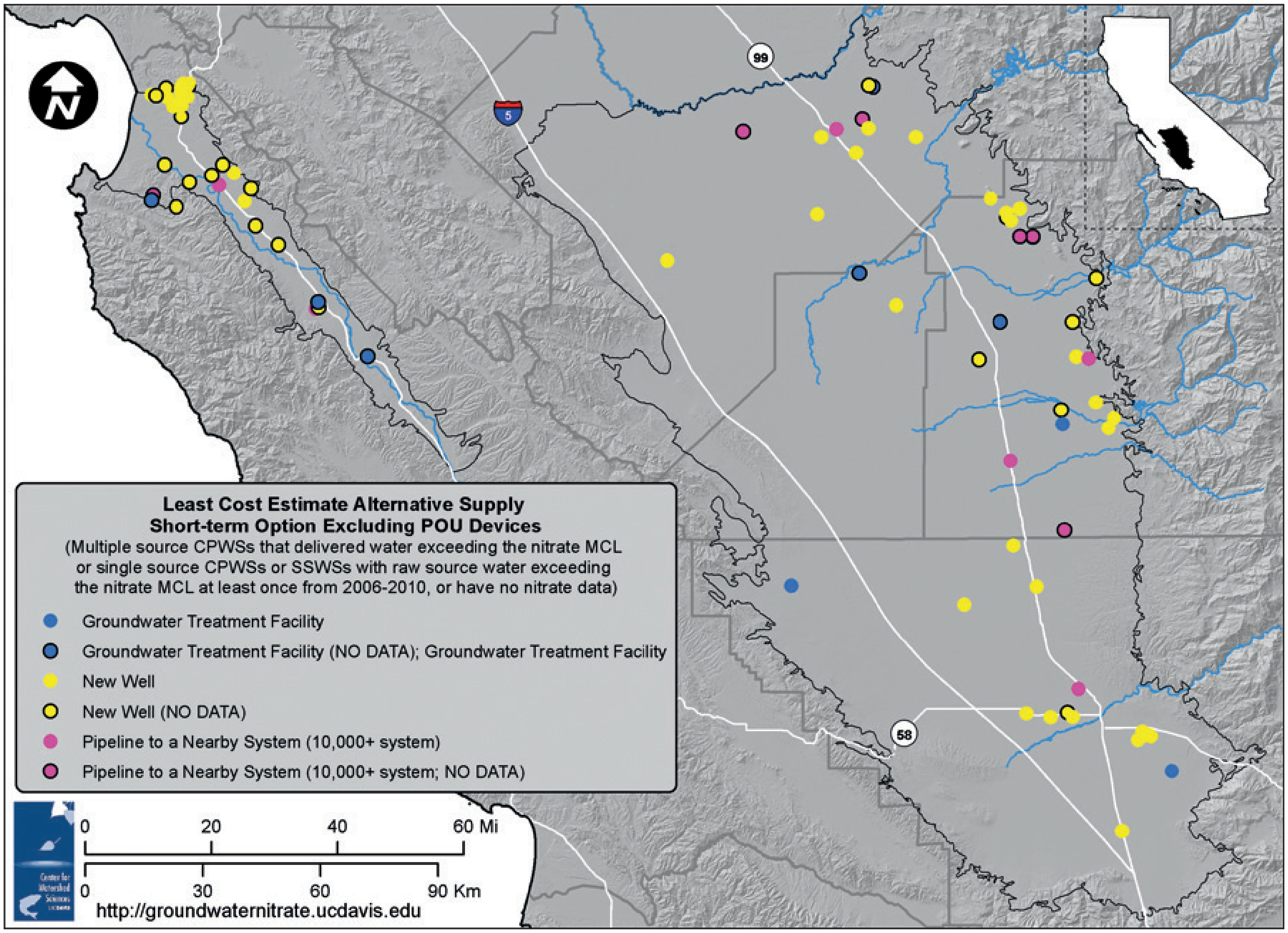

Figure 22. Lowest-cost alternative supply option (excluding POU systems) based on a high estimate of option costs for susceptible community public water systems and state small water systems (multiple source CPWS or SSWSs exceeding the nitrate MCL; or single-source CPWS or SSWSs exceeding the nitrate MCL at least once from 2006–2010; or those having no data). Source: Honeycutt et al. 2012.

4.4 Cost of Providing Safe Drinking Water

Roughly $12 to $17 million per year in additional costs in the near term will be needed to provide safe drinking water for people on community systems in the Tulare Lake Basin and Salinas Valley affected by nitrate contamination of groundwater (see Table 15). These costs are for 85 susceptible systems currently serving roughly 220,000 people. To provide safe drinking water for long-term solutions for these 85 systems will cost roughly $34 million per year if new wells are no longer sufficient. As additional systems become affected by nitrate contamination, these costs could increase.

The annualized additional cost of providing nitrate-compliant drinking water to the estimated 34,000 people (10,000 rural households) using domestic wells or local small water systems that are highly susceptible to current or future nitrate contamination is at least $2.5 million per year for point-of-use treatment for drinking purposes only. These costs could be lower if a manufacturing discount for bulk purchase of POU/POE systems were available. The lowest-cost POU option is used for all domestic well and local small water systems in the study area, estimated for both the short and long term. This does not include the cost of monitoring, public awareness, or regulatory programs to identify and reach out to this currently unregulated and unmonitored population.

The short-term cost to fund alternative water supplies for the highly susceptible nitrate-affected population amounts to $60 to $80 per susceptible person per year, $4 to $5 per irrigated acre per year for the 4 million acres of agriculture in these basins, or $75 to $100 per ton of fertilizer nitrogen (assuming about 200,000 tons of fertilizer nitrogen is applied in the study area). Allowing for only long-term, more viable, and sustainable alternative drinking water solutions for the affected population, the total cost amounts to $142 per susceptible person per year, $9 per irrigated acre per year, or $180 per ton of fertilizer in the long term.

Table 16. Estimated cost of the lowest-cost long-term alternative water supply options for susceptible community public water systems and state small water systems based on system size and proximity to a larger system

Option	Number of Susceptible CPWSs/SSWSs	Population	Total Cost ($/year)
Pipeline to a nearby system (10,000+ system)	29	36,600	$5,592,000
Groundwater treatment facility	51	8,000	$6,344,000
Surface water treatment facility	5	175,300	$21,532,000
Total	**85**	**219,900**	**$33,468,000**

Source: Honeycutt et al. 2012.

5 Policy Options for Nitrate Source Reduction and Funding

This section summarizes a range of policy options for reducing nitrate sources of contamination to groundwater and funding for resolving the problems of nitrate contamination. These options are drawn from the more detailed and extensive examination in Canada et al. (2012). Promising actions on future nitrate source reduction and funding options are discussed in Section 6.

5.1 Nitrate Source Reduction Policy Options

A wide range of policy options are available to reduce nitrate contamination to groundwater over time. We use four criteria for evaluating broad classes of regulatory options: the costs incurred by dischargers to reduce nitrate loading to achieve a nitrate standard (abatement costs), the costs of monitoring and enforcement, the information requirements, and the potential for raising revenues (for funding drinking water actions and other purposes related to nitrate contamination). These results are summarized in Table 17 and further described by Canada et al. (2012).

Specific technology mandates on farmers and agriculture will result in high per-unit costs for reducing nitrate contamination. Farming practices vary tremendously, even within these basins, so specific technology standards would be unlikely to be broadly effective or economical. Less-specific performance standards would provide more flexibility but still do not account for the variation in costs across farms. Nitrate or nitrogen fees or cap-and-trade approaches give farmers more flexibility to respond to required reductions in nitrate loading, thereby reducing the costs of nitrate abatement. If these actions are monitored and enforced based on nitrate leaching rates, much more costly and extensive on-site monitoring would be needed, whereas enforcement and accounting of fertilizer application requirements would be much less burdensome. Reducing nitrate leachate by imposing fees on nitrate or nitrogen has an added advantage of raising funds that may be used to compensate affected drinking water users. A cap-and-trade approach can also raise funds if nitrogen use permits are auctioned.

Hybrid options are also available to regulate nitrate. For nearly 15 years, the Netherlands has used a hybrid approach to manage nitrate (Kruitwagen et al. 2009; Ondersteijn et al. 2002). Under this system, agricultural sources are regulated using a performance standard combined with a fertilizer fee. (see "The Dutch Experience," p. 46). Hybrid regulations might be practical for managing nitrate leachate.

Information disclosure would have dischargers of nitrate or users of nitrogen make such information public. Water systems could also face more stringent water quality consumer reporting rules. Such disclosures should provide some motivation to reduce nitrate discharges.

Table 17. Summary of regulatory options to reduce nitrate contamination to groundwater

Regulatory Option	Abatement Costs	Monitoring and Enforcement Costs	Information Requirements	Revenue Raising
Technology mandate	high	Fertilizer application: low Nitrate leachate: high		no (unless fines)
Performance standard	medium			no (unless fines)
Fee	low			yes
Cap and trade	low			yes (if permits auctioned)
Information disclosure	medium	low	low	no (unless fines)
Liability rules	—	high	high	yes
Payment for water quality	low	low (if payment made to farmers) high (if payment made to state)	high	yes (if payment made to state)
De-designation of beneficial use	low	high	medium	no

Source: Canada et al. 2012.

Liability rules would make nitrate dischargers liable to users of drinking water and other groundwater users for the costs imposed by their discharges. If liability is established in courts, the costs could be quite high and may not necessarily result in much discharge reduction. Porter-Cologne Act Water Code Section 13304 might provide a useful framework.

Having water users or the state pay nitrate dischargers to reduce their dischargers ("payment for water quality") also has high transaction costs, without immediate effect to drinking water quality. But nitrate dischargers might find this an attractive long-term or preventive solution.

De-designating groundwater for drinking water use would shift all drinking water burdens to local water users. This would be administratively and politically awkward, acknowledging a permanent degradation to groundwater quality without compensating drinking water users.

Major Findings: Future Source Reduction Options

1. **Many options exist to regulate nitrate in groundwater, but there is no ideal solution.** The costs of regulatory options vary greatly, and while no option is perfect, some seem preferable to others.

2. **Regulating fertilizer application has lower monitoring and enforcement costs and information requirements than does regulating nitrate leachate, but it may be less effective in achieving nitrate reduction targets**. While the regulation of fertilizer application is easier to implement and enforce than the regulation of nitrate leachate, fertilizer regulation does not guarantee that water quality standards will be met. Due to nonuniform mixing, transport, and dispersion of nitrate in groundwater, it is difficult to quantify the impact of a unit of fertilizer on nitrate contamination of drinking water over time.

3. **Costs to farmers for reducing nitrate contamination can be lower with market-based regulations (fertilizer fees or cap-and-trade programs) than with technology mandates or prescriptive standards because of the additional flexibility farmers have in complying with market-based regulations.** Market-based instruments also encourage the development and adoption of new technologies to reduce fertilizer use, but they may lead to the formation of contamination hot spots.

4. **Well-defined and enforceable regulatory requirements are needed for liability rules to work.** In California, all groundwater is considered to be suitable, or potentially suitable, for municipal or domestic water supply and should be so designated by the Porter-Cologne Section 13304 which gives the California Water Boards authority to force polluters to pay for alternative water supplies for affected users of public water systems and private wells. Legislation might be useful to solidify Regional Board authority to apply this provision broadly.

5.2 Funding Options

Existing funding to address the costs of drinking water actions for communities and systems affected by nitrate contamination appears to be inadequate for many systems and largely requires drinking water users to bear the costs of groundwater contamination by others. The cost of nitrate contamination is felt disproportionately for small water systems (Honeycutt et al. 2012; Canada et al. 2012). Funding is also sparse for monitoring and for broad understanding of groundwater nitrate.

Many state, federal, and local programs exist to help fund local communities responding to nitrate contamination of their groundwater supplies, as discussed in Section 3 and Canada et al. (2012) and summarized in Table 9. Although current programs provide useful resources, they have been insufficient in addressing problems of nitrate groundwater contamination, particularly for smaller and poorer communities, who have less technical, managerial, and financial capacity for safe drinking water infrastructure and who are often ill-equipped for formal funding program applications.

A wide range of options is available to improve funding for drinking water supplies in areas affected by groundwater nitrate contamination, in addition to funding for nitrate source reduction and groundwater remediation activities. These options include state funding options summarized in Table 18 as well as traditional local water utility and tax options for funding water systems. These funding alternatives are addressed in greater depth by Canada et al. (2012). That examination and analysis led to the following findings for state funding and the promising options that are stated in Section 6.1(F).

Major Findings: Future Funding Options

1. **Many options exist to raise funds for safe drinking water and nitrate source reduction actions, but but all require that someone bear the cost, and many are awkward or insufficient.** Water use fees, groundwater pumping fees, bottled water fees, crop fees, and fertilizer fees are a few of the many potential sources for funding safe drinking water and source reduction actions.
2. **Some funding options give polluters a useful price signal.** Fertilizer (or nitrate leachate) fees and auctioned permits induce emitters to reduce fertilizer or nitrate use. Farmers do not pay sales tax on fertilizer in California.

Table 18. Summary of future state funding options

Option	Incentive to Reduce Nitrate	Who Pays	Example
Crop tax	no	producers and consumers of food	State Sales Tax Rate for Soft Drinks: The State of Maryland charges a 6% sales tax for soft drinks.
Fixed fee on drinking water agricultural water	 no no	 drinking water users agricultural users	Federal Communications Commission Universal Service Fee: A fixed fee placed on monthly phone bill to assure universal access to telecommunications for low-income and high-cost rural populations.
Volumetric fee on **drinking water** **agricultural water**	 no low	 drinking water users agricultural users	Gas Public Purpose Program Surcharge: A volumetric fee on gas bills in California to fund assistance programs for low-income gas customers, energy efficiency programs, and public-interest research.
Groundwater pumping fee	medium	agricultural groundwater users	Pajaro Valley Groundwater Pumping Fee: A per-acre-foot charge to secure financing for debt stabilization and to address groundwater overdraft.
Fee on bottled water	no	consumers of bottled water	California Redemption Value: A refundable fee placed on recyclable bottles at the point of sale.
Agricultural property tax	no	agricultural property owners	CA State Property Tax: A statewide ad valorem tax equal to a percentage of the purchase price is collected from all properties in the state, with some exceptions.
Fertilizer tax	high	consumers of fertilizer	Mill Assessment Program: The state imposes a fee of 2.1 cents per dollar on pesticide sales at the point of first sale into the state.
Nitrate leachate tax	highest	nitrate emitters	Duty on Wastewater: In the Netherlands, a tax of approximately $3.60 is imposed on each kilogram of nitrate in wastewater.
Cap and trade with auctioned permits	high/ highest	consumers of fertilizer and nitrate emitters	Title IV of the Clean Air Act Amendments: Established a tradable permit approach to control sulfur dioxide emissions. A small portion of permits sold in an auction.

Source: Canada et al. 2012.

Payment for Ecosystem Services in New York City

Currently, New York City participates in a payment for ecosystem services program for watershed protection. Under the U.S. Safe Drinking Water Act (SDWA), the city was required to meet the state water quality standards by either constructing a water filtration plant at an estimated cost of $6 billion in capital and $300 million in annual operating costs (Postel and Thompson 2005) or implementing a much less expensive watershed protection program. New York successfully requested a waiver from the SDWA filtration requirement and negotiated an agreement with upstream landowners and communities within the Catskill-Delaware watershed to establish a watershed protection plan. In 1997, a memorandum of agreement (MOA) was signed by state and federal officials, environmental organizations, and 70 watershed towns and villages to invest $1.5 billion over ten years to restore and protect the watershed (Postel and Thompson 2005). Program financing comes from bonds issued by the city and increases in residential water bills.

The program's fundamental activities include land acquisition; a program to manage and reduce agricultural runoff; a program for better forestry management; a program for enhanced stream management to reduce erosion and habitat degradation; improvements for wastewater infrastructure in the watershed; construction of an ultraviolet disinfection plant; and new regulation and enforcement of mechanisms to ensure continued water quality protection within the watershed (Postel and Thompson 2004). As of 2004, New York City has put $1 billion into the watershed protection program (Ward 2004). The negotiated partnership creates a watershed that provides high-quality drinking water, provides landowners with additional income, and improves recreational usage for nearby communities.

In this instance, negotiation or payment for ecosystem services led to the provision of safe drinking water at a lower cost than the default water filtration plant. By linking the ecosystem service providers with the beneficiaries, New York City successfully executed a comprehensive watershed protection program that delivers safe drinking water at a relatively low cost. New York City's watershed protection program is an example of a payment for ecosystem services program that guarantees the supply of high-quality drinking water and is financed via residential water bills and city bonds.

6 Promising Solutions

Many options are available to address the problems of drinking water quality, aquifer degradation, and economic costs from nitrate contamination of groundwater and its regulation. Of the many options available, some are more promising than others. But even among these promising options, major policy choices must be made.

6.1 Areas of Promising Action

Addressing groundwater nitrate contamination 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. Promising actions for legislative and state agency consideration in these areas appear below. Starred (*) actions do not appear to require legislative action, but might benefit from it. All actions are compared in Table 19.

Safe Drinking Water Actions (D)

Safe drinking water actions are the most effective and economical short- and long-term approach to address nitrate contamination problems in the Tulare Lake Basin and Salinas Valley. These actions apply especially to small and self-supplied household water systems, which face the greatest financial and public health problems from nitrate groundwater contamination.

D1: Point-of-Use (POU) Treatment. CDPH reports on how to make economical household and point-of-use treatment for nitrate contamination an available and permanent solution for small water systems.*

D2: Small Water System Task Force. CalEPA and CDPH convene an independently led Task Force on Small Water Systems that would report on problems and solutions of small water and wastewater systems statewide as well as the efficacy of various state, county, and federal programs to aid small water and wastewater systems. Many nitrate contamination problems are symptomatic of the broad problems of small water and wastewater systems.*

D3: Regional Consolidation. CDPH and counties provide more legal, technical, and funding support for preparing consolidation of small water systems with nearby larger systems and creating new, regional safe drinking water solutions for groups of small water systems, where cost-effective.*

D4: Domestic Well Testing. In areas identified as being at risk for nitrate contamination by the California Water Boards, as a public health requirement, CDPH (a) mandates periodic nitrate testing for private domestic wells and local and state small systems and (b) requires disclosure of recent well tests for nitrate contamination on sales of residential property. County health departments also might impose such requirements.

D5: Stable Small System Funds. CDPH receives more stable funding to help support capital and operation and maintenance costs for new, cost-effective, and sustainable safe drinking water solutions, particularly for disadvantaged communities.

Source Reduction Actions (S)

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. Within the framework of Porter-Cologne, 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. The following options seem most promising to reduce nitrate loading.

S1: Education and Research. California Department of Food and Agriculture (CDFA), in cooperation with the University of California and other organizations, develops and delivers a comprehensive educational and technical program to help farmers improve efficiency in nitrogen use (including manure) and reduce nitrate loading to groundwater. This could include a groundwater nitrate–focused element for the existing CDFA Fertilizer Research and Education Program (FREP), including "pump-and-fertilize" remediation and improved recharge options for groundwater cleanup.*

Table 19. Likely performance of promising state and agency actions for nitrate groundwater contamination

Action	Safe Drinking Water	Groundwater Degradation	Economic Cost
No Legislation Required			
Safe Drinking Water Actions			
D1: Point-of-Use Treatment Option for Small Systems +	◆◆		low
D2: Small Water Systems Task Force +	◆		low
D3: Regionalization and Consolidation of Small Systems +	◆◆		low
Source Reduction Actions			
S1: Nitrogen/Nitrate Education and Research +		◆◆◆	low–moderate
S2: Nitrogen Accounting Task Force +		◆◆	low
Monitoring and Assessment			
M1: Regional Boards Define Areas at Risk +	◆◆◆	◆◆◆	low
M2: CDPH Monitors At-Risk Population +	◆	◆	low
M3: Implement Nitrogen Use Reporting +		◆◆	low
M4: Groundwater Data Task Force +	◆	◆	low
M5: Groundwater Task Force +	◆	◆	low
Funding			
F1: Nitrogen Fertilizer Mill Fee		◆◆◆	low
F2: Local Compensation Agreements for Water +	◆◆	◆	moderate
New Legislation Required			
D4: Domestic Well Testing *	◆◆		low
D5: Stable Small System Funds	◆		moderate
Non-tax legislation could also strengthen and augment existing authority.			
Fiscal Legislation Required			
Source Reduction			
S3: Fertilizer Excise Fee	◆◆	◆	low
S4: Higher Fertilizer Fee in Areas at Risk	◆	◆	moderate
Funding Options			
F3: Fertilizer Excise Fee	◆◆	◆◆	moderate
F4: Water Use Fee	◆◆	◆◆	moderate

◆ Helpful

◆◆ Effective

◆◆◆ Essential

+ Legislation would strengthen.

* County health departments may have authority; CDPH requires legislation.

S2: Nitrogen Mass Accounting Task Force. CalEPA establishes a Task Force, including CDFA, to explore nitrogen mass balance accounting methods for regulating agricultural land uses in areas at risk for nitrate contamination, and to compare three long-term nitrogen source control approaches: (a) a cap-and-trade system; (b) farm-level nutrient management plans, standards, and penalties; and (c) nitrogen fertilizer fees.*

S3: Fertilizer Excise Fee. Significantly raising the cost of commercial fertilizer through a fee or excise tax would fund safe drinking water actions and monitoring and give further incentive to farmers for reducing nitrate contamination. An equivalent fee or excise tax could be considered for organic fertilizer sources (manure, green waste, wastewater effluent, biosolids, etc.).

S4: Higher Fertilizer Fee in Areas at Risk. Areas declared to be at risk for nitrate contamination might be authorized to maintain a higher set of excise fees on nitrogen fertilizer applications (including synthetic fertilizer, manure, waste effluent, biosolids, and organic amendments), perhaps as part of a local safe drinking water compensation agreement.

Monitoring and Assessment (M)

Monitoring and assessment is needed to better assess the evolving nitrate pollution problem and the effectiveness of safe drinking water and nitrate source loading reduction actions. Such activities should be integrated with other state agricultural, environmental, and land use management, groundwater data, and assessment programs (source loading reduction actions), along with other drinking water, treatment, and wastewater management programs (safe drinking water actions).

M1: Define Areas at Risk. Regional Water Boards designate areas where groundwater sources of drinking water are at risk of being contaminated by nitrate.*

M2: Monitor at-Risk Population. CDPH and the State Water Board, in coordination with DWR and CDFA, issue a report every 5 years to identify populations at risk of contaminated drinking water and to monitor long-term trends of the state's success in providing safe drinking water as a supplement to the California Water Plan Update.*

M3: Learn from Department of Pesticide Regulation Programs. CalEPA and CDFA examine successful DPR data collection, analysis, education, and enforcement programs for lessons in managing nitrogen and other agricultural contaminants, and consider expanding or building upon the existing DPR program to include comprehensive nitrogen use reporting to support nitrate discharge management.*

M4: Groundwater Data Task Force. CalEPA, in coordination with CalNRA and CDPH, convenes an independently led State Groundwater Data Task Force to examine the efficacy of current state and local efforts to collect, maintain, report, and use groundwater data for California's groundwater quality and quantity problems.*

M5: Groundwater Task Force. CalEPA, CalNRA, and CDPH maintain a joint, permanent, and independently led State Groundwater Task Force to periodically assess and coordinate state technical and regulatory groundwater programs in terms of effectiveness at addressing California's groundwater quality and quantity problems. These reports would be incorporated into each California Water Plan Update.*

Funding (F)

Little effective action can occur without funding. Four funding options seem most promising, individually or in combination. State funding from fees on nitrogen or water use, which directly affect nitrate groundwater contamination, seem particularly promising and appropriate.

F1: Mill Fee. Increase the mill assessment rate on nitrogen fertilizer to the full authorized amount (CAL. FAC Code Section 14611). This would raise about $1 million/year statewide and is authorized for fertilizer use research and education.*

F2: Local Compensation Agreements. Regional Water Boards can require and arrange for local compensation of affected drinking water users under Porter-Cologne Section 13304. Strengthening existing authority, the Legislature could require that a Regional Water Board finding that an area is at risk of groundwater nitrate contamination for drinking water be accompanied by a cleanup and abatement order requiring overlying, current sources of nitrate to financially support safe drinking water actions acceptable to the local County Health Department. This might take the form of a local "liability district."*

F3: Fertilizer Excise Fee. Introduce a substantial fee on nitrogen fertilizer sales or use, statewide or regionally, to fund safe drinking water actions, nitrate source load reduction efforts, and nitrate monitoring and assessment programs.

F4: Water Use Fee. A more comprehensive statewide fee on water use could support many beneficial activities. Some of such revenues could fund management and safe drinking water actions in areas affected by nitrate contamination, including short-term emergency drinking water measures for disadvantaged communities.

6.2 Developing an Effective Solution Strategy

Table 19 summarizes the required implementation levels and likely performance of promising actions identified above. Much can be done under existing authority and by existing agencies, although additional legislation could strengthen, augment, and further support these capabilities. While these actions include many helpful and effective solutions, none alone are sufficient to address the problems of groundwater nitrate contamination and the resulting drinking water problems. The most effective results will arise through a synergistic combination of major policy direction, legislation, and appropriate blends of of these identified actions.

Options without Fiscal Legislation

Without fiscal (tax, fee) legislation, there are several options to address drinking water or groundwater degradation, though each has a separate suite of choices. The most essential is having the Water Boards formally declare areas at risk for nitrate contamination. Such a declaration (M1) might entail a series of complementary actions, such as requiring domestic well testing in at-risk areas (D3), monitoring of at-risk populations (M2), and formation of a local compensation agreement or liability district for at-risk areas under Water Code Section 13304 (F2). Perhaps greater education and outreach to farmers in at-risk areas would also occur, along with discharger fees to fund safe drinking water actions to reduce nitrate discharges.

Porter-Cologne Act, Water Code Section 13304, states that "a cleanup and abatement order issued by the State Water Board or a regional Water Board may require the provision of, or payment for, uninterrupted replacement water service, which may include wellhead treatment, to each affected public water supplier or private well owner." This provides authority for the California Water Boards to require landowners contributing to nitrate in groundwater drinking water supplies to fund drinking water actions for affected public water supplies and private wells.

Using this authority, when a Regional Water Board establishes that an area is at risk for nitrate contamination of groundwater, it could simultaneously issue a cleanup and abatement order initiating a process for overlying landowners and contributors of nitrate to groundwater in that area to respond with an area drinking water compensation plan.

This process might involve requiring overlying landowners to support drinking water actions that comply with public health requirements established by the local County Health Department, including:

- an initial date by which groups of overlying landowners would submit a proposed area drinking water compensation plan for actions, implementation, and funding to the County Health Department;
- an intermediate date by which the appropriate Regional Water Board and County Health Department would approve such a plan, or one of their own, for overlying landowners to support drinking water actions; and
- a date by which any overlying landowner not complying with the area drinking water compensation plan would be required to cease and desist applications of nitrogen to overlying land exceeding a standard established by the Regional Water Board to protect drinking water users from nitrate pollution. This condition would apply to all overlying landowners if no alternative local compensation agreement drinking water action plan had been approved.

CDPH could issue suitable guidance to County Health Departments on establishing public health requirements.

County Health Departments would need to be empowered to collect fees from landowners pursuant to a drinking water action plan under a cleanup and abatement order. These fees would include the cost to the County Health Department of overseeing the drinking water action plan. Fees could be collected as part of annual county property tax assessments. This approach would provide a relatively organized and efficient means for landowners contributing nitrate to a contaminated aquifer to help decrease the additional costs incurred by drinking water users from nitrate contamination.

To protect public health, requiring testing of domestic wells in areas declared to be at risk of nitrate contamination seems prudent and in the public interest. Legislation seems needed to require such testing (perhaps periodically or on property sale), although perhaps this can be done by county ordinance or administratively as a requirement to receive compensation under Water Code Section 13304.

Options Requiring Fiscal Legislation

Raising additional revenue to address nitrate issues seems to likely require legislation. The only exception is raising the small mill fee on fertilizer to its full authorized limit, which is approved for funding nitrogen use education and research activities.

Among these funding options, perhaps the most promising is to establish a statewide fee on the sale of nitrogen fertilizers, or a more administratively awkward fee on nitrogen use only in designated drinking water contamination risk areas. Such fees would act as both funding sources for safe drinking water actions and as an incentive to reduce nitrogen use, thereby somewhat reducing nitrate loading to groundwater. Partial rebates on these fees could be arranged for farmers who are involved in local area drinking water compensation plans or who have agreed to enforceable reductions in nitrate loads to groundwater.

6.3 Getting Organized

Many promising options are organizational. The management of nitrate groundwater contamination and its drinking water consequences is currently divided among several state agencies, each with historically derived authorities, purposes, and funding, as summarized in Section 3. In particular, the State and Regional Water Boards have the greatest authority under California's Porter-Cologne Act for groundwater quality. The California Department of Public Health and County Health Departments have authority over drinking water quality and public health. The California Department of Food and Agriculture has the greatest authority over fertilizer management and agricultural activities. The Department of Pesticide Regulation has no authority or direct interest in nitrate problems, but it has a successful, modern, integrated program for pesticide management, which may serve as a model for other forms of contamination, including nitrate. California's Department of Water Resources has overall water planning responsibility for the state, including oversight and funding authority for Integrated Regional Water Management Plans, and the State Water Board regulates water rights. The nitrate issues of the Tulare Lake Basin and Salinas Valley overlap several agencies. As environmental problems evolve beyond the origins of these agencies, there is often a need to evolve and coordinate the actions of different state and local agencies.

Nitrate contamination of groundwater is just one example of groundwater quality (and quantity) issues that many state agencies have in common. Each of the above agencies has its own groundwater monitoring, data, management, and often funding programs for groundwater overall or for individual groundwater quality or quantity concerns. Each of these agencies is facing, or will soon face, a range of similar and related groundwater problems regarding nitrate, pesticides, salts, and groundwater recharge and overdraft quantities.

Informational Actions

To help prepare the state to better address these problems, we propose several informational actions. Many informational actions could be triggered by requiring each of the California Water Boards to declare areas at risk of drinking water contamination from nitrate in groundwater (promising action M1). This finding is purely technical and seems well within the means of the Regional Water Boards, perhaps with some coordination from the State Water Board. A declaration of an area being at risk for nitrate groundwater contamination could also trigger several other informational actions. To protect public health, households and other very small water systems would be required to test drinking water wells for nitrate concentration upon sale and periodically thereafter (D4). Populations depending on groundwater in at-risk areas would also be reported to DWR for inclusion in state water planning efforts (M2). The "area at risk" designation could also serve to prioritize or trigger other funding, fee, education, monitoring, or regulatory actions.

Task Forces

We also propose four independently led task forces consisting of a core of agencies with overlapping interests. Having independent leadership would provide some assurance that each task force views the subject problem from more than just a collection of pre-existing agency perspectives.

- A task force on small water systems would seek to develop a common state policy for the problems of small water and wastewater systems in California. Small systems have inherent problems with higher costs, more precarious finance, and fewer technical and managerial resources, as they lack economies of scale. CDPH has long recognized these problems on the water supply side, but there are likely to be benefits from addressing these local water and wastewater utility problems together.

- A task force on nitrogen mass accounting would explore the technical, economic, and institutional issues of having farms account for nitrogen and nitrate fluxes as a basis for regulation or fees. Currently, such detailed accounting is done for pesticides, air emissions, and dairy nitrogen, and it is being contemplated for salts and irrigation water. Having widespread and relatively detailed accounting for nitrogen would allow for some forms of economic management, such as cap and trade, and could also potentially support various educational and regulatory means of reducing nitrate loads to groundwater. This leads to a larger strategic question of whether the range of environmental emissions from agriculture should be accounted for separately by different agencies, gathered together in a single agency, or coordinated among separate agencies. Having a fragmented accounting system seems likely to increase costs and the regulatory burden, while reducing overall insight and understanding of environmental and agricultural problems. Accounting systems can be costly and time consuming for agencies and nitrogen users to administer.
- Two groundwater task forces are proposed. The first is in regard to groundwater data. A major difficulty in preparing this Report has been the fragmentation of groundwater data within and between agencies, as well as the lack of general access to groundwater data. Groundwater has become such an important issue that most agencies have their own groundwater activities. It is now critical that the state has a coherent and more forward-looking policy and technical capability for the collection and management of groundwater data. This issue seems sufficiently complex to call for a separate groundwater data task force.
- The many state interests and agencies involved with groundwater issues also seem to call for a periodic assessment of how effective these distributed programs are in practically addressing California's groundwater problems. This second independent groundwater task force would periodically review and report on the effectiveness of state groundwater activities to each California Water Plan.

6.4 Dilemmas for State Action

Groundwater nitrate contamination poses several overarching dilemmas and challenges for state policy, which will likely require broader discussions.

Local, statewide, or no compensation for pollution. In practice, the costs of pollution of drinking water sources are often borne by drinking water users. Some aspects of state policy (Water Code Section 13304) allow for fairly direct compensation for such costs. And general state support for water treatment also helps cover such costs. State general funds seem unlikely to be able to provide substantial support in the future, and many local communities, particularly small systems, are unlikely to have financial resources to cover such costs. Can the state establish a reasonable, relatively low-cost means to assess non-point source polluters for the drinking water (and perhaps other) costs entailed?

Degradation of groundwater. Current state law and policy does not allow degradation of groundwater quality to levels above water quality objectives defined in the applicable Basin Plan. However, no technological and institutional strategy has been found to economically reduce all nitrate discharges to levels that prevent further groundwater degradation. More modest approaches to reducing nitrate loads are likely to be economical. However, these more moderate reductions in nitrate loads would typically reduce the rate of groundwater degradation, but they would not always prevent degradation, particularly in the short term. If degradation is practically inevitable for some sources, how should state policy best oversee and regulate degradation?

Policy and policy implementation for environmental effects of land use. Both agriculture and urban land uses now face a host of environmental issues overseen by separate agencies and programs. The environmental causes and effects of nitrate contamination alone, for example, involve a diverse array of state agencies and programs. However, these same land uses also imply environmental impacts via pesticides, salinity, water use, air pollution, surface runoff, and endangered species. Many of these regulated (or potentially regulated) aspects interact environmentally, or their solutions have interactive effects and costs for land management. Is there a more effective and efficient policy approach to managing the environmental effects of land uses than mostly independent agencies and programs for each impact?

7 Conclusions

1. **Nitrate problems will likely worsen for decades.** For more than half a century, nitrate from fertilizer and animal waste have infiltrated into Tulare Lake Basin and Salinas Valley aquifers. Nitrate will spread and increase nitrate concentrations in many areas for decades to come, even if the amount of nitrate loading is significantly reduced. Most nitrate in drinking water wells today was applied to the surface decades ago.

2. **Agricultural fertilizers and animal waste applied to cropland are the two largest regional sources of nitrate in groundwater.** Although discharges from wastewater treatment plants, food processors, and septic tanks also contribute nitrate to groundwater and can be locally important, almost all of the regional groundwater nitrate contamination in the Tulare Lake Basin and Salinas Valley is from agricultural fertilizers and confined animal waste.

3. **Nitrate loading reductions are possible, some at modest cost. Large reductions of nitrate loads to groundwater can come at substantial economic cost.** Farm management is improving, but further improvements are necessary. While some are immediately achievable at modest cost, significant barriers exist, including logistical constraints and inadequate education. The cost of reducing nitrate loads to groundwater can be considerable for large reductions, especially on crops that require a substantial (much greater than 25%) decrease in nitrogen application from today's agronomically accepted, typical rates. Such dramatic reductions in fertilization rates without crop yield improvements can decrease net revenues by possibly several hundred million dollars per year within the study area.

4. **Direct remediation to remove nitrate from large groundwater basins is extremely costly and not technically feasible.** The volume of nitrate-contaminated groundwater is far larger than for urban contamination plumes. Standard pump-and-treat remediation to treat the groundwater underlying the Salinas Valley and Tulare Lake Basin would cost tens of billions of dollars. Instead, "pump-and-fertilize" and improved groundwater recharge management are less-costly long-term alternatives.

5. **Drinking water supply actions, such as blending, treatment, and alternative water supplies, are most cost-effective. Blending will become less available in many cases as nitrate pollution continues to spread.** Regardless of actions taken to reduce long-term nitrate loading to groundwater, many local communities in the Tulare Lake Basin and Salinas Valley will need to blend contaminated groundwater with cleaner water sources, treat contaminated well sources, or develop and employ safe alternative water supplies. Blending will become less available as an option in many cases as nitrate pollution continues to spread. The cost of alternative supplies and treatment for these basins is estimated at roughly $20 million to $36 million per year for the next 20 years or more.

6. **Many small communities cannot afford safe drinking water treatment and supply actions. High fixed costs affect small systems disproportionately.** Many small rural water systems and rural households affected by groundwater nitrate pollution are at or below the poverty level. Treatment and alternative supplies for small systems are more costly, as they lack economies of scale. Adherence to nitrate drinking water safety standards without substantial external funding or access to much less expensive treatment technology will potentially bankrupt many of these small systems and households.

7. **The most promising revenue source is a fee on nitrogen fertilizer use in these basins. A nitrogen fertilizer use fee could compensate affected small communities for mitigation expenses and effects of nitrate pollution. Under Water Code Section 13304, California Water Boards could also mandate that nitrate dischargers pay for alternative safe drinking water supplies.** Either mechanism would provide funds for small communities affected by nitrate pollution, allowing them to develop treatment or alternative water supplies that reduce the cost and effect of nitrate pollution over time.

8. **Inconsistency and inaccessibility of data from multiple sources prevent effective and continuous assessment. A statewide effort is needed to integrate diverse water-related data collection activities by various state and local agencies.** Throughout this study, we often faced insurmountable difficulties in gaining access to data already collected on groundwater and groundwater contamination by numerous local, state, and federal agencies. Inconsistencies in record keeping, labeling, and naming of well records make it difficult to combine information on the same well that exist in different databases or that were collected by different agencies. A statewide effort is needed to integrate diverse water-related data collection activities of various state and local agencies with a wide range of jurisdictions. Comprehensive integration, facilitation of data entry, and creation of clear protocols for providing confidentiality as needed are key characteristics of such an integrated database structure.

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The Tulare Lake Basin and the Salinas Valley, with 2.6 million inhabitants and home to nearly half of California's agricultural production, are the focus of this report. Nearly one in ten people in these two regions are currently at risk for nitrate contamination of their drinking water. Water systems providing water for half of these regions' population have encountered excessive nitrate levels in production wells at least once over the last five years.

An independent team of scientists at The University of California, Davis, was contracted by the State Water Resources Control Board to examine this problem. Working in consultation with an Interagency Task Force representing many state and local agencies, the authors undertake a uniquely broad and comprehensive assessment of the wide spectrum of technical, scientific, management, economic, planning, policy, and regulatory issues related to addressing nitrate in groundwater and drinking water for the Tulare Lake Basin and Salinas Valley.

This report identifies, describes, and quantifies past and current sources of nitrate, details the extent of groundwater nitrate contamination, and provides a comprehensive, up-to-date guide to the many options available to address the problems of drinking water quality, aquifer degradation, and economic costs from nitrate contamination of groundwater and its regulation. The report concludes by outlining promising actions in four key areas: safe drinking water actions for affected areas; reducing sources of nitrate contamination to groundwater; monitoring and assessment of groundwater and drinking water; and revenues to help fund solutions. Even among these promising options, major policy choices must be made. The research compiled in this report provides a foundation for informed discussion among the many stakeholders and the public about these policy choices.

The Center for Watershed Sciences at the University of California, Davis, brings a wide range of experts together to examine California's major water issues and problems. Its activities range from scientific and analytical modeling studies to major works on urgent problems. More about the Center can be found at watershed.ucdavis.edu.

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