Final Report

Nitrogen Fertilizer Loading to Groundwater in the Central Valley

FREP Projects 11-0301 and 15-0454

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Prepared by

Thomas Harter, Kristin Dzurella, Giorgos Kourakos, Andy Bell, Aaron King, and Allan Hollander

University of California, Davis

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Project Information

Project Leaders:

Thomas Harter, Robert M. Hagan Endowed Chair in Water Management and Policy, Department of Land, Air, and Water Resources, (530) 752-2709, ThHarter@ucdavis.edu.

Minghua Zhang, Adjunct Professor, Department of Land, Air and Water Resources, (530) 752-4953, MHZhang@ucdavis.edu.

Thomas P. Tomich, Ph.D., W.K. Kellogg Endowed Chair in Sustainable Food Systems, Professor and Director, Agricultural Sustainability Institute and Sustainable Agriculture Research and Education Program, (530) 752-4563, TPTomich@ucdavis.edu.

G. Stuart Pettygrove, Cooperative Extension Soil Specialist Emeritus, Department of Land, Air, and Water Resources, (530) 752-304-1007, GSPettygrove@ucdavis.edu.

Affiliation of all Project Leaders: University of California; One Shields Ave.; Davis, CA 95616

Collaborating Personnel:

Kristin Dzurella, Research Analyst, Department of Land, Air and Water Resources, UC Davis
Giorgos Kourakos, Visiting Research Scientist, Dept. of Land, Air, and Water Resources, UC Davis
Allan Hollander, Project Scientist, Information Center for the Environment, UC Davis
Andy Bell, Research Analyst, Center for Watershed Sciences, UC Davis
Nicholas Santos, Research Analyst, Center for Watershed Sciences, UC Davis
Quinn Hart, Data Scientist, Shields Library, UC Davis
Aaron King, Graduate Student Researcher, Center for Watershed Sciences, UC Davis
Jim Quinn, Professor Emeritus, Information Center for the Environment, UC Davis
Gail Lampinen, Project Scientist, Center for Watershed Sciences, UC Davis
Daniel Liptzin, Post-doctoral Scholar, Institute of Arctic and Alpine Research, University of Colorado
Todd Rosenstock, Research Scientist, World Agroforestry Centre (ICRAF)

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Executive Summary

Highlights

- Agricultural lands are the largest contributor of nitrate to Central Valley groundwater. Urban and domestic contributions to potential groundwater nitrogen loading are less than 10%.
- Synthetic fertilizer contributes nearly 60%, dairy manure nearly 20% of nitrogen to croplands.
- New technologies are urgently needed to derive synthetic fertilizer-like materials from dairy manure to address the largest pollution risks.
- A wide range of agricultural practices are available to improve crop nitrogen use efficiency at a region-wide scale.
- Agricultural management improvements will only gradually affect groundwater quality in supply wells, at decadal time-scales.
- New modeling tools can assess future groundwater quality trends including those achievable from broader adoption of currently available or future best agricultural practices.

Introduction

Nitrate-nitrogen is the most common pollutant found in the Central Valley aquifer system of California. This project provides a long-term assessment of past and current potential nitrogen loading to groundwater on irrigated and natural lands across the entire Central Valley of California using a nitrogen mass balance approach; assesses the long-term implications for groundwater quality in the Central Valley (Sacramento Valley, San Joaquin Valley, and Tulare Lake Basin); evaluates potential best management practices to reduce groundwater nitrogen loading from irrigated lands; and provides a planning tool to better understand local and regional groundwater quality response to specific best management practices and policy/regulatory actions. The project complements other work to assess the vulnerability of Central Valley groundwater to nitrate contamination, sources of nitrate in groundwater, and how to reduce source loading.

Methods/Management

The primary tool for this Central Valley assessment are field-scale, crop-scale, crop-group scale, county-scale, groundwater-basin scale, and Central Valley-wide nitrogen mass balance computations that can be linked to groundwater transport models. We developed a GIS framework and a compilation of spatial land use data, collecting and digitizing data for performance of the nitrogen mass balance (historic and current). Data collection included a comprehensive assessment of historic and current nitrogen applications to cropland (from atmospheric, fertilizer, animal, and human sources) and field nitrogen removal (harvest removal, atmospheric losses, surface runoff). Agricultural Commissioner reported crop area and production data have been used to determine the mean period harvest removal rates of nitrogen. We used the tabularized county-by-county crop acreage information and a number of existing geospatial databases to generate digital maps of current and 1990 landuses; and then developed an algorithm that backcasts agricultural crop maps of the Central Valley to the mid-1970s, late 1950s/early 1960s and to the 1940s when fertilizer use in the Central Valley first started to be widespread. Published N fertilization rates (Viers et al. 2012, Rosenstock et al. 2013) were updated through an extensive interview process and used to estimate total synthetic N applications based on reported crop area. New concepts for handling various components of crop data emerged, and extensive quality control was performed on the data collected.

For comparison of synthetic fertilizer nitrogen loading to that from other sources, we tabularized nitrogen loading from wastewater treatment plants, food processors, and from septic systems. Dairy manure nitrogen amounts and fate were assessed through review of existing research results and by performing dairy nitrogen mass balances.

We also extended the computational performance of groundwater transport modeling software: The groundwater nitrate transport modeling tool developed here allows computation of long-term transport of nitrate to individual domestic/municipal/irrigation wells, based on the spatially distributed, field-by-field, annual nitrogen loading to groundwater. We have developed new solver capacities and the ability to run the software program on parallel computing machines, with initial runs of a highly detailed flow and transport model for several basins in the Central Valley.

Findings

This report updates and expands the 2012 SBX2 1 Report "Addressing Nitrate in Groundwater", which focused geographically on the Tulare Lake Basin and Salinas Valley. The data presented here confirm the major findings of the earlier report and of information since then submitted by agricultural coalitions and CV-SALTS to the Central Valley Regional Water Quality Control Board:

The largest nitrogen fluxes into the agricultural landscape include synthetic fertilizer (504 Gg N/yr), land application of manure on dairy cropland or exported to other crops and land application of wastewater effluent (220 Gg N/yr), and nitrogen fixation in alfalfa (115 Gg N/yr). The largest nitrogen fluxes out of the agricultural landscape include harvested nitrogen (450 Gg N/yr including alfalfa), potential nitrogen losses to groundwater from cropland (331 Gg N/yr), and atmospheric nitrogen losses (209 Gg N/yr, which includes 131 Gg N/yr of atmospheric N losses from dairy manure prior to land application).

The Tulare Lake Basin accounts for the largest nitrogen fluxes but it also reflects nearly half of the total irrigated cropland area – 1.5 million ha of 3.2 million ha in the Central Valley. Nitrogen flux rates in the Tulare Lake Basin largely mirror those in the San Joaquin Valley, with large amounts and rates of manure land applications.

The Sacramento Valley, in contrast, has only small amounts of dairy cropland with manure land applications and little manure export. Lacking manure nitrogen sources to augment synthetic fertilizer, the Sacramento Valley in turn has a slightly higher rate of synthetic nitrogen application (175 kg N/ha/yr instead of 165 and 158 kg N/ha/yr in the San Joaquin Valley and Tulare Lake Basin, respectively).

To reduce potential groundwater nitrogen loading from cropland across the Central Valley and thus improve the quality of recharge water from the agricultural landscape, there are only few options, dictated by the magnitude of nitrogen fluxes:

- Increase the amount of harvest without also increasing the amount of synthetic or organic fertilizer
- Reduce the nitrogen input to the agricultural landscape. However, of all fluxes into the agricultural landscape, only synthetic fertilizer use can be reduced significantly without significantly changing Central Valley landuse: Cities and particularly dairy farming are generating large amounts of nitrogen that is currently recycled in the agricultural landscape.

A central challenge to improving groundwater quality in the Central Valley is to develop nutrient management practices that make more efficient and effective use of animal derived nutrients to allow growers to increasingly rely on organic fertilizer. This will require the development of new processes to transform manure into a fertilizer product that can be marketed and that performs much like synthetic fertilizer.

In the meantime, a wide range of agricultural practices have been documented, as part of this work, as part of CDFA FREP’s work, and elsewhere, that significantly improve crop nitrogen use efficiency at a region-wide scale from today’s practices. Extending this knowledge to growers will be a key goal for the agricultural coalitions in the Central Valley that are engaged in the implementation of the Irrigated Lands Regulatory Program and the Dairy Order. Agricultural management improvements are urgently needed to not further degrade groundwater recharge quality, even if improvements of groundwater quality in supply wells will only be felt at decadal time-scales, due to the slow-moving nature of groundwater.

Project Objectives

1. Develop a field-scale nitrogen mass balance for all major irrigated crops and other landuses across the entire Central Valley.
2. Determine nitrogen leaching to groundwater as closure term to the nitrogen mass balance, where possible, and from literature review, where nitrogen mass balance is not possible, e.g., septic systems and other non-cropped areas.
3. Apply the nitrogen loading rates with our non-point source assessment tool to several large pilot areas in the Tulare Lake Basin, the San Joaquin Valley, and the Sacramento Valley for a groundwater nitrate pollution assessment and assess the prediction uncertainty inherent in the approach.
4. Provide results within a GIS atlas that is publishable on the web and also in form of extension and outreach activities including newsletter articles, interviews with news outlets, web-based materials, and publication in California Agriculture and other grower-geared magazines, and in peer-reviewed scientific journals.

Introduction

An overarching objective of this project is to assess the potential impact of fertilizer use in the Central Valley relative to other sources of nitrogen on groundwater quality. In hydrologic investigations, this type of assessment is sometimes referred to as a vulnerability assessment, impact assessment, or risk analysis. Such assessments can be implemented to various degrees of accuracy using a number of different approaches, at various spatial and temporal scales. The hydrologic literature distinguishes four major categories useful for the assessment of impacts of pollution sources (here: fertilizer applied in agricultural and urban settings) on groundwater quality and the risk for groundwater quality degradation (Harter, 2008):

- Mapping-based index and overlay methods:
    - Single indicator based approach (e.g., crop type or fertilizer application rate)
    - Aggregation of multiple risk factors (e.g., recharge rate, depth to groundwater, soil type, source intensity, landuse/crop)
- Computer-based, numerical water flow and pollutant fate and transport simulation methods:
    - Water and pollutant mass flux based (zero-dimensional) approach
    - Crop and root zone processes modeling (one-, two-, or three-dimensional)
    - Vadose zone process modeling (including the root zone, most commonly one-dimensional, but also two- and three-dimensional)
    - Groundwater flow and transport modeling (two- or three-dimensional)
- Statistical analysis, including regression models relating groundwater quality to potential explanatory factors, including landuse
- Field monitoring approaches
    - Root zone / vadose zone monitoring at selected sites

- Groundwater monitoring at selected sites or across a (regional) monitoring network

Mapping-based index and overlay methods are commonly used for vulnerability or risk assessments (Harter, 2008). In the Central Valley, recent efforts under Irrigated Lands Regulatory Program (ILRP) of the Central Valley Water Quality Control Board (CVRWB, 2017) have provided a vulnerability analysis of nitrate in groundwater across the entire Central Valley: As part of their regulatory compliance under the ILRP, agricultural water quality coalitions prepared a so-called Groundwater Quality Assessment Report (GAR) that provides a baseline understanding of the hydrology, hydrogeology, water quality, and landuse within each coalitions area and the factors potentially leading to groundwater nitrate contamination. As part of the GAR, each coalition developed a vulnerability mapping approach that summed indeces related to climate, landuse, geography, soil type, crop type, groundwater quality, urbanization, the presence of groundwater users, especially domestic well and economically disadvantaged public water supply users, and other factors (the GARs can be found under each "Coalition Group" at http://www.waterboards.ca.gov/centralvalley/water_issues/irrigated_lands/water_quality/coalitions/index.shtml). These and other mapping-based index and overlay methods rely on spatial analysis of multiple maps, each representing certain quantitative or quality indicator variables. The assembly of maps are overlaid and digitally evaluated based on an expert-based or other algorithm that combines indicator values at one location into a final location-based vulnerability score.

Computer-based, numerical simulation models range from lumped mass flux based models to process-based models that may encompass crop, atmosphere, root zone, vadose zone (below the root zone), and groundwater processes of water movement and pollutant fate and transport. These methods use detailed spatio-temporal information about a site or region – the distribution of climate, soil, landuse, and hydrogeologic properties – to predict the flow of water and the associated fate and transport of pollutants in the subsurface. Numerical simulation models are commonly used in the site assessment and evaluation of point sources of groundwater contamination (e.g., groundwater contamination from leaky underground storage tanks at gas stations, discharge of industrial solvents from leaky waste impoundments). Numerical methods have also been commonly used in assessing nutrient and pesticide fate and transport in the root zone of agricultural crops. To date, such methods have been less commonly used to assess pollutant fluxes from nonpoint sources to groundwater (Harter, 2008).

Statistical approaches have been used to relate the presence of potential pollutants in the source area of groundwater to measured groundwater quality data, where the transport pathway via the crop root zone and vadose zone to groundwater and subsequently through the aquifer to a well, spring, or stream is represented in a "black box" approach via a statistical model. For example, Nolan et al. (2014, 2015) developed and compared three advanced, machine-learning based statistical approaches to relate groundwater nitrate measurements to a large number of potential factors influencing groundwater nitrate concentration. Similarly, Nolan et al. (2002), used a statistical regression technique to relate measured groundwater nitrate to a number of factors thought to influence groundwater nitrate concentrations, at the national scale. Statistical methods, once developed from existing data are then commonly employed to make predictions at unmeasured locations, e.g., to predict nitrate concentration at locations with the Central Valley (Nolan et al., 2014, 2015; Ransom et al., 2017) or within the US (Nolan et al., 2002), where data currently do not exist. The information is also used to delineate regions with higher pollution risk for a particular contaminant: the California Department of Pesticide Regulation used statistical regression to identify regions that are vulnerable to groundwater pesticide contamination (so-called "groundwater protection zone") based on information about depth to groundwater, soil texture, and the presence of soil hardpans (Troiano et al., 1992).

Monitoring of pollutants in the environment is used to obtain direct observations of groundwater quality impacts. Properly designed monitoring networks (of the root zone, unsaturated zone, or groundwater) ideally provide information on groundwater quality impacts from specific sources. Often, significant uncertainty exists about the exact source locations that contribute to the water quality in a particular well. Monitoring wells, constructed with relatively short screens (up to 25 feet) in the uppermost groundwater zone typically provide the most constraint on the uncertainty about the source location of water measured in the well. Source area location of domestic wells is much more uncertain and even larger for large production wells used for municipal or agricultural water supplies. Often, monitoring methods are used in conjunction with computer-based methods and statistical methods of pollution source assessments.

In this project, our goal has been to better assess the role of synthetic fertilizer in contributing to groundwater nitrate pollution in California's Central Valley, relative to the many other sources. We map the potential for groundwater nitrate pollution based on the information obtained on nitrogen fluxes associated with urban areas, golf courses, wastewater treatment plants, food processing plants, septic systems, dairies, and 58 agricultural crops, using mapping and mass balance simulation tools. This report steps through the various tasks designed to assemble the mapping and simulation data layers, including literature surveys, extensive data collection from over a half century of agricultural commissioner reports on crop acreage and crop harvest, from fertilizer sales reports, from interviews with fertilizer application experts, and through the development of mapping and simulation tools. This final report follows the originally proposed project Task schedule. Work description, data and results, and discussion are provided within each Task chapter. A synthesis discussion is provided at the end of the report.

Task 1 describes the overall database architecture, the spatial extent of the study, and the temporal extent of the study. Tasks 2, 4, 9, and 10 describe the development of Central Valley landuse layers with 50 m resolution using existing digital information (Task 2), existing county-level agricultural crop acreage information (Task 4), and through back-simulation for historic periods (Task 10) based on a unified crop classification scheme with 58 individual crops and crop classes (Task 9).

Tasks 3 and Tasks 5 through 8 describe the data collection associated with various components of the agricultural nitrogen cycle: historic and current fertilizer sales data (Task 3), historic and current fertilizer practice recommendations (Task 5), historic and current crop harvest rates and associated nitrogen removed (Task 6), atmospheric nitrogen deposition (Task 7), and nitrogen losses to the atmosphere (Task 8).

The data and information discovery described in Tasks 1 through 10 is employed in Task 11. Task 11 describes the methodology and additional data sources used to perform a Central Valley-wide, detailed historic and current nitrogen mass balance, at the county-level and at the 50 m field scale, to estimate the potential groundwater nitrogen loading from key urban and agricultural nitrogen sources. Task 13 describes the development of a groundwater flow and transport modeling tool that can be used in conjunction with the estimated potential groundwater nitrogen loading maps (historic and current) to assess long-term impacts on groundwater quality.

Finally, alternative agricultural management practices available to address potential high groundwater nitrogen loading rates are summarized in Task 12.

Task 1: Develop GIS Database Structure

1.1 Work Description

The study area includes the California Central Valley floor, roughly following the CV aquifer as defined in the USGS Central Valley Hydrological Model (CVHM, Faunt 2009). Crop area and crop production statistics were compiled from annual county agricultural commissioner offices for 20 Central Valley Counties. These include counties in three regions:

- Sacramento Valley (SCV): Butte, Colusa, Glenn, Placer, Sacramento, Shasta, Solano, Sutter, Tehama, Yolo, Yuba
- (Northern) San Joaquin Valley (NSJV): Contra Costa, Madera, Merced, San Joaquin, Stanislaus
- Tulare Lake Basin (TLB): Fresno, Kings, Kern, Tulare

To enable running the GNLM on the full Central Valley study region, it is necessary to create historical land cover layers to initialize the model at prior times. As current and future groundwater nitrate concentrations are the results of a long history of nitrate loading, the annual mass balance is performed in 15 year intervals from 1945 to 2005 requiring landuse data back to 1945. For improved accuracy, needed data collection for this task (e.g. harvest statistics from Agricultural Commissioner Reports, see Task 4) includes not only each interval year (1945, 1960, 1975, 1990, 2005), but 2 years prior to and after the individual interval year, for a total of 25 years:

1943 – 1947 for the period year "1945"

1958 – 1962 for the period year "1960"

1973 – 1977 for the period year "1975"

1988 – 1992 for the period year "1990"

2003 – 2007 for the period year "2005"

The approach to generating landuse maps for these five periods was two-fold: the "1990"and "2005" periods are compiled from existing county-level landuse surveys, compiled digitally by the California Department of Water Resources and others. Digital landuse maps for the earlier periods ("1975", "1960", and "1945") are obtained by back-simulating landuse using information available on the extent of agricultural landuse from county agricultural commissioner's crop acreage data, other available land classification sources, and known spatial landuse distribution in 1990.

1.2 Results/Data

Using ArcGIS® as the GIS platform, a spatial framework for data compilation and model simulation has been developed. All spatial data and maps are converted into a uniform coordinate system using California Albers projection. Base maps include 1:24,000scale National Elevation Dataset (NED), 1:100,000 scale National Hydrography Dataset (NHD), and 1:24,000 scale Soil Survey Geographic (SSURGO) database, landuse and weather data (CIMIS) from California Department of Water Resources. GIS databases have been developed for the San Joaquin Valley watershed, with details documented in Zhang and Luo, 2007; and for the Tulare Lake Basin as documented in Viers et. al., 2012.

Task 2: Compile landuse data that are available in GIS format; historic and current, by CDWR landuse unit / field (crop classification I)

2.1 Digital Landuse Map Representing the 2005 Period: Work Description for CAML 2010

A map of current land use was developed to provide a statewide view of land cover using the most recent data sources as of 2010 (Figure 2.1). In the context of this project, the statewide view was necessary because it served as an input for a parallel project developing a nitrogen budget for the entire state of California. This map was based upon the earlier California Augmented Multisource Landcover (CAML) raster layer (Hollander, 2007) , developed at ICE in 2007. This 2007 map augmented the earlier 2002 Multi-Source Land Cover (MSLC) map from the California Department of Forestry and Fire Protection by dividing its single agricultural class into the 8 agricultural classes used in the California Wildlife Habitat Relationships classification system (California Department of Fish and Game, 1999), the primary focus of the MSLC map being on natural vegetation. The differences of the current map (henceforth CAML 2010) from the 2007 map include the following: 1) the data sources are up-to-date (the most recent being 2008); 2) given the agricultural focus of this project, the number of agricultural classes have been expanded drastically, to a fairly large subset of the agricultural classes used in the landuse mapping efforts by the California Department of Water Resources (DWR)(about 120 classes). The raster cell resolution has been increased from 100 meters to 50 meters (see http://cain.ice.ucdavis.edu/caml).

The initial base layer for this product was the MSLC layer from 2002. This layer pools the best regional vegetation maps into a single statewide raster map, at 100 meter resolution. The land cover classes use the California Wildlife Habitat Relationships system, which is organized around differentiating habitat types for wildlife. The MSLC layer is used for the natural vegetation component of CAML 2010.

The DWR land use maps were the main input for the agricultural component of the map. DWR has been mapping land cover types on a county-by-county basis on a rotation of about every 7 years. We used the most recent maps for each county, specifically 1997 for Monterey, 1999 for Tulare, 2000 for Fresno, 2003 for Kings, and 2006 for Kern County. The GIS workflow was to load the shapefiles for each county into a single table in the spatial database PostGIS (Refractions Research, 2008). We then associated each polygon with a single land cover classification type using a two-column lookup table which referred to the fields labeled class1 and subclass1 in the DWR shapefile. We then exported this table via spatial analysis to another shapefile. The shapefile was then rasterized at 50 meter resolution raster using the raster centroid landuse and retaining a single integer coded value for the land cover classification within the raster cell.

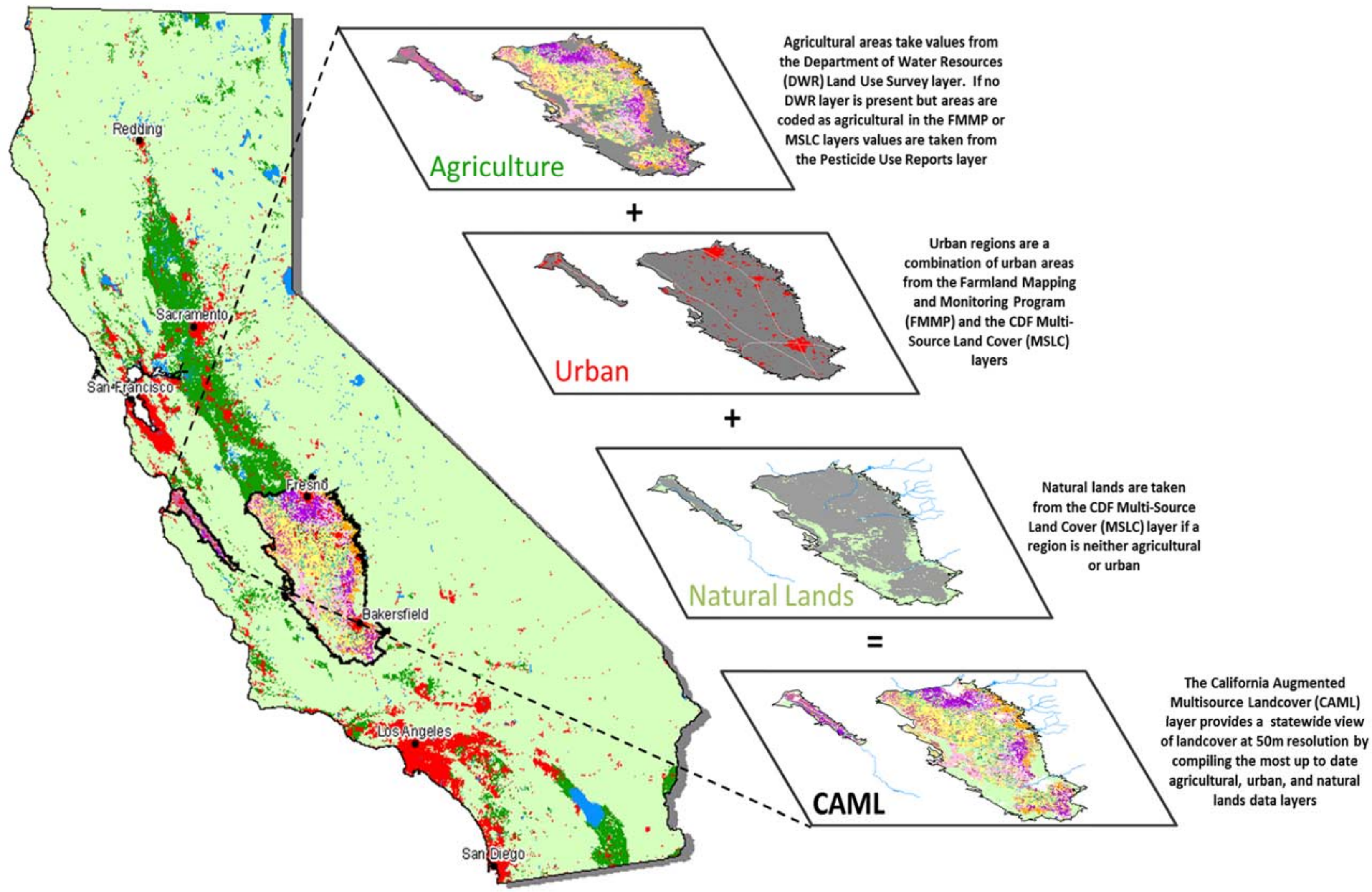

Figure 2.1: The input layers for the final 2010 raster layer with insets illustrating the SBX2 1 study area portion of the Central Valley. (Viers et al. 2012, used with permission)

Another input to the CAML 2010 map were the Farmland Mapping and Monitoring Program (FMMP) maps produced by the California Department of Conservation. These identify prime farmlands, locally important farmlands, grazing lands and so on for most counties in the state. FMMP has been mapping these in two-year intervals since 1984. Most importantly, FMMP has mapped conversion of farmlands to developed lands. We use the FMMP layer from 2008 as a source for urban boundaries. Equivalent to the processing of the DWR shapefiles, we add all of the FMMP maps to a single table in PostGIS and then export that to a shapefile which was subsequently rasterized at 50 meter resolution. This raster layer had 15 distinct categories in it (Table 2.1)

Table 2.1 - FMMP Land use categories

Land Use Categories for FMMP
Confined Animal Agriculture (Cl)
Urban and Built-up Land (D)
Grazing Land (G)
Farmland of Local Importance (L)
Farmland of Local Potential (LP)
Natural Vegetation (nv)
Prime Farmland (P)
Rural Residential Land (R)
Farmland of Statewide Importance (S)
Semi-Agricultural and Rural Commercial Land (sAC)
Unique Farmland (U)
Vacant or Disturbed Land (V)
Water (W)
Other Land (X)
Area Not Mapped (Z)

One issue was that not all agricultural areas of the state had been mapped by DWR at any point, even once, one example of this being southern Santa Clara County. Yet these areas show up as agricultural regions in the MSLC map or the FMMP mapping. We need to populate these areas with agricultural land classes, so we need an alternative source for these. This is provided by the Pesticide Use Reporting available from the California Department of Pesticide Regulation (PUR) (California Department of Pesticide Regulation, 2000). When farmers apply pesticides they document this with their county agricultural commissioner, who in turn reports these data to the DPR. These data include amounts and types of pesticides applied spatially located to the nearest one square mile section. Significantly, these pesticide use reports also include the crop type of application. We converted the list of crop types in the PUR database to the lookup table used with the DWR maps and summed up the crop types by area for each square mile section, the rule being to assign each section the crop with the greatest total by area. The table was referenced spatially to a public land survey system layer for the state. The township-range-section map was then rasterized with the values for each pixel being the crop code for the majority crop type within each section according to the PUR data.

These 4 inputs to CAML 2010 were then all put together (Figure 2.2). The urban regions are a combination of the urban areas from the MSLC and FMMP maps. The agricultural areas took values from the DWR layer where that was present. If no DWR layer was present but the area was coded as agricultural in MSLC or FMMP, we took the values from nearest PUR square-mile section, using a raster-based region growing algorithm to determine the crop type of the nearest section). If the region was neither urban nor agricultural, it is natural vegetation, so these values were taken from the MSLC layer.

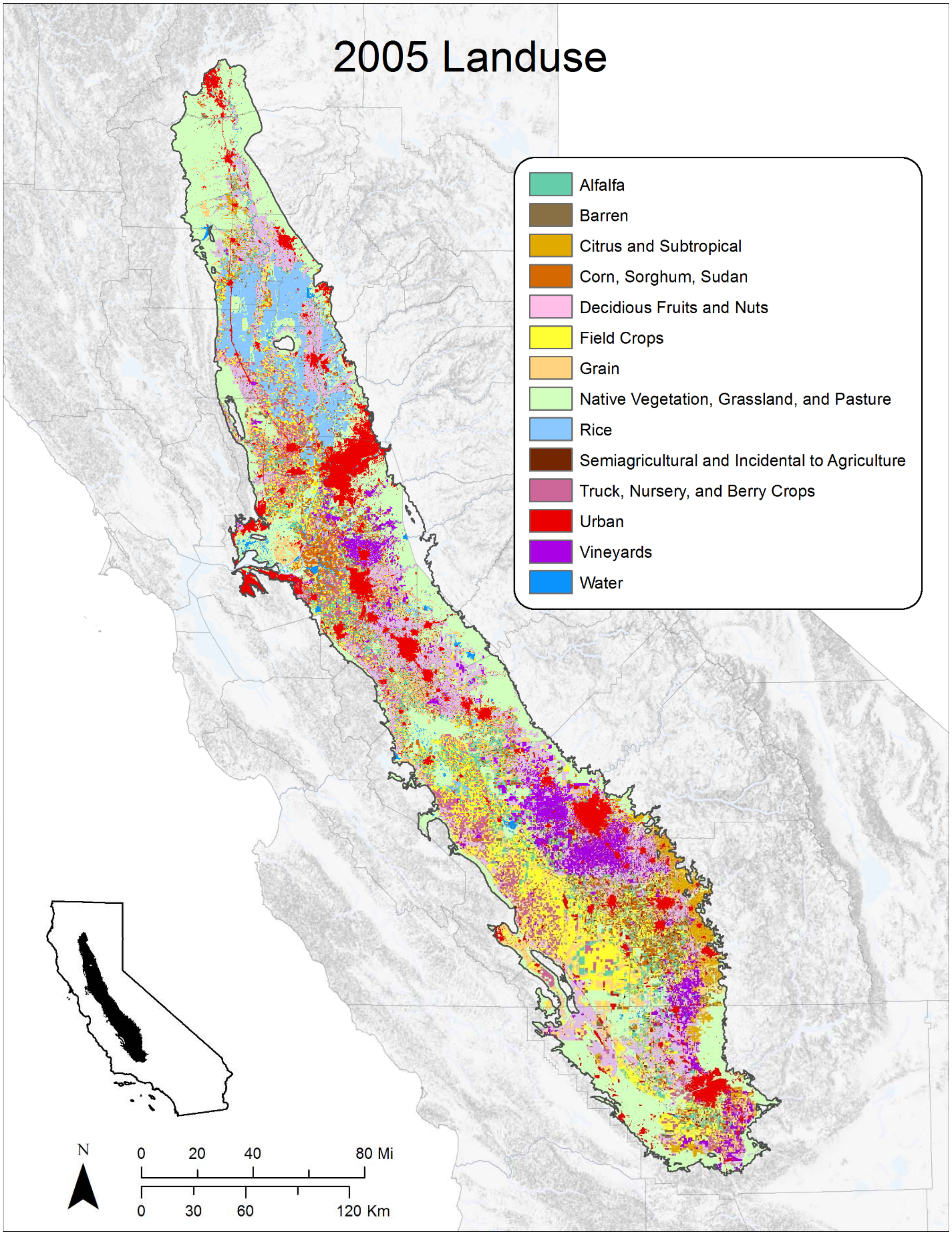

Figure 2.2: California Augmented Multisource Landcover (CAML) landuse map for the 2005 period.

2.2 Landuse Map for the 1990 Period: Work Description for CAML 1990

The time period of the 1990 era is the furthest back when there is digital mapping available that provide details on the spatial distribution of crop patterns, the data coming from the DWR Land Use Survey. Construction of the 1990-era land cover map for the Central Valley proceeded in three stages. The first was a map of the 4 Tulare Lake Basin counties (Fresno, Tulare, Kings, and Kern) produced in 2011 for the SB2X 1 nitrate project. The second stage, completed in spring of 2013, extended this collation to the other counties in the San Joaquin Valley as part of the San Joaquin Valley Greenprint project. The final stage, completed in summer of 2014, added the Sacramento Valley counties to the set as well.

Three input layers went into the processing for the 1990 land cover map. First, the 1992 NLCD, a raster layer at 30 meter resolution, was used to distinguish between agricultural, natural vegetation, and urban land cover areas. Second, the 2002 Multi-Source Land Cover (MSLC) map from the California Department of Forestry and Fire Protection (California Department of Forestry and Fire Protection 2002), a raster map with 100 m resolution, was used as a source of information on natural vegetation. Areas of natural vegetation in the NLCD map were assigned land cover classes from pixels in the MSLC map. Third, areas marked as agriculture in NLCD were assigned land cover classes from the DWR land cover mapping. The DWR map for each county was selected from the one closest in time to 1990 from the list of all maps for each county; these ranged from 1989 for Yolo County to 1998 for Sutter County, with the median year being 1994. The output for this processing was a set of raster layers by county at a 50 meter pixel resolution. These layers were then patched together to form a single 1990-era raster land cover map for the Central Valley counties.

We have assembled a circa 1990 land cover layer for the entire Central Valley, using a combination of Department of Water Resources land cover layers, the 1992 National Land Cover Dataset, and the California Department of Forestry and Fire Protection Multi-Source Land Cover dataset. An image of this 1990 land cover dataset is provided in Figures 2.3 and 2.4.

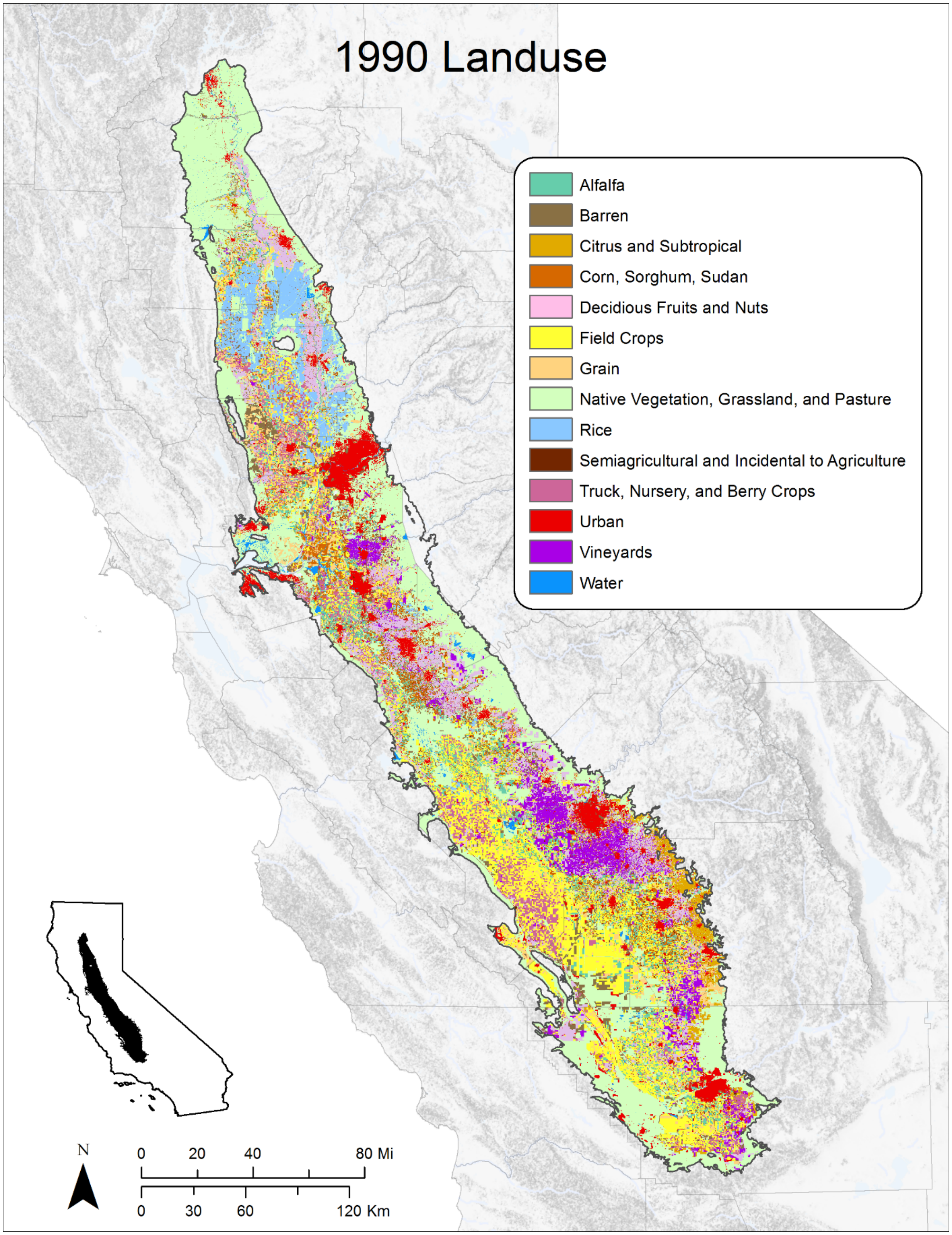

Figure 2.3: Reconstructed 1990 land use and cropping systems map for the Central Valley with over sixty landuse classes grouped here into 14 landuse groups.

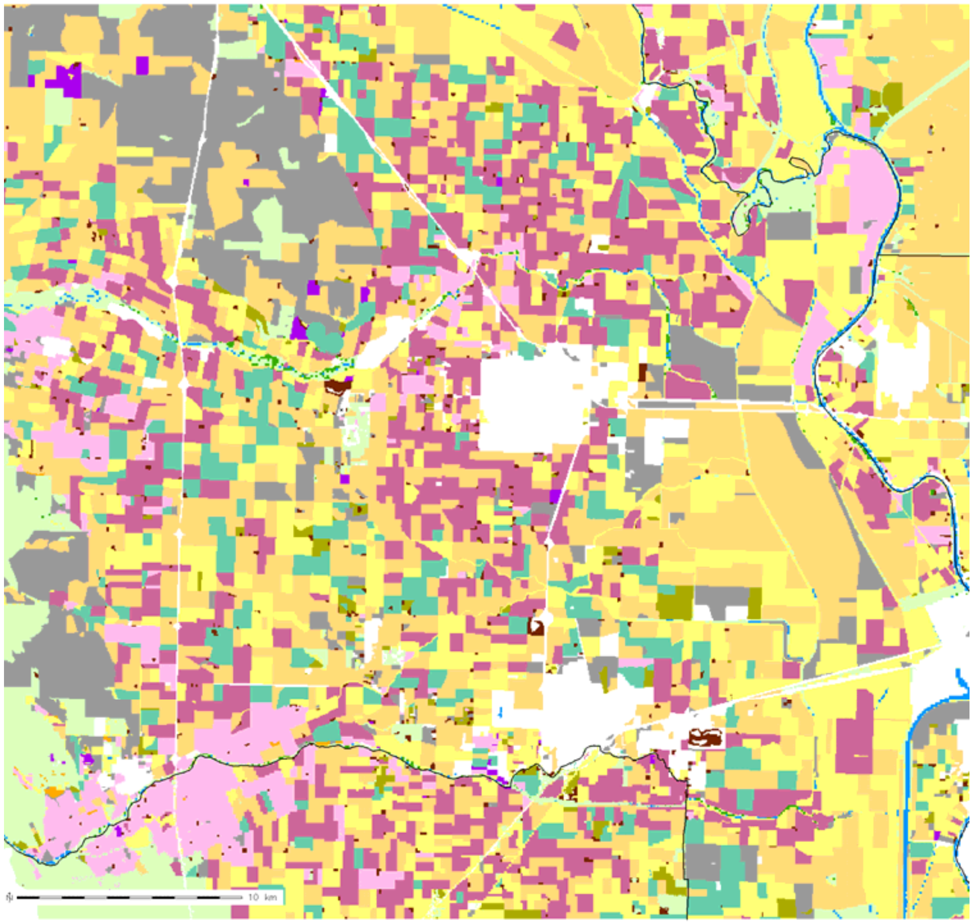

Figure 2.4: Detail of the Central Valley 1990 landuse map , showing Yolo County with Woodland and Davis in the center of the map (white: urban areas).

Task 3: Fertilizer sales, historic and current, by county

3.1 Work Description

California Department of Food and Agriculture publishes fertilizer sales reports bi-annually, in which the second report for the year lists annual total N by county (appearing after individual product totals), under a column variously named “All Nutrients Tons, N”; or “All N” (https://www.cdfa.ca.gov/is/ffldrs/Fertilizer_Tonnage.html). We digitized these reports for the years 1988-2011 and processed average sales for the 1990 and 2005 periods (1988-1992, 2003-2007) to compare to synthetic N application totals. Additionally, the decadal averages prior to and after 2002 were analyzed, and significant outliers were removed.

3.2 Results and Discussion

Statewide nitrogen fertilizer sales vary from less than 500,000 tons in 1991 to over 900,000 tons reported for 2002. Significant variability is observed in statewide fertilizer sales. By 2011, reported nitrogen fertilizer sales had decreased from 2002 levels to less than 750,000 tons. Counties in the Central Valley account for a significant amount of state-wide fertilizer sales. In 1991, sales in the Central Valley counties were nearly 300,000 tons. By 2011, fertilizer sales in the Central Valley had doubled to nearly 600,000 tons. These counties make up between two-thirds and three-quarters of statewide fertilizer sales, depending on the year. Annual variations largely follow those of the statewide fertilizer sales.

A significant increase in reported N sales occurred in 2002, with high sales continuing thereafter. While it may be expected that such a sudden rise in fertilizer demand is driven by sudden landuse or landuse practice changes, our analysis shows that statewide nitrogen demand does not significantly change in 2002 (Figure 3.1). Instead, the bulk of the reported sales increases in 2002 are attributable specifically to reported sales of anhydrous ammonia in San Joaquin County, and to a lesser degree, to reported sales of aqua ammonia sales in Colusa County. In 2002, 97% of the reported statewide anhydrous ammonia sales took place in two counties. San Joaquin county accounts for 56% of that year’s reported sales, with the remainder reported in San Luis Obispo County, which in all other years reports zero sales of anhydrous ammonia. In 2008, 90% of the statewide anhydrous ammonia sales were reported in San Joaquin County, accounting for over 35% of statewide total N sales.

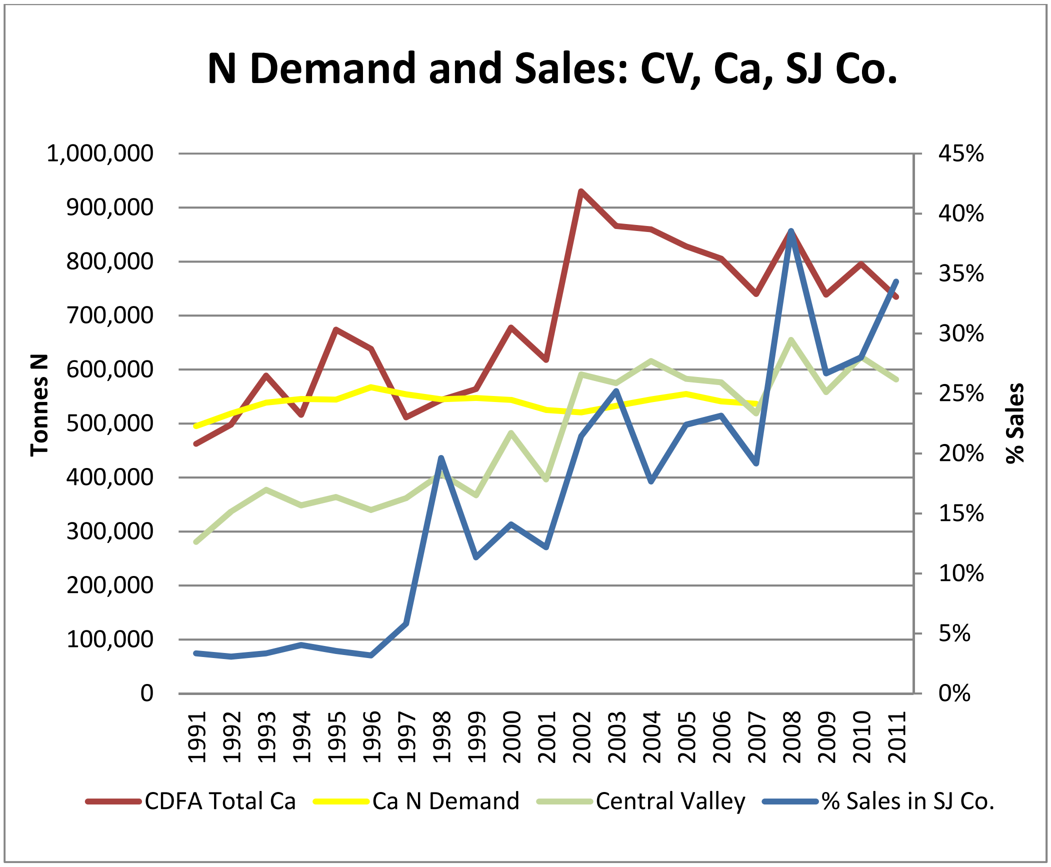

Figure 3.1: Statewide and Central Valley N sales as reported in CDFA tonnage reports. Statewide N demand, based on yields, does not show a similar increase, highlighting a sales reporting anomaly. The CV accounts for ~65-75% of statewide sales while the sales in San Joaquin County have been increasingly and disproportionately high, accounting for up to 38% of statewide sales.

While fertilizer sales should be reported by the dealer who sells to the end-user only (from a licensed dealer to an unlicensed buyer), products may change hands several times before being purchased by the end-user. A possible explanation for over-reporting could occur if a company reports sales to "middlemen," who then also report sales to the end-user. Such double reporting by one prominent company was verified by a California fertilizer industry expert whom we interviewed. According to this anonymous source, this error has affected reliability of reported values for anhydrous ammonia in San Joaquin County and aqua ammonia in Colusa County "for at least 10 years". These are the counties and N materials that show the largest anomalies in the sales reports. Nationally, the relationship between an individual state's N fertilizer sales data and reported crop acreage do not vary as dramatically from year to year as shown here. While transcription errors, unit conversion errors, and other anomalies may contribute to reported sales anomalies, we conclude that double reporting is the main factor in the inaccurate sales data since 2002. The differences in decadal average N sales within each county before and after the 2002 sales jump are shown in Table 3.1.

Table 3.1: Central Valley county synthetic nitrogen fertilizer sales; averages for the decade prior to and after the 2002 jump in statewide sales. Differences > 10,000 tons highlighted in bold. Outliers were removed from the analysis on 3 occasions as noted, and are assumed reporting errors. N sales occurring in county "unknown" average 35K per year, ranging 1k-100k.

County	Avg. 1991-2001	Avg. 2002-2012	(tons N)
Butte	18,362*	18,207	**removed 1995 outlier of 43,000 tons*
Colusa	**22,932**	**38,549***	**large increase in aqua ammonia*
Contra Costa	2,262	2,443	
Fresno	64,784	67,342	
Glenn	13,545	15,019	
Kern	44,304	50,509	
Kings	28,091	33,168*	**spike in 2006*
Madera	10,148	9,413	
Merced	17,130	23,217	
Placer	850	1,363	
Sacramento	13,525	18,529	
San Joaquin	**44,265**	**208,549***	**large increase in anhydrous ammonia*
Shasta	1,566	4,254*	**removed 2002 outlier of 15,000 tons*
Solano	9,142	9,633	
Stanislaus	**18,867***	**28,687**	**removed 1995 outlier of 66,000 tons*
Sutter	17,482	14,397	
Tehama	1,345	2,113	
Tulare	24,589	26,808	
Yolo	16,472	14,729	
Yuba	3,262	2,781	
Central Valley	**369,333**	**587,802**	*Above outliers excluded*
California Total	**572,042**	**815,416**	*Outliers and county 'unknown' included*

Estimating more realistic sales figures for the 2005 period based on the relationship between application and sales or harvest estimates in the 1990 period, is not possible with any reasonable certainty. But it is helpful to compare the reported fertilizer sales figures to estimated synthetic fertilizer application rates and estimated harvest rates for nitrogen. In Task 11 we describe two approaches to estimate county level synthetic fertilizer applications: one is based on county agricultural commissioner reports of land area harvested (Section 11.7); the second is based on the detailed CAML 2010 landuse map (Task 2) with detailed spatial accounting for manure utilization that may affect synthetic fertilizer use (Section 11.8). Tasks 4-10 describe further details behind these approaches. Here we use county reported crop land area as the basis of computing synthetic fertilizer use, by county (Section 11.7):

Figure 1 shows fertilizer sales records, estimated synthetic N application and estimated N harvests (see tasks 4, 5, and 11) for the 1990 and 2005 periods, based on mean crop acreages reported by county agricultural commissioners for those periods. Estimated synthetic N applications increased by 7% from 1990 to 2005 while estimated harvest increases by 27% indicating significant improvements in overall synthetic nitrogen fertilizer use efficiency. However, reported Central Valley fertilizer sales of 306 Gg N/yr are 40 Gg N/yr less than estimated synthetic N applications in the 1990 period. In the Sacramento Valley and San Joaquin Valley, estimated synthetic N applications exceed reported synthetic N fertilizer sales in those regions by 11% and 37%, respectively. In the Tulare Lake Basin, the difference is less than 5%.

The difference between estimated synthetic N application and reported synthetic N sales in the 1990 period may be due to significant imports of synthetic N fertilizer to the Central Valley from counties outside of the Central Valley. Actual estimates for synthetic fertilizer movement into or out of the Central Valley are not available. Statewide sales for synthetic fertilizer N averages 499 Gg N/yr during the 1990 periods. Given that more than 70% of California irrigated cropland is in the Central Valley, the estimated synthetic N application (345 Gg N/yr, Figure 3.2) is not unreasonable and may indicate that fertilizer was indeed imported to the Central Valley during the 1990 period.

In contrast to the 1990 period, the average reported N fertilizer sales for the 2005 period (2003-2007) exceed the estimated synthetic N application in all three Central Valley regions: estimated synthetic N applications in the Central Valley rise by 7% to 370 Gg N/yr, while the reported N sales rise by 40% to 520 Gg N/yr. The average reported state-wide synthetic N sale for the 2005 period is 761 Gg N/yr. These numbers would indicate significant net export of nitrogen fertilizer from the Central Valley to other California counties – on the order of 150 Gg N/yr. Net exports on that order of magnitude seem unlikely. These numbers instead appear to be consistent with the observation that some double-counting of sales occurredfor the reported synthetic N fertilizer sales in the 2005 period. Tomich et al. (2016) estimate 2005 statewide synthetic N use to be 590 Gg N/yr. Urban areas and industrial horticulture account for 53 Gg N/yr, chemical production use is 71 Gg N/yr, and California cropland application accounts for 466 Gg N/yr, i.e., 79% of statewide synthetic fertilizer N application is on cropland. Tomich et al. (2016) used mostly the same estimated synthetic N application rates as those used here (without our updates described under Task 5), assuming 3.66 Mha of cropland (including 0.46 Mha of alfalfa). For comparison, the county agricultural commissioners in the Central Valley reported an average cropland area of 2.73 Mha (including 0.32 Mha of alfalfa) for the 2005 period, 75% of the statewide cropland area (see Task 4).

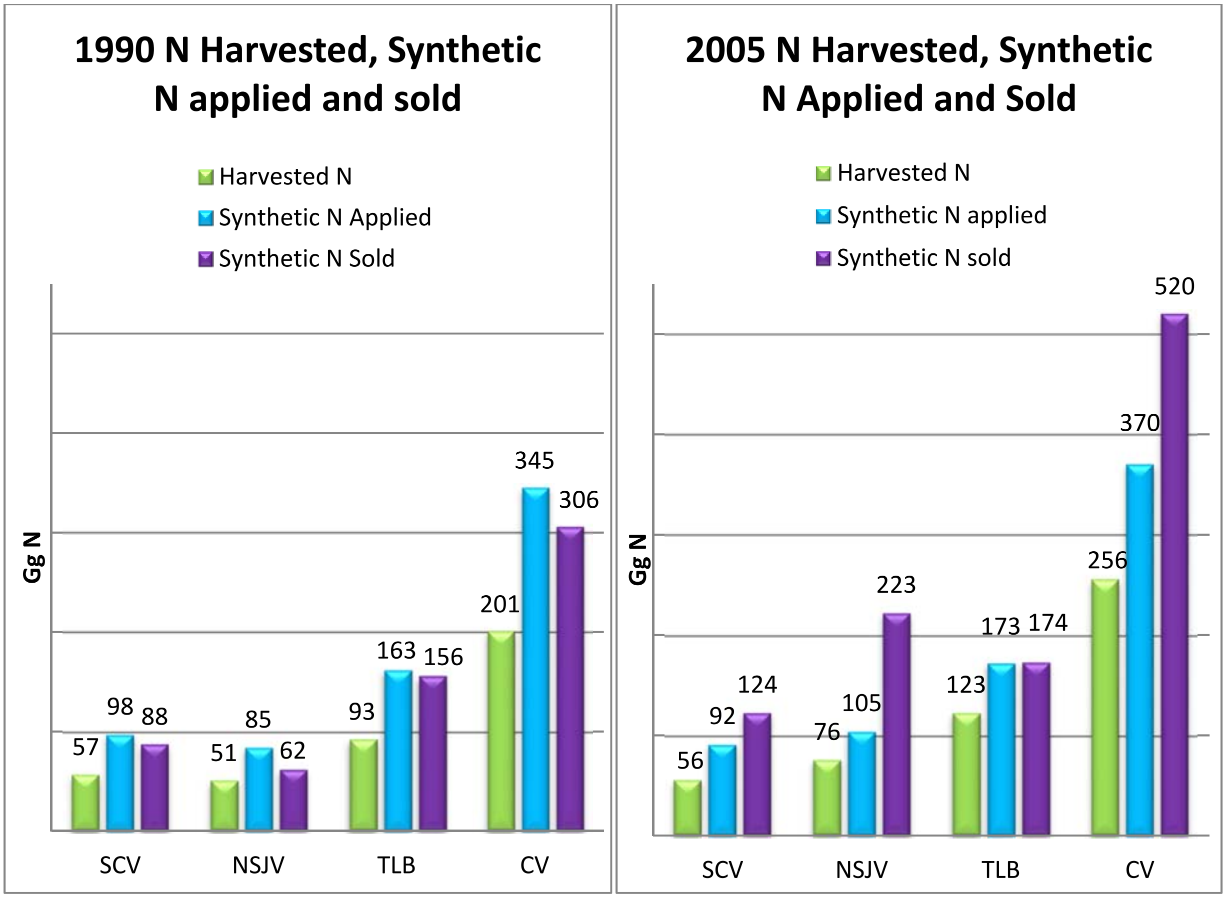

Figure 1.2. Estimated nitrogen harvested based on county agricultural commissioner reports, estimated synthetic N applied based on crop areas reported by country agricultural commissioners and typical N application rates for each of 59 crops, and synthetic nitrogen reported by CDFA as sold for the 1990 (left) and 2005 (right) periods in the respective county regions. The reported sales in the 2005 period are known to be inaccurate due to double reporting in San Joaquin and Colusa counties.

At the county level, the change in reported synthetic N sales (from 1990 to 2005) do not correlate with synthetic N applied, N harvested, or area (Figure 3.2; Table 3.2). This is not restricted to Colusa and San Joaquin counties: Sacramento and Placer counties' production and N applications dropped while reported N sales increased dramatically. Merced, Tehama, Shasta, and Butte counties also report dramatically higher reported N sales in the 2005 period than would be expected given changes in harvested and applied N from 1990 and 2005. However, because some counties are significant importers or exporters of product, the expectation that sales on the county level would match fertilizer needs is unfounded.

The apparent export of nitrogen fertilizer from one county to other counties is concentrated in the NSJV and TLB counties in both periods (Table 1). It would be expected that the port of Stockton would contribute to higher sales than crop N need in the San Joaquin County as is the case in the 1990 period (along with the highly abnormal 2005 period in that county). Similarly, exporting behavior would be expected in counties in which N fertilizer is produced (such as Fresno). However, adjusting 2005 data based on net N-exporting and N-importing behavior is not possible with any degree of certainty. For example, while Madera, Merced, Kern and Tulare counties (among others) reported less N sales than total synthetic N application for both periods, the majority of the remaining counties do not share a relationship between the two periods. Accounting of cross-county N sales is further complicated by the fact that there are many different individual nitrogen products and formulations sold, each of which may be more or less regionally important and/or with more or less local dealer representation. While one county may import more of one N product, they may export more of another with a different percentage of total N in the formulation. Additionally, fertilizer sales made across state lines (or across counties that are not within the study area) may contribute to differences between sales records and application estimates.

While we are able to provide an explanation for the largest reported nitrogen sales anomalies, no attempt was made to adjust sales figures for the 2005 period (and beyond) or estimate importing and exporting habits of individual counties, due to lack of consistent data and county relationships.

Table 3.2: County percent sales of total state-wide N fertilizer sales, and percent change between the 1990 and 2005 periods for: reported synthetic N sales, cropped area, N harvest, and synthetic N applied. Highlighted in bold are significant county anomalies in reported N sales, given estimated total N harvest and synthetic N applications. Sorted by percent sales in the 1990 period.

County	1990 % sales	2005 % sales	% Change synthetic N sales	% Change area	% Change N harvest	% Change synthetic N applied
Fresno	12.9%	12.8%	3%	0%	21%	-4%
Kern	8.3%	9.6%	20%	0%	35%	11%
Kings	5.5%	6.4%	17%	-2%	27%	4%
San Joaquin	5.5%	30.8%	**740%**	38%	51%	38%
Colusa	5.4%	6.9%	**109%**	9%	21%	8%
Yolo	4.5%	2.0%	-34%	-5%	-17%	-15%
Glenn	4.1%	2.4%	-11%	14%	26%	17%
Tulare	4.0%	4.6%	15%	12%	55%	22%
Stanislaus	3.6%	5.6%	63%	13%	52%	25%
Merced	3.5%	4.4%	**94%**	18%	50%	24%
Madera	3.3%	1.6%	-26%	4%	45%	7%
Butte	3.1%	3.5%	**93%**	5%	12%	6%
Sutter	3.0%	2.4%	18%	5%	13%	4%
Solano	2.4%	1.4%	-11%	-43%	-53%	-43%
Sacramento	2.3%	3.5%	**138%**	-8%	-20%	-38%
Yuba	0.7%	0.4%	-12%	9%	0%	9%
Contra Costa	0.6%	0.4%	2%	-28%	10%	-26%
Shasta	0.3%	0.6%	**162%**	18%	19%	20%
Tehama	0.3%	0.4%	**150%**	2%	24%	5%
Placer	0.2%	0.3%	**135%**	-19%	-13%	-26%

Task 4: Compile crop acreage and crop production, historic and current, by county (crop classification II)

4.1 Work Description

Crop area and production statistics were compiled from annual county agricultural commissioner offices for 20 Central Valley Counties in 3 Regions (see Task 1).

We digitized tabularized data, including area and harvest weights, for each of the Central Valley counties, for each of the 5 years representing the 5 periods in this study (1945, 1960, 1975, 1990, 2005--see Task 1). Thus, a total of 500 annual county reports have been compiled into digital spreadsheets. The crop classification used in these reports have been aligned via cross-walk tables with the crop classification scheme utilized by the DWR (see Task 9), keeping with the latter's spatial resolution of cropping patterns.

Several complications arose in the effort to create a comprehensive database of crops, their land area in each county, and their harvest amount in each county: It is common for the county reports to indicate total area of, for example, corn, while separating the yield associated with that reported total area into corn grain and corn silage. Therefore, subtotaling the two N harvests into a single total that can be compared to the reported total land acreage for "corn" is required for accurate representation of the harvest rate (where "rate" refers to the harvested amount per hectare or per acre). If area is reported separately for two sub-crops, but yield for only one, subtotaling will result in inaccurate representation of total yield, as was found and corrected for in the database. In other cases, many crops may be categorized together in the reports (e.g. miscellaneous field crops), in which area is reported but individual yields are not. In some cases, the area reported in such miscellaneous categories by the Agricultural Commissioners is large, but without corresponding yield data. These data cannot be incorporated into the mass balance work, representing a source of uncertainty.

Area and production results are reported by county and individual crops, but also by county and region in aggregated crop groups:

- Alfalfa and clover (pasture)
- Pasture (other than natural pasture) was considered but has highly unreliable harvest figures. If harvests are reported at all it is often only seed. If there was no harvest reported, then the area was excluded from the dataset, as in all other crops.
- Corn, sorghum, and sudan
- Cotton
- Field crops – safflower, sugar beets, sunflower, dry beans, and miscellaneous field crops
- Grain and Hay – barley, wheat, oats, and miscellaneous grain and hay
- Nuts – almonds, walnuts, and pistachios
- Olives
- Subtropical Tree Fruit – oranges, lemons, grapefruit, avocado, kiwi, pomegranates, and miscellaneous citrus

- Deciduous Tree Fruit – apples, apricots, cherries, peaches, nectarines, pears, plums, prunes, figs and miscellaneous tree fruit
- Grapes – raisin, table and wine grapes
- Vegetables and Berries – artichokes, asparagus, green beans, carrots, celery, lettuce, melons and squash, garlic and onions, green peas, potatoes, sweet potatoes, spinach, processed tomatoes, berries, strawberries, peppers, broccoli, cabbage, cauliflower, Brussels sprouts, and miscellaneous truck crops

4.2 Results and Discussion

In 1945, reported cropland area in the 20 Central Valley counties encompassed 1.7 Mha. Fifteen years later, that number had increased by 44% to nearly 2.5 Mha, close to the modern-day extent of cropland (2.7 Mha). Table 4.1 shows the historical development of crop area for the various crop groups. Area dedicated to woody perennials, which includes grapes, tree fruits, and nuts, has increased substantially and rapidly since 1945, from 291,000 to 851,000 hectares. Nut crops alone account for nearly half of this increase. Rice, vegetables and berries have seen modest increase in production area over the time period. The area in alfalfa, field crops, and grain and hay has seen a general decline since 1975, while corn, sorghum and sudan have fluctuated only slightly since 1960 (despite an increase in dairy operations that typically grow many of these crops as animal forage).

In the 2005 period in the CV, woody perennials (grapes, fruit and nut trees) account for 31% of the cropped area, field crops (including cotton, corn, and other field crops) for 22% of cropped area, grain and hay crops account for 17%, vegetables and berries 10% and rice 8% of the total cropped area. Approximately half the cropped area is located in the 4 TLB counties, while the SJV and SCV regions each account for about 25% of the CV cropping area. The majority of the state's rice production takes place in the SCV, where 35% of the cropped area in the 2005 period was devoted to that crop alone. Table11.16 (Task 11) includes crop areas by region.

Table 4.1: Total harvested area (ha), by crop group, periods 1945-2005. Each period is the mean of five annual years. Reported pasture area is much higher than that shown here due the lack of reported harvests in much of the area. One hectare is approximately 2.5 acres. Essentially all of the re

Crop Group	1945	1960	1975	1990	2005
Alfalfa	249,547	360,745	296,419	281,463	319,880
Pasture	1,018	17,341	6,038	3,098	930
Corn, Sorghum, Sudan	55,073	206,395	242,069	149,465	256,940
Cotton	145,305	312,253	426,868	484,958	259,669
Field Crops	88,905	206,788	184,291	181,722	81,437
Grain and Hay	650,483	771,576	617,912	400,855	466,463
Rice	96,164	119,101	174,511	171,852	229,803
Nuts	33,870	64,194	151,016	251,717	390,478
Subtropical Tree Fruit	18,694	17,159	54,421	63,116	84,602
Olives	7,064	10,022	11,230	12,102	11,485
Deciduous Tree Fruit	76,488	81,234	94,986	109,919	126,260
Grapes	154,808	140,335	178,741	210,990	237,830
Vegetables and Berries	132,890	162,059	184,135	251,892	265,001
TOTAL	**1,710,309**	**2,469,202**	**2,622,637**	**2,573,149**	**2,730,778**

Task 5: Compile crop fertilizer practices recommendations, historic and current

5.1 Work Description

The most recently published nitrogen fertilization practices for the major crops in California (Viers et al. 2012, Rosenstock et al., 2013), are based on the average of UC Davis ARE agricultural cost and return studies and USDA Chemical Usage Reports for the 1990 and 2005 periods, and on a 1973 survey of extension specialists (Rauschkolb & Mikkelsen 1978) for the 1945-1975 periods.

We corrected for a transcription error between the historic rates reported by Rauschkolb & Mikkelsen (1978) and these same rates published in more recent research (Viers et al 2012, Rosenstock et al 2013, Rosenstock et.al. 2014). These changes most significantly affected the historical nut, grape and orange application rates. Additionally, the 1990 and 2005 period rates have also changed slightly from the original database (Viers et al., 2012) to ensure that significant digits used to convert pounds per acre to kilograms per hectare remained consistent for all periods.

To vet published application rates for the 2005 period, we designed a survey of UCCE crop advisors. Of the 56 DWR defined crop/crop-group categories within the Central Valley, and as shown in Table , we chose 22 crops of high nitrogen yields and application totals[1]. In the fall of 2013, for each of these 22 crops, we consulted UCCE crop advisors chosen for their expertise on the crop in question in high area locales.

Table 5.1: Crops included in N application rate survey, chosen based on study area N harvest and application totals.

Field and Grain Crops	Woody Perennials	Vegetables
Corn (grain and silage)	Almonds	Garlic and onions
Cotton (lint and seed)	Walnuts	Processing tomatoes
Safflower	Pistachios	Potatoes
Sudan	Prunes	Melons and squash
Barley	Oranges	Lettuce
Wheat	Peaches and nectarines	Broccoli
Oats	Olives	
Rice	Grapes (all)	

We interviewed a total of 33 advisors, many of whom commented on multiple crops, so that an average of 2 advisors were consulted per crop. We requested opinions of published rates, rate range speculations, and commentary on any regional differences in application rates and micro-regional influence on growers’ rate decisions (soil texture for example):

[1] Note that two broad DWR crop groups, “Miscellaneous Truck Crops” and “Miscellaneous Grain, Hay, and Straw” have very high total N harvest and total N applied, but being a “miscellaneous” category inclusive of multiple crops, could not be included in the survey.

1. **What is the typical or average N rate applied to [CROP] in Central Valley or in the geographic area you are comfortable commenting on?** Viers (2012) and Rosenstock (2013) report [RATE] lb N/acre. Does that sound about right for an average value?
2. What is the range of N rates applied in the Central Valley (or area you have experience in)? Consider the "range" to encompass rates that would not be surprising to you – not necessarily the very most extreme values.
3. What are the factors contributing to the range of values, i.e., that will lead growers to use different annual total N applications?
4. Are you aware of any industry surveys of grower N rates applied? Any other surveys or reliable values? Do processors track or have knowledge fertilization rates? What about the commodity board?
5. Can you comment on average yields?
6. How is the crop residue and (for orchards/vineyards) the middles and floor managed? How are prunings and leaf litter managed?
7. Are there experts besides yourself in UC and industry who likely have knowledge of this? Anyone you could recommend that we contact for this survey?

5.2 Results and Discussion

UCCE advisors included in our telephone survey consistently disagreed with the 2005 published nitrogen application rates for 5 crops, including wheat, potatoes, and three tree crops (oranges, walnuts, and almonds). Experts considered the application rates to be too low for each of these crops, with the exception of potatoes. While geography (generally north-south within the valley) was implied in application rate ranges in some crops (e.g. wheat, rice), the specific variety grown, yield goals, and method of irrigation were also considered central to growers' differing application rate decisions for many crops. We updated our database to use the average of the range estimates provided by extension staff for these 5 crops for both the 1990 and 2005 periods (Table 5.2). The application rates for the other 17 crops subject of the survey were not adjusted as there was no significant disagreement with those rates (as published in Viers et al., 2012, Rosenstock et. al., 2013), although we note an advisor familiar with carrots (a minor crop that was not specifically questioned but that shows an abnormally high efficiency in our analyses) suggested the application rates are typically much lower than our figures, (90-120 lbs/acre, approximately 118 kg/ha compared to 242 kg/ha in our database) and that furthermore the harvest rates were in his experience much higher than reported in the ACRs.

Appendix Table 3 includes application rates for all 56 DWR crops for each period.

Table 5.2: Disputed published nitrogen application rates (Rosenstock et al. 2013) and updated figures based on 2013 UCCE expert opinion.

	Almonds	Walnuts	Oranges	Wheat	Potatoes
Published application rates kg/ha	196	151	104	194	272
Updated application rates kg/ha	246	196	146	231*	202

*average of 3 regional rates: SCV:179, NSJV:235, TLB:280

Task 6: Compile crop nitrogen uptake estimates by major crops from literature review, extension reports; historic and current (crop classification IV)

6.1 Work Description

As discussed in Task 4, we digitized county agricultural commissioner's reports for 25 years for the 5 periods to obtain the harvested area and crop tonnage. For Task 6, reported yields were converted to an estimated N removal for each crop record by using the USDA Crop Nutrient Tool (http://plants.usda.gov/npk/main). The tool estimates crop harvest nitrogen (N) removals based on typical N content and user-specified moisture content in specific crops. The final production data tables were used together with the USDA nitrogen content data to calculate N harvest rates (kg N/ha) for each crop, for each year within each of the five periods, in each county. Statistical analysis was performed to aggregate data to the period, region, and the Central Valley as a whole. The statistical methods used deviated from the median-based approach used in Viers et. al. 2012 and Rosenstock et al 2014. Hence, harvested N reported here deviate somewhat from those reported for TLB counties in the above references.

Specifically, we compute, for each county, crop, and period, the arithmetic mean over the five years within the period to obtain the period mean harvested area and the period mean harvested mass of nitrogen for each crop in each county. For the specific regions (SCV, SJV, and TLB) and for the CV, the period mean area and mean harvested mass of nitrogen are summed over the respective counties, separately by crop. County N harvest rates are obtained by taking the ratio of the period mean mass of nitrogen harvested and the period mean harvested area. Regional and Central Valley harvest rates are obtained by taking the ratio of the respective sum (over counties) of period mean mass of nitrogen harvested and the respective sum (over counties) of the period mean harvested area. This calculation is equivalent to a county-harvested-area weighted mean of the county nitrogen harvest rates.

Some harvest data are more difficult to convert into harvested nitrogen mass: Calculating N content of reported nut yields is complicated by nut hull and shell N content, and how much of these byproducts are typically removed from the field or included in the reported yield weights. Almond hulls specifically are marketed as a commodity on their own, along with the nut meats, and are reported separately by many, but not all, Central Valley counties. Due to the inconsistency of reporting between counties (some reporting only meats, some reporting all almond tonnage together, and some reporting hull and meat tonnage separately), the almond N harvest determined via use of the USDA crop nutrient tool and the methods outlined in Viers et. al. (2012) was not reflective of the actual amount of nitrogen removed from the field. Additionally, in the Viers (2012) database, nut meat N content was being attributed not only to reported meat weights, but to hull tonnage (when such tonnage was reported). Hull N content differs significantly from meat N content, although the literature lacks published values for average hull N content.

Recent studies however, have determined whole-tree N content partitioning in California orchards, including whole-nut N content based on kernel weight (Brown et al. 2013). Because the whole nut (including meats, hulls, and shells) is included, but is based on kernel weight alone, removing all reported hull yields from the database rectified the issue of inconsistent almond yield reporting between counties (i.e. meats, meats+hulls separately, or together). This also avoided the need to determine and apply a separate hull N content to calculate total N field removal. Similar nutrient portioning studies have been performed for both pistachio and walnut orchards in California (Weinbaum et al. 1991, Brown and Siddiqui, 2008). We chose to also utilize the average N content figures from these studies to determine actual field N harvest removal.

The dataset includes some discrepancies that were not addressed fully. Olive oil yields for example, are reported in different ways: in liquid units, as the weight of the olives used to create the oil product, and sometimes counties report the weight of all olives, used for both fruit and oil production. Summing these various weights together skews the yield calculations for the crop to be higher than actual. Additionally, olives grown for their fruit or for oil may have different N contents, and usually require different amounts of N fertilizer, which was not accounted for when applying average fertilizer rates to reported crop area. Olives are a relatively significant crop within the subtropical tree fruit group. To separate the accounting issues for olive harvest N rates from the better known rates of other subtropical fruit (mostly oranges), we retained the olive data but treated them separately in the analysis of crop groups to avoid representing the N harvest from the subtropical tree group as higher than actual.

Some vegetable crops are grown for either their fruit (or root) or for their seed (e.g. melons, carrots, etc.). The ACRs usually include harvest weights for fruit and seed individually. However, the crop area is most often lumped together. While calculated total N harvest calculations are clearly incorrect in many of these cases due to fruit N content being applied to both seed and fruit weights, we did not address this discrepancy, because vegetable seed crops account for a small area overall and we felt it more important to retain data for these crops. N content of seed products is not well known, and there is also uncertainty regarding how much of the fruit is removed from the field when the crop is grown for seed, how the extended maturity of the fruit may affect moisture and N percentages used in the calculation of the total N removal from the field, and the exclusion of the weight of the fruit weight in the reported seed yields. Cotton and alfalfa seed are usually not reported separately from the weight of the main crop, but where they are, similar issues present themselves. Seed crops are sometimes reported in miscellaneous categories as well (e.g. truck crops for carrots, field crops for cotton). We note that carrots show an abnormally high efficiency in our analysis, and a UCCE advisor familiar with the crop suggested the harvest rates reported in the ACRs were in his experience much lower than his estimation of 50-60 tons per acre (and furthermore suggested the application rate was much lower than used in our analyses).

6.2 Results and Discussion

N harvest from most crop groups has increased steadily since 1945 (Table 6.1), driven both by changes in area (see Task 4) as well as increased NUE (see Task 11). The drop in N harvest from cotton and other field crops is driven by shrinking production areas, whereas the dramatic increase in nut harvest is mirrored by large increases in harvested area. Overall N harvest increased by 27% from 1990 to 2005 alone. Across all crops in the central valley, the N harvest rate has increased from 69 kg/ha in 1945 to 144 kg/ha in 2005. Harvest rates in the TLB counties closely follow the overall CV rates in increase and scale, while harvest rates are the highest in the NSJV and lowest in the SCV valleys. This is due to primarily to crop distribution (see Task 4). Appendix Table 1 shows harvest rates and total harvest for each crop group within the central valley. Appendix Table 3 shows harvest rates for each crop for each period. Also see Table in Task 11 for regional harvest sums.

Table 6.1: Total harvest N (Gg) from crop groups, periods 1945-2005. Olive data have unreliable harvest figures. Each period is the mean of 5 years centering around the year shown. One Gg=1,100 tons N. See Task 9 for crop group classification.

Crop	1945	1960	1975	1990	2005
Alfalfa	73.1	121.8	105.5	108.3	136.9
Corn, Sorghum, Sudan	2.0	15.9	26.8	25.4	51.9
Cotton	6.0	20.6	29.0	38.6	23.3
Field Crops	4.7	15.0	19.1	19.1	6.8
Grain and Hay	17.0	32.1	46.6	44.4	60.4
Grapes	1.7	2.1	2.9	3.4	4.1
Nuts	1.8	4.1	11.9	23.5	46.9
Olives	0.5	0.8	0.8	1.6	1.3
Rice	4.0	7.8	13.3	18.4	25.2
Subtropical	0.6	0.5	1.4	2.2	3.6
Tree Fruit	1.4	1.7	2.5	3.3	3.2
Vegetables and Berries	5.2	8.5	12.7	20.7	29.1
Total (including alfalfa)	**118**	**231**	**273**	**309**	**393**
Total (not including alfalfa)	**45**	**109**	**167**	**201**	**256**

Among regions, overall crop yield is highest in TLB counties, where half of the crop producing area is located. Production in the SCV has not changed significantly since 1975, unlike the NSJV and TLB where production has continued to increase (Figure). While the total cropped area in the CV has remained relatively stable since 1975, changes in the distribution of individual crop areas (e.g. a general decline in field crops and increase in nuts and other permanent crops, see Table) is largely responsible for the increases in the total nitrogen harvested and applied, as well as increased nitrogen use efficiency (see Task 11).

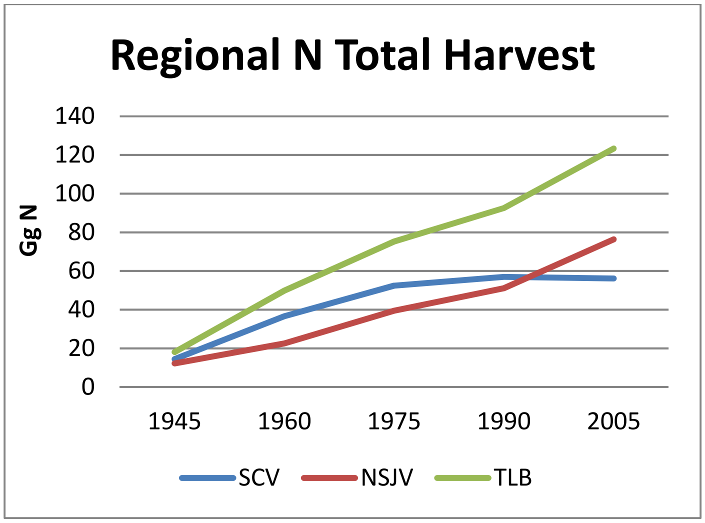

Figure 6.1: Regional change in total harvested N, 1945-2005. 1Gg = 1100 tons.

Not including alfalfa (which represents 35% of the study area N harvest), field crops (including cotton, corn and other field crops) represent over 30% of the remaining N harvest, followed by grain and hay at 24%, woody perennials at 23%, and with rice and vegetables and berries each representing 10% of the remaining N harvest within the study area. Regionally, the northern and southern valley differ, primarily due to rice production being concentrated in the north. In the SJV, excluding alfalfa (27% total N harvest), rice alone accounts for 40% of the remaining N harvest, with 20% from woody perennials and 15% each from grain and hay, and field crops, and the remaining 8% from vegetable production. In the southern valley, excluding alfalfa, field crops represent 37% of the remaining N harvest, about 25% each from woody perennials and grain and hay, with vegetables accounting for 15% of the remaining N harvest in the TLB and 7% in the SJV (where alfalfa represents 35% of the total harvest, compared to 25% in the TLB).

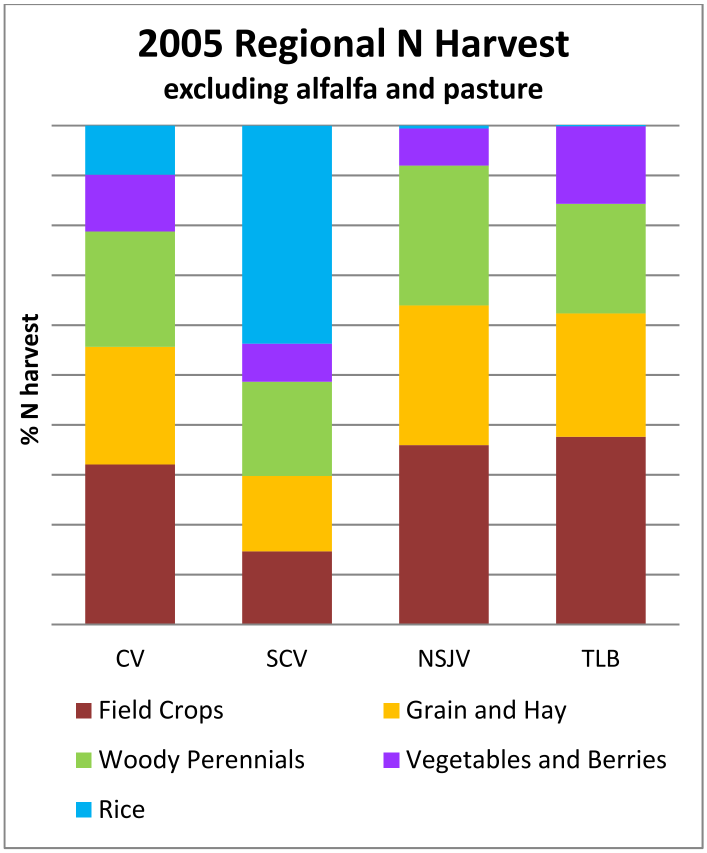

Figure 6.2: 2005 regional crop group percent of total N harvest, excluding alfalfa and pasture.

Task 7: Review literature on atmospheric deposition; historic and current, by air basin

7.1 Work Description

Atmospheric deposition is rarely measured continuously and wet deposition is monitored much more frequently than dry deposition. The most comprehensive network of sample sites is run by the National Acid Deposition Program. There are approximately 10 sites in California included in this wet deposition monitoring program, but individual researchers have expanded the spatial distribution of measurements. Because N deposition varies spatially, especially dry deposition, N deposition estimates at broader spatial scales are typically based on modeled data. The most widely used model, the Community Multiscale Air Quality (CMAQ) model, was developed by the U.S. EPA. This model combines N emission inventories with meteorological data to estimate N deposition. The highest resolution version of CMAQ for California is a 4 km grid (Tonnensen et al. 2007). This estimate was updated by Fenn et al. (2010) to take into account the fact that measured rates of deposition exceeded the rates predicted by the model.

We used the current and historic statewide emissions data from the California Air Resources Board to estimate historic and future N deposition. Historic and future NO_x deposition was based on NO_x emissions reported by the California Air Resources Board (ARB).[2] As the ARB estimates begin in 1975, we assumed a linear decrease to zero NO_x emissions going backward to 1900. If the current decreasing trend in NO_x continues, then by 2050, there will again be zero NO_x emissions. The past and future of NH_3 emissions is poorly delineated because NH_3 is not a criteria pollutant. Similar to past NO_x emissions, we assumed a value of zero NH3 emissions for 1900. However, we assumed a linear increase to the current day based on the continued growth of livestock populations.

7.2 Data

We prepared a GIS layers for the project area using these data, including the Tulare Lake Basin, the northern San Joaquin Valley and the Sacramento Valley. Atmospheric deposition of nitrogen is highest in the SJV and eastern TLB, mostly due to the high dairy animal densities in these regions. Atmospheric deposition in these regions exceed 10 kg N/ha/yr and sometimes can be higher than 20 kg N/ha/yr. In the SCV and westernmost portions of the SJV and TLB, atmospheric N deposition typically does not exceed 10 kg N/ha/yr (Figure 7.1).

[2] http://www.arb.ca.gov/app/emsinv/fcemssumcat2009.php

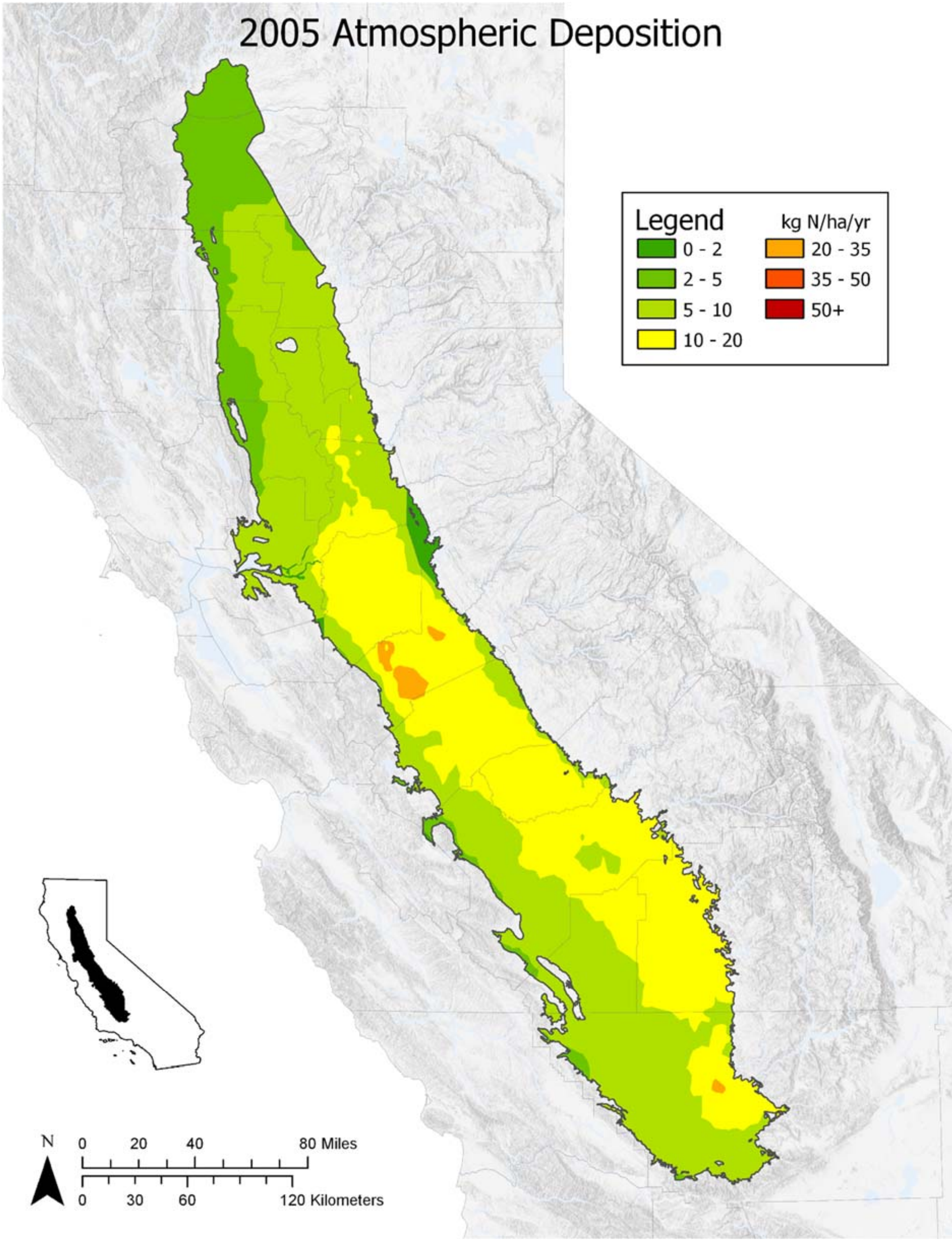

Figure 7.1: Nitrogen deposition in the Central Valley (Tonnenson et al., 2007; updated by Fenn et al., 2010).

Task 8: Quantify nitrogen volatilization and denitrification; develop an atmospheric loss rate as a function of major fertilization practices, irrigation practices, and major soil groups; historic and current.

8.1 Work Description

The rate of nitrogen gases emitted from agricultural fields (N_2, N_2O, NH_3, and NO_x) in California is not well constrained. For the field scale nitrogen mass balance in agricultural crops (Task 11), a default emissions factor of 10% of applied nitrogen to account for total gaseous emissions. The emission factor is derived from available data and reported as percentages of nitrogen applied:

- N_20: 1% The default emissions factor of direct field emissions used by the IPCC (De Klein et al. 2006).
- N_2: 1.8% This emissions factor is based on the average N_2:N_2O ratio reported in agricultural sites (Schlesinger 2009).
- NH_3: 3.6% Average emissions measured from 10 California fields (C. Krauter et al. 2009).
- NO_x: 2.1% Average emissions across 8 crops and 20 sites (Matson et al. 1997).

Based on these four fluxes, a total of 8.5% of applied nitrogen is emitted to the atmosphere as gas. Thus, the assumption to 10% is reasonable, if not conservative. N_{loss} on irrigated agricultural lands is estimated to be 10% of all input N, not only synthetic fertilizer or manure N:

$$N_{atmLoss} = 0.1\ N_{fertilizer} + 0.1\ N_{manure} + 0.1\ N_{WWTP\text{-}FP} + 0.1\ N_{atmDeposition} + 0.1\ N_{irrigation}$$

where $N_{fertilizer}$ refers to the amount of synthetic fertilizer nitrogen applied, N_{manure} refers to the amount of manure nitrogen applied, $N_{atmDeposition}$ refers to the rate of atmospheric nitrogen deposition, and $N_{irrigation}$ is the amount of nitrogen contained in irrigation water.

8.2 Results and Discussion

(See Sections 11.7 and 11.8 for Results and Discussion).

Task 9: Develop a unified crop classification scheme

9.1 Work Description

The various crop data sources used when calculating the mass balance and modeling of groundwater nitrate differ in their classification schemes. Rectifying these differences into a unified crop coding was necessary. We reviewed and modified our recently developed classification scheme (Viers et al., 2012), which combines each of the individual crops or crop groups utilized by the Department of Water Resources[3] (as in CAML), the USDA Crop Nutrient Tool, USDA National Agricultural Statistics Service categories and the Agricultural Commissioner Reports into a unified scheme.

9.2 Results

Table 9.1 shows the crops, crop groups, and DWR/CAML codes used for the data analysis. County agricultural commissioner reports used many more crop classifications, which were manually associated with one of the crops listed in Table 9.1.

Table 9.1: For some analyses and for data representation and visualization, crops were also grouped into crop groups, listed here, by crop and their corresponding code in the DWR and CAML landuse coverage.

Crop Group	DWR/CAML Landuse Code	Crop
Subtropical	300	citrus, pomegranates
Subtropical	301	grapefruit
Subtropical	302	lemons
Subtropical	303	oranges
Subtropical	305	avocadoes
Olives	306	olives
Subtropical	308	kiwi
Tree Fruit	400	persimmons, nuts (not walnuts, pistachio, or almonds)
Tree Fruit	401	apples
Tree Fruit	402	apricots
Tree Fruit	403	cherries
Tree Fruit	405	peaches, nectarines
Tree Fruit	406	pears
Tree Fruit	407	plums
Tree Fruit	408	prunes
Tree Fruit	409	figs
Nuts	412	almonds
Nuts	413	walnuts

[3] Note that the California Augmented Multisource Landcover layer used for the spatial analysis uses DWR classification

Crop Group	DWR/CAML Landuse Code	Crop
Nuts	414	pistachios
Field Crops	600	field crops
Cotton	601	cotton (lint and seed)
Field Crops	602	safflower
Field Crops	605	sugar beets
Corn, Sorghum, Sudan	606	corn (grain and silage)
Corn, Sorghum, Sudan	607	sorghum
Corn, Sorghum, Sudan	608	sudan
Field Crops	610	dry beans
Field Crops	612	sunflower
Grain and Hay	700	grain hay, straw
Grain and Hay	701	barley
Grain and Hay	702	wheat
Grain and Hay	703	oats
Pasture	1600	pasture
Alfalfa	1601	alfalfa
Pasture	1602	clover(pasture)
Rice	1800	rice
Vegetables and Berries	2000	truck crops
Vegetables and Berries	2002	asparagus
Vegetables and Berries	2003	beans (green)
Vegetables and Berries	2006	carrots
Vegetables and Berries	2007	celery
Vegetables and Berries	2008	lettuce
Vegetables and Berries	2009	melons, squash
Vegetables and Berries	2010	garlic, onions
Vegetables and Berries	2011	peas, green
Vegetables and Berries	2012	potatoes
Vegetables and Berries	2013	sweet potatoes
Vegetables and Berries	2014	spinach
Vegetables and Berries	2015	tomatoes, processed
Vegetables and Berries	2019	berries
Vegetables and Berries	2020	strawberries
Vegetables and Berries	2021	peppers (chili, bell)
Vegetables and Berries	2022	broccoli
Vegetables and Berries	2023	cabbage
Vegetables and Berries	2024	cauliflower
Grapes	2200	grapes (raisins, table, wine)

Task 10: Develop and test simplified methodology to account for year-to-year landuse changes (historic and future) in a GIS framework

10.1 Work Description: Data Sources

Historical landuse data preceding the 1990s has been compiled in tabular format, by county as part of Task 4. We developed and completed a spatio-temporal mapping algorithm that takes the tabular historic data and current GIS-based landuse maps to regenerate agricultural crop maps as far back as 1945. We have developed an approach to backcast past land use distribution based on current land use and changes in agricultural land use as reported in the county agricultural commissioner reports (Viers et al., 2012). The starting point is the 2010 California Augmented Multisource Landcover (CAML) (Hollander, 2007, 2010) and the equivalent 1990 digital landuse cover developed under Task 2 (Figures 2.2 and 2.3, respectively). We reviewed the backcasting technique that had been used to generate landuse maps for 1945, 1960, and 1975 as part of the SBX 2 1 report (Viers et al., 2012). The algorithm was improved and recoded, then applied it to the entire Central Valley, based on the data collected in Task 4.

Because our modeling of nitrate contamination of groundwater commences in 1945, well before the large-scale development of digital spatial datasets, it is necessary to combine a wide variety of information to model land cover over that entire time period. Effectively, digital spatial data becomes sparser the earlier one goes. Although there may be a paper cartographic record of a particular theme of interest extending well back in time, it is often uneconomic to digitize this record if one's project is extensive enough. For instance, in California, a primary source for mapped crop information is the Land Use Survey maps created by the Department of Water Resources (DWR 2011). Extensive paper archives of these maps exist and go back into the 1950s, but DWR did not start to directly create digital georeferenced maps of these surveys until 1986, with the bulk of the digital mapping commencing in the 1990s.

Table 10.1 provides an overview of agricultural land cover data availability in California by time period. In the contemporary period (circa 2005 for the nitrate project), there is a wealth of available data. The aforementioned DWR Land Use Survey maps are available as a set of vector-formatted maps that emphasize agricultural land cover classes with 15 m accuracy for the linework and with individual fields being delineated. These have been compiled on a county-by-county basis with a return interval of about seven years. Thematically these maps are quite detailed, broken down into about 95 different crop types and often containing information on irrigation type (DWR 2015). The Land Use Survey maps provided the primary source of crop location data for this project for the 2005 and 1990 periods.

Another important data source for current-day agricultural land cover in the United States is the National Agricultural Statistics Service Cropland Data Layer (Boryan et al. 2011, Han et al. 2012). This is a series of raster datasets derived from satellite remote sensing beginning in 1997, the land cover types being classified using decision tree algorithms. Spatial resolution is 56 meters or 30 meters depending upon the satellite used for the imaging. The diversity of cropping patterns in California poses difficulties for applying this dataset. Although major California crops such as rice, tomatoes, and almonds are

Table 10.1 - Data Sources For California Agricultural Land Cover Mapping

Dataset	Era	Geographical Extent	Notes
DWR Land Cover Mapping (digital)	1990-present	Most California counties	Detailed crop classification; counties remapped about every 7 years
NASS Cropland Data Layer	1997-present	Conterminous United State	Satellite remote sensing product; uncertain how applicable to complexities of California agriculture
National Land Cover Database	1992. 2001, 2006, 2011	United States	Landsat-derived product, coarse thematic resolution. Best at delineating broad land cover distinctions.
California Pesticide Use Reporting	1990-present	California	Database lists crop types where pesticides applied; spatial resolution 1-mile sections
USGS Land Use/Land Cover	1970s	United States	Vector product mapped using aerial photography; coarse thematic resolution
DWR Land Cover Mapping (paper)	1960-1990s	California agricultural counties	Extensive collections in archives but access difficult; mostly not scanned or digitized
Central Valley Historic Mapping Project	pre-1900, 1945, 1960, 1995	California Central Valley	Land cover digitized from paper map archives; does not distinguish agriculture from urban areas
USGS Topographic Mapping	1880s-present	United States	Good for ag/urban/natural vegetation distinction; scans of most historical maps available
County Agricultural Commissioner's reports	1940s-present	United States	Yearly reports of crop production and acreage available for most agricultural counties

mapped with high accuracy (i.e. >90% producer's and user's accuracy, according to the accuracy assessment in the dataset's metadata (NASS 2014)), specialty crops are mapped with relatively poor accuracy. Moreover, the focus of the Cropland Data Layer is on large area summer crops, with little capture of information on winter fruit and vegetable crops or multiple cropping patterns (Han et al. 2012). Accordingly, we made no use of the Cropland Data Layer in our land cover modeling.

The National Land Cover Database (NLCD) (Jin et al. 2013, Fry et al. 2011), first released for 1992 with subsequent editions covering 2001, 2006 and 2011, provides a synoptic overview of land cover in the United States. Based on Landsat imagery, it is spatially detailed at a 30 meter pixel resolution but thematically coarse, with only 20 land cover types in its classification system to cover all agricultural, urban, and natural vegetation categories. Its use in this project has been to help demarcate those three major land cover divisions, especially in the 1990 period when the digital versions of DWR Land Use Surveys are not available for certain counties of interest.

In the current era, a final spatial data source for crop information in California is given in the Pesticide Use Reporting (PUR) database collated by the California Department of Pesticide Regulation (California Department of Pesticide Regulation 2000). As a requirement of pesticide permits, farmers record application locations and dates with their county agricultural commissioner, who in turn reports these data to the Department of Pesticide Regulation. The PUR data include amounts and types of pesticides applied spatially located to the nearest one square mile section (260 ha), and include the crop type of application, listing about 207 different crop types. As this data is spatially quite coarse, it was used in this project to provide supplemental information about crop types, particularly in areas with poor coverage by DWR Land Use Survey maps, for instance in Santa Clara County which has never been mapped digitally by DWR.

Prior to the time period of the 1990s and later, there are no digital spatial data sources that give details of the locations of particular crop types. Rather, starting in the 1970s, the U.S. Geological Survey mapped land cover digitally to a broader thematic classification. This was the USGS Land Use Land Cover (LULC) map series (U.S. Geological Survey 1986), which was a vector product based on digitizing high-altitude aerial photography at 1:250,000 and 1:100,000 map scales. Thematically it breaks down land cover to the second level of the Anderson land cover classification system (Anderson et al.1976). Agriculturally this distinguishes orchards and vineyards from croplands and pastures but provides no further information on crop types. For this project the LULC maps were used to map in the 1970s era three major classes: agricultural lands, urban areas, and natural vegetation.

Very few digital map layers exist that give land cover information prior to the 1970s. The Department of Water Resources Land Use Surveys are illustrative. As discussed above, paper archival maps exist of these surveys going back into the 1950s, but very few of these have been digitized. In the Central Valley in particular, there was a project completed in 2003 that digitized a wide variety of historical vegetation records to document changes in natural vegetation over four time periods: pre-1900, 1945, 1960, and 1995 (Geographical Information Center 2003). In this project, this dataset was used to distinguish natural vegetation from developed lands for the 1945 and 1960 periods. One problem with this dataset was that because of its emphasis on natural vegetation, the compilers did not distinguish agricultural lands from urban areas. For the backcasting modeling, this lack necessitates a workaround.

One potential reference for distinguishing agricultural lands, urban areas, and natural vegetation in historic times is the archive of topographic maps produced by the U.S. Geological Survey since 1884. The USGS has recently embarked on the project of scanning and georeferencing the complete series of topographic maps and this work has been completed for many areas (Allord and Carswell 2011). Details on these maps are generally sufficient to distinguish these three major classes of land cover. However, to work with this information in a GIS context it is necessary to digitize these land cover distinctions from the scanned maps. Over a large enough area, such as the entire Central Valley, such an effort would be too time consuming.

Though it is not explicitly spatial, a key data source for this project was the set of annual reports published by each county's agricultural commissioner's office. These reports provide information pertaining to commodities produced in the county like crop type, harvested acreage, production and crop value. The purpose for using these data were twofold: 1) the production numbers for each commodity were used to help calculate the amount of nitrogen removed from the landscape during harvest; and 2) the harvested acreage numbers were used in the backcasting model to help spatially reconstruct historic cropping patterns and land use in the study area.

10.2 Work Description: Assembly of Land Cover Data

The backcasting algorithm requires three data items as input. The first is a recent digital land cover map that includes mapped crop patterns. The second item is a digital map for the historical period of interest classifying the landscape into three categories agricultural land cover, urban areas, and natural vegetation. The third item is the set of county agricultural commissioners' reports for the year of interest. Below is described details for producing each of these.

The first item, the digital land cover map, was assembled from 1990-era data (see Task 2). The second needed item was a layer for each of the 1975, 1960, and 1945 eras dividing the Central Valley region into the broad categories of agriculture, urban areas, and natural vegetation. For the 1975 era, this layer was simply extracted from the LULC vector maps covering the region. For the 1960 and 1945 eras, the Central Valley Historic Mapping layer was used to distinguish natural vegetation from developed lands. The method for distinguishing urban from agricultural lands within this layer differed depending on the phase of the project. For mapping the 4 Tulare Lake Basin counties as part of the SB2X 1 nitrate effort, urban boundaries were digitized from 7.5 minute USGS topographic maps, taking advantage of the long revision cycle of these products. For instance in one region of Tulare County, many of the quadrangles were last photo-revised in 1969, using a base that was originally published in 1951 from aerial photography taken in 1946. This 1946 date corresponds well to the 1945 time period of interest, and details from the 1951 base are often preserved in the current digital raster versions of the maps that are readily available online (e.g., http://www.atlas.ca.gov/quads/). To simplify digitizing, the urban boundaries in the 1970s era digital USGS LULC map were edited these to match the smaller urban extents in the 1950 era maps.

When this project was expanded north to the rest of the Central Valley, a different approach was taken to distinguish agricultural from urban areas in the 1960 and 1945 eras since digitizing every town would be too time-consuming. This method utilized a statewide spatial database of land parcels. One attribute in this database gives the most recent year a structure was built on a parcel, information which potentially can be used to establish neighborhood age and determine urban growth boundaries. This attribute was used in the following method to create layers showing urban change from 1945 to 1960 and 1960 to 1975. First, a list of the year-built dates across all 13.1 million parcels in the state was reviewed to make obvious corrections. Second, each parcel was tagged with its enclosing census block boundary. These correspond well to actual city blocks and provide a good coarser-scale geography by which to aggregate parcel dates. Third, an approximate neighborhood age was calculated for each census block. Because the oldest structure in a block may be too much of an outlier to adequately represent neighborhood age, the value for the 12.5th percentile of the list of year built dates was assigned as the census block age. The census block map was then queried by this age attribute to extract binary layers showing where census blocks were built up from 1945 to 1960 and from 1960 to 1975. Data manipulation was performed using a combination of PostGIS, QGIS, and R: in particular R was used to calculate aggregated built dates at a specific percentile value.

The final data item used as input into the backcasting was the set of tables of county crop reports. To gain a better understanding of what the typical agricultural land use was within each county for each of the time periods represented by the specific target years, two years both preceding and succeeding the target year were included in the analysis. For example, the average agricultural land use for target year 1945 also includes crop data from years 1943, 1944, 1946 and 1947. Where available, crop report data for each county within the target years were downloaded from each county's Agricultural Commissioner's webpage. For counties whose ACR data were not available online, paper copies were obtained through Shields Library at UC Davis, and electronically scanned and saved as in PDF document format. Crop data from these reports were compiled into a spreadsheet with the following columns:

year
crop name
DWR Land Use Survey code
NASS commodity code
total ground acreage
total harvested acreage
total non-harvested acreage
production unit
production per acre

The above data (except DWR land use code and NASS commodity code) were entered directly from the crop reports using both manual and optical character recognition methods. A visual comparison between the crop report spreadsheet and the .pdf version was performed at this time and any identified errors were corrected. Once standardized, each of the spreadsheets was aggregated into one multi-year spreadsheet representing each county. The data were sorted by agricultural crop, and commodities were first combined by assigning the appropriate commodity code used by the National Agricultural Statistics Service (NASS). We further narrowed the number of commodities by matching each NASS commodity code to a DWR land cover code (via a lookup table). For each county for each year, the acreage and production were calculated for each DWR land cover representing a crop. The median crop acreage for each era (1945, 1960, and 1975) was used as the area of each crop in a county for the backcasting algorithm.

10.3 Work Description: Backcasting Algorithm

With the three elements described above — a historical map layer demarcating agricultural, urban, and natural lands, a table giving historical crop areas, and a more recent layer that maps individual crop patterns to serve as a template — we are able to run the backcasting algorithm to model the spatial patterns of the crops in the historical period. Detailed steps for the algorithm are listed in Table 10.2. This algorithm works as follows: from the earliest period for which we have a digital map of crop locations (1990) we compared the total area for each crop in that year and in our historic target period (for example 1945). There are two resultant possibilities, where either the area in the historic period is less than or equal to the area in the 1990 period, or it is greater than the area in 1990. The algorithm uses the mapped recent pattern of each crop as a spatial core for modeling the historical pattern. If the historical area is less than the recent area, the crop pattern is shrunk from its recent core to match historical area. Conversely, if the the historical area is greater than the recent area, the crop pattern is expanded from its recent core.

In the first phase of the algorithm we considered all crops where the historic area is less than or equal to the 1990 period. Proceeding crop-by-crop, we deallocated crop pixels so as to reduce the 1990 total area to the reported total for the earlier year. Within each crop, we chose pixels for deallocation based upon the distance from centers of distribution of each crop considered. This distance was calculated by running a circular kernel summary filter over a binary presence-absence map of the particular crop, a procedure that results in the highest values at the center of distribution, with the sums diminishing as the distance increases from the center. Crop pixels are then deallocated in descending order by distance, so as to reduce the area of the crop to the area in the historic period. A small random value was added to each pixel in the distance map to allow for tie-breaking in the distance determination if needed. The rationale for this approach, rather than simply adjusting area by randomly deallocating pixels, was that locations in which neighbors grow the same crop probably attract further increases in area, due to some combination of attractive growing conditions, access to water, processing, or transport, or perhaps simply social facilitation through experience and personal influences. As the adjusted distribution for each crop was determined, the binary raster representing the crop distribution was inserted into an initially empty raster layer that served as an accumulator raster using “or” logic.

In the second phase of the algorithm, we considered the crops where the area is greater in the historic period than the 1990 period. Proceeding in crop-by-crop order from most to least area in the historic period, we reallocated “deallocated” pixels so as to unify the area total for the historic period for that crop. This reallocation proceeds outwards in distance from pixels of each crop in 1990. That is, pixels adjacent to the 1990 fields were allocated first, then the next closest pixels are allocated, and so on, until the allocated acreage matches the historic acreage. This method of reallocating pixels was intended to preserve spatial patterning of crop types, and should be more realistic than random

Table 10.2 - Steps in backcasting algorithm (r.historiclc Python script for GRASS)

1.		Read in parameters and names of input files
2.		Get area of current land cover by type and store in a dictionary.
3.		Spatially filter current land cover by historic agricultural area and save as temporary layer
4.		Determine area of temporary layer in step 3
5.		Read in list of land cover types
6.		Read in table of historic land area
7.		Create a (initially empty) list for "decliners" - land cover types that have less area historically than presently
8.		Create a (initially empty) dictionary for "gainers" - land cover types that have more area historically than presently
9.		Create an initially empty raster layer to store modeled historic crop distribution
10.		Loop through list of all land cover types, compare present area to historic area from table, determine whether a gainer or a decline, if a gainer put historic area in dictionary keyed by land cover
11.		Create sorted list of gainers in reverse order by area (i.e. biggest gainer comes first)
12.		Loop over decliner list. For each decliner:
	12.1	Determine difference between historical area and current area
	12.2	Create a binary raster ("currcrop") of the distribution of the current crop
	12.3	Run a kernel filter over currcrop to sum up density of crop pixels
	12.4	Normalize this summed density to create raster scaled 0 to 1
	12.5	Create a random raster with values uniformly distributed between 0 and 1
	12.6	Add to the density raster the random raster weighted by factor giving relative contribution of randomness
	12.7	Sort a list of all pixel values of layer generated in 12.6
	12.8	Loop over this list, determine cut level where summed area of pixels is greater than decline amount
	12.9	Filter layer from 12.6 by removing pixels whose value is greater than the cut level
	12.10	Use pixel-by-pixel "or" logic to append the raster from step 12.9 to the accumulating raster created in step 9
13.		Now loop over "gainer" crops in reverse area of importance
	13.1	Determine difference between historical area and current area
	13.2	Create a binary raster ("currcrop") of the distribution of the current crop
	13.3	Run a kernel filter over currcrop to sum up density of crop pixels
	13.4	Normalize this summed density to create raster scaled 0 to 1
	13.6	Add to the density raster the random raster weighted by factor giving relative contribution of randomness
	13.7	Sort a list of all pixel values of layer generated in 11.7
	13.8	Loop over this list, determine cut level where summed area of pixels is greater than decline amount
	13.9	Filter layer from 11.7 by removing pixels whose value is greater than the cut level
	13.10	Use pixel-by-pixel "or" logic to append the raster from step 12.10 to the accumulating raster created in step 9

reallocation. This step of the algorithm was processed on a pixel basis rather than using the field boundaries provided by the DWR land use maps. Although a per-field basis crop allocation might better reflect actual crop patterning for the simulated time period as compared to the employed per-pixel basis, doing so would have complicated the algorithm enormously. Just as in the first phase of the algorithm, as each crop distribution was reallocated, the binary raster representing the crop distribution was added to the accumulator raster already present from the first phase of the algorithm. Once all crops have been considered, the accumulator raster contains the modeled crop distribution for the historic period.

10.4 Work Description: Extension of Backcasting Methods to Central and Northern Central Valley

The 1990 land cover layer for the San Joaquin Valley counties was assembled in two stages: first, the Tulare Lake Basin counties were collated under the SB2X 1 nitrate project; second, the additional counties in the San Joaquin Valley were assembled as part of the San Joaquin Valley Greenprint project in spring of 2013. In a third additional phase in 2014 this 1990 land cover map was extended to the counties in Sacramento Valley. Three input layers went into this processing. First, the 1992 National Land Cover Database (NLCD), a raster layer at 30 meter resolution, was used to distinguish between agricultural, natural vegetation, and urban land cover areas. Second, areas of natural vegetation in NLCD were assigned land cover classes from pixels in the FRAP dataset. Third, areas marked as agriculture in NLCD were assigned land cover classes from the DWR land cover mapping, using the land cover code assignment already used in CAML 2010. The DWR map for each county was selected from the one closest in time to 1990 from the list of all maps for each county; these ranged from 1989 for Yolo County to 1998 for Sutter County, with the median year being 1994. The output for this processing was a set of raster layers by county at a 50 meter pixel resolution. These layers were then patched together to form a single 1990-era raster land cover map for the Central Valley counties.

Because running the backcasting algorithm requires agricultural areas to be delineated from urban and natural vegetation areas, it is necessary to have layers distinguishing these for each time period of the backcasting. For the era of the 1970s, digital land cover mapping is available from the U.S. Geological Survey through their Land Use and Land Cover (LULC) mapping program which ran at that time. This distinguished 21 different land cover classes at a mapping scale of 1:250,000. The 19 LULC data tiles that covered the Central Valley counties were downloaded from http://water.usgs.gov/GIS/dsdl/ds240/index.html and merged together to form a single vector layer. This vector layer was then rasterized at a 50 meter pixel resolution using the land cover code in the layer's attribute table as the raster value for each pixel. Pixels in this raster layer were then assigned to natural vegetation, agriculture, or urban based upon their land cover code. This new raster layer provided the agricultural/natural vegetation/urban base layer for the 1975 period backcasting.

For the 1945 and 1960 periods, there is no single digital map source that distinguishes between agriculture, natural vegetation, and urban regions. The Central Valley Historic Mapping Project (Geographical Information Center 2003) from the California State University, Chico used historic maps to identify different types of natural vegetation in the Central Valley for four different time periods, but the maps created by this project do not distinguish between agricultural and urban land uses, treating these all as developed lands. In other words, these maps do not portray the history of urban growth.

One approach to capturing urban boundaries in the 1945 and 1960 time periods is to digitize these boundaries off historical topographic maps. Across the entire Central Valley, this method would be too time-consuming, so another approach was sought. This involved working with a statewide spatial database of land parcels. One attribute in this database gives the most recent year a structure was built on a parcel, information which potentially can be used to establish neighborhood age and determine urban growth boundaries. This attribute was used in the following method to create layers showing urban change from 1945 to 1960 and 1960 to 1975. First, a list of the year built dates across all 13.1 million parcels in the state was reviewed to make obvious corrections (e.g. changing "97" to "1997" or "1801" to "1901"). Second, each parcel was tagged with its enclosing census block boundary. These correspond well to actual city blocks and provide a good coarser-scale geography by which to aggregate parcel dates. Third, an approximate neighborhood age was calculated for each census block. Because the oldest structure in a block may be too much of an outlier to adequately represent neighborhood age, the value for the 12.5th percentile of the list of year built dates was assigned as the census block age. The census block map was then queried by this age attribute to extract binary layers showing where census blocks were built up from 1945 to 1960 and from 1960 to 1975. Data manipulation was performed using a combination of PostGIS, QGIS, and R: in particular R was used to calculate aggregated built dates at a specific percentile value. One difficulty is that the parcels for Yolo and Colusa counties lack built date information due to the reluctance by these counties to share this information. Since there are only several towns in each of these counties, their changes in urban extent were digitized from historic topographic maps.

10.5 Results: Backcasting Landuse for the 1945, 1960, and 1975 Periods

After the agricultural/natural vegetation/urban layer for the entire Central Valley was assembled using the methods described above, the backcasting algorithm outlined above was run for the central and northern Central Valley counties. These runs were checked by comparing the county-by-county crop totals from the backcasting runs with the tables for the county crop production. There was good agreement throughout, the one exception being totals for Yolo County in 1960, where the area of crops to be allocated exceeded the available agricultural area as mapped above. Recalling that there was significant amounts of dryland barley production in Yolo County in that time period, a fix for this problem was to expand the agricultural areas in the agricultural/natural vegetation/urban layer for the county by including relatively large grassland areas (> 175 ha) as areas with potential agriculture.

Results of the backcasting, with crops grouped for readability, are shown in Figure 10.1 – 10.3.

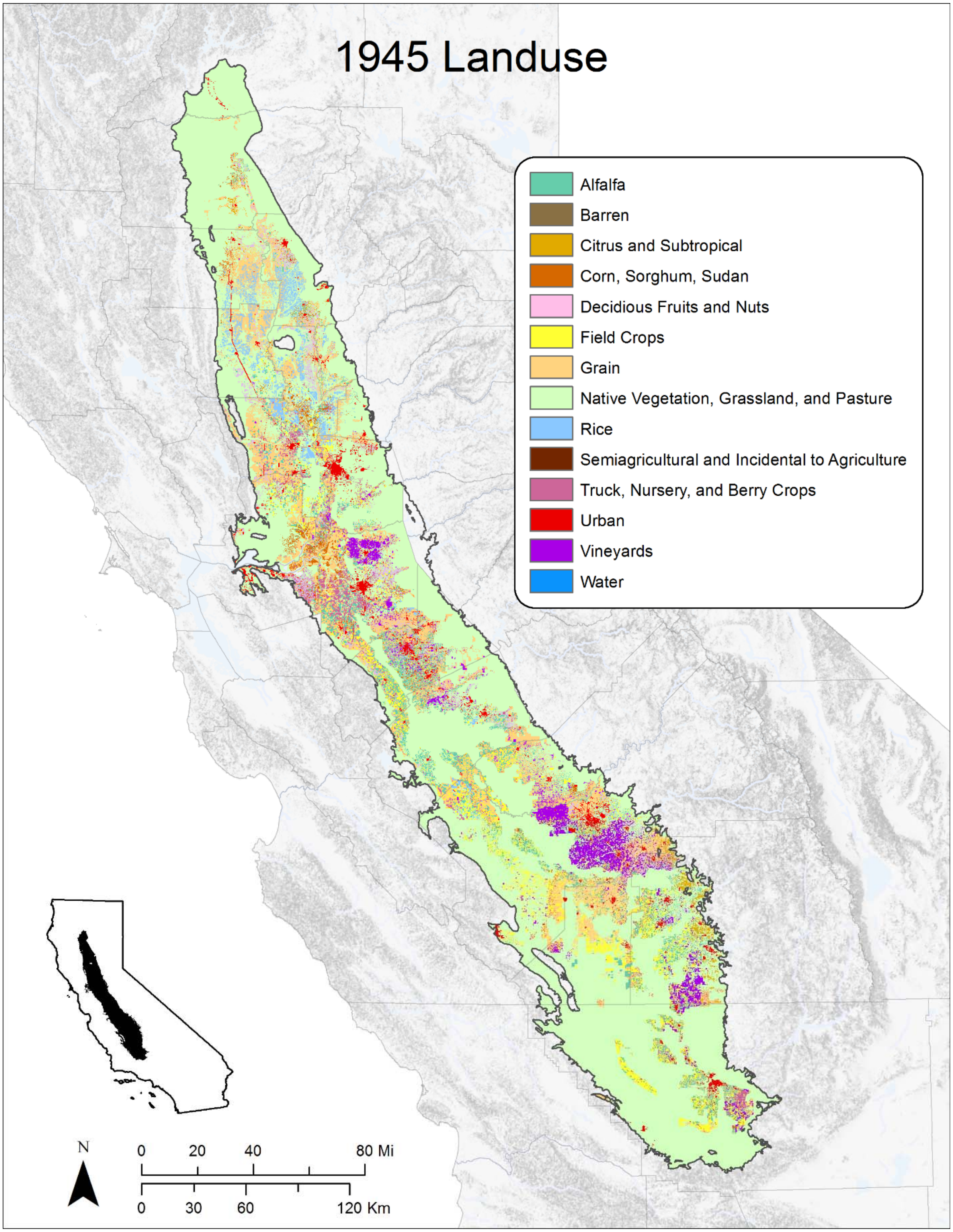

Figure 10.1: 1945 landuse map obtained through back-casting of CAML, county agricultural commissioner reports, and other information.

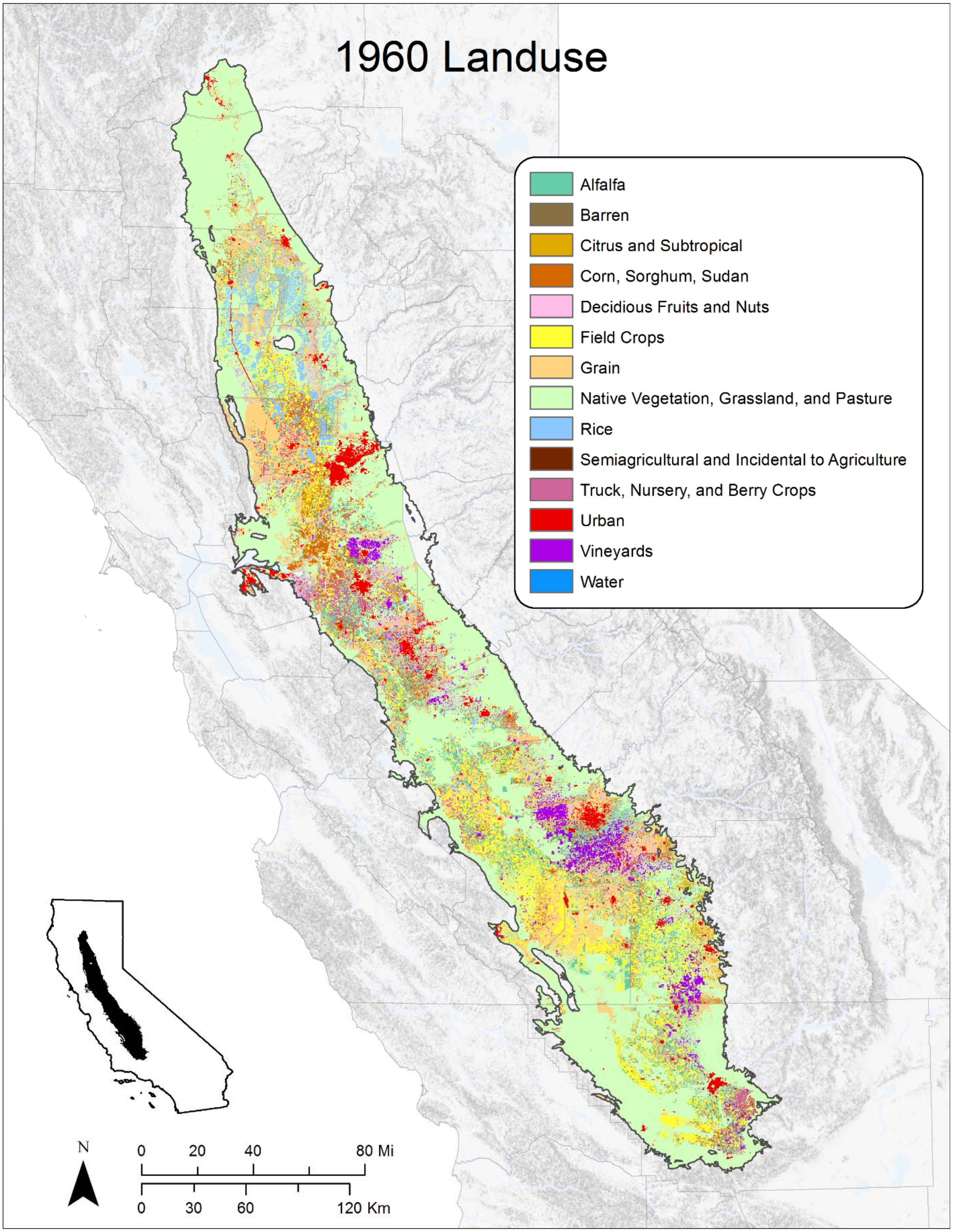

Figure 10.2: 1960 landuse map obtained through back-casting of CAML, county agricultural commissioner reports, and other information.

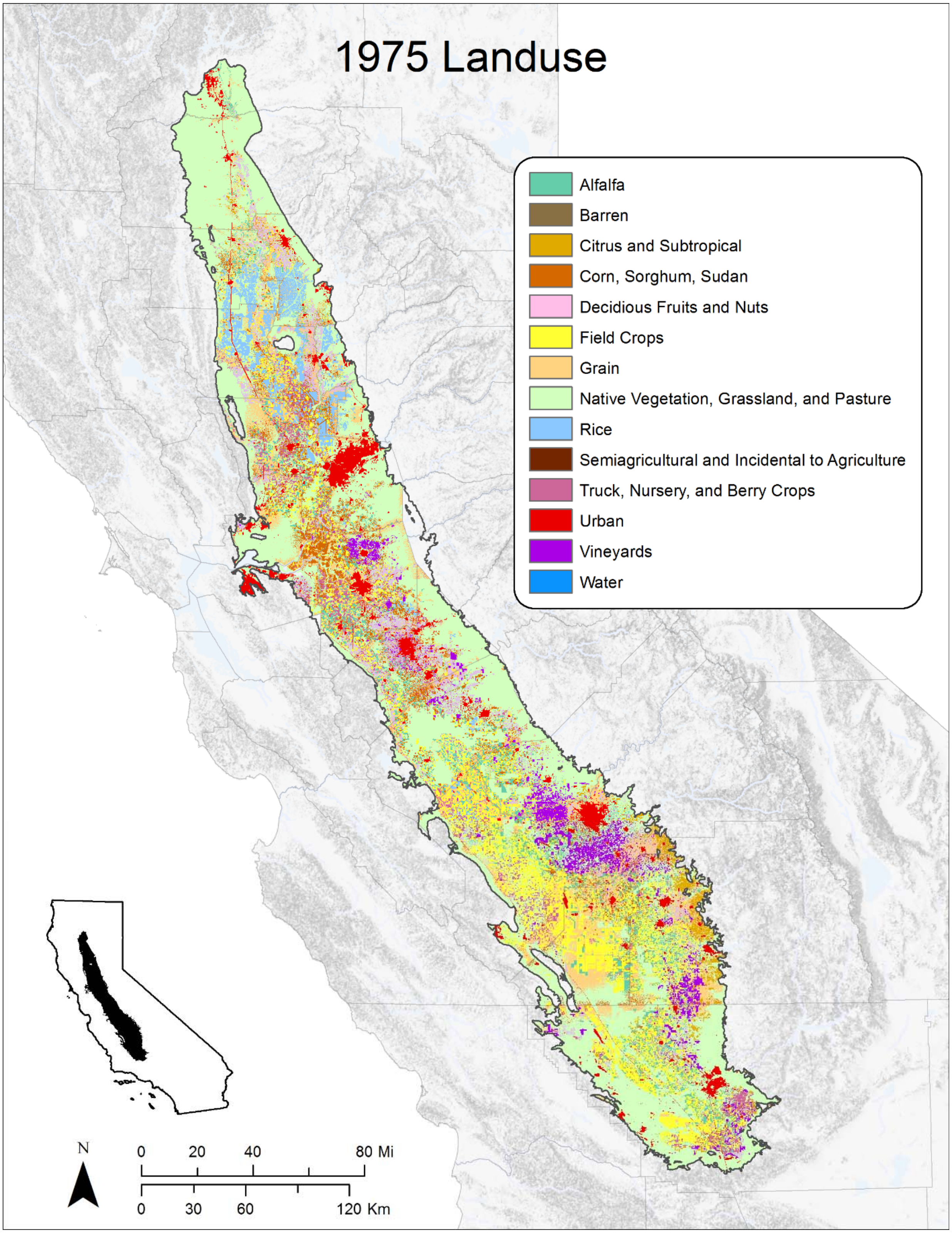

Figure 10.3: 1975 landuse map obtained through back-casting of CAML, county agricultural commissioner reports, and other information.

Task 11: Implement field nitrogen balance and estimate historic and current potential groundwater nitrate loading

11.1 Introduction

For this project, we performed a mass balance analysis to determine the net annual average nitrogen mass flux from the land surface or – where plants are present – from the bottom of the root zone to groundwater. The mass balance analysis is conceptually the simplest of the various methods under the second category of assessment methods (computer-based methods, see Introduction). It is a zero-order, lumped approach in that the analysis is zero-dimensional and aggregates nitrogen mass fluxes into and out of a specific control volume at the scale of the entire control volume. Within the control volume, the methodology does not explicitly simulate processes affecting the fate and transport of nitrogen. It is a conceptually simple accounting method, whereby a control volume is considered to be an “account”, annual nitrogen inflows from various sources of processes are added to the “account” and annual nitrogen outflows from the control volume are subtracted from the “account”.

We perform mass balances at several spatial aggregations and using a variety of datasets. This chapter provides descriptions of the methodological approaches employed and presents the results of the mass balance analyses to illustrate the nitrogen fluxes in the Central Valley landscape and the potential nitrate leaching to groundwater. Results of this chapter illustrate the contribution of synthetic nitrogen fertilizers to potential groundwater nitrate loading, relative to other source of nitrogen in the agricultural, urban, and natural landscape that potentially lead to groundwater nitrate loading.

11.2 Work Description: Estimating Potential Nitrogen Loading to Groundwater from Crops and Other Vegetated Non-Urban Landscapes

11.2.1 Mass Balance Approach for Vegetated Landscapes

In this work, we consider the mass balance of nitrogen in a control volume (black box) that vertically spans from approximately 6 feet below the land surface (bottom of the root zone, where present) to the land surface (at the top), and includes crops or plants growing at the land surface. For any given time period, and across any given horizontal extent of the control volume, the mass balance equation for nitrogen flux into and out of the control volume is expressed as:

$$\Delta NStorage = NInputs - NOutputs$$

where:

$$NInputs = N_{deposition} + N_{irrigation} + N_{synthetic} + N_{landApplied} + N_{manureSale}$$

$$NOutputs = N_{harvest} + N_{runoff} + N_{GW\_nondirect} + N_{AtmLosses}$$

$$N_{landApplied} = N_{manure} + N_{WWTP\text{-}FP}$$

ΔNStorage: change in total mass of N within the control volume over the time period of interest

$N_{deposition}$: atmospheric deposition of nitrogen

$N_{irrigation}$: application of nitrogen contained as nitrate in irrigation water

$N_{synthetic}$: application of synthetic fertilizer nitrogen

N_{manure}: application of dairy manure nitrogen (only on lands managed by dairies)

$N_{WWTP\text{-}FP}$: application of wastewater effluent nitrogen from treatment plants and food processors

$N_{manureSale}$: application of (solid) dairy manure nitrogen exported from dairy facilities

$N_{harvest}$: nitrogen removed with harvest

N_{runoff}: nitrogen removed by runoff

$N_{GW\_nondirect}$: nitrogen leached to groundwater from vegetated or cropped land areas

$N_{AtmLosses}$: nitrogen lost to the atmosphere via denitrification or volatilization

For golf courses, alfalfa (the most prominent legume crop in the Central Valley), and non-vegetation land uses, we did not perform the above explicit root-zone/landscape mass balance. Instead, source-specific mass balance computations or direct evidence of nitrogen losses to groundwater are considered to determine the magnitude of potential nitrogen leaching to groundwater, N_{GW_direct}. These sources include:

- Leguminous crops: Alfalfa, clover
- Domestic septic systems
- Urban areas including fertilized lawns, leaky sewer lines, and golf courses
- Wastewater percolation ponds associated with wastewater treatment plants and food processors
- Dairies: Liquid manure holding ponds and animal holding (corral) areas

Some of the above sources divert wastewater for application on agricultural crops, namely some wastewater treatment plants and food processors and most dairy facilities. Application of wastewater effluent and dairy manure is typically integrated into the nutrient management activities on crops. Later sections of this chapter will explain in more detail the estimation methods used to estimate nitrogen leaching to groundwater, N_{GW_direct}, from these sources and also how the amount of N is estimated that is applied to agricultural crops (N_{manure_sale}, and N_{WWTP_FP} in the above landscape nitrogen budget equation).

11.2.2 Time Period of Interest, Temporal Discretization

For this investigation, the period of interest is from the mid-20th century to current. Specifically, we consider the period from 1942 to 2007, a 65-year period divided into five periods centered around years 1945, 1960, 1975, 1990, and 2005 and referred to as periods “1945”, “1960”, “1975”, “1990”, and “2005”. Unless otherwise specified, these specific years in this report refer to the 15 year period rather than the specific year (see Task 1).

The fate of fertilizer and other nitrogen compounds at the land surface and in the root zone of crops is subject to changes that may occur within very short periods of time (seconds to hours) or over very long periods of time (weeks, months, or years). Short-term nitrogen fate and transport processes in the environment may strongly control it’s long-term fate and presence within a given control volume, especially the soil-plant environment.

It may therefore seem important to capture many of these rapid nitrogen processes at the land surface with some detail. However, groundwater wells in the Central Valley – smaller, mostly shallow domestic supply wells and larger municipal and agricultural water supply wells – typically have screen lengths of several tens if not hundreds of feet. Groundwater entering the well screen is composed of water of different ages (time period since recharge): In the Central Valley aquifer system, water entering the well in the deepest screen sections is typically at least couple of years, if not many decades older than water entering the well in the shallow-most part of the well screen. Within the well, this water is typically thoroughly mixed before being delivered to the tap or water quality sampling point. The mixing of water of different ages within the well dilutes potential spikes of pollutant concentration that occur, e.g., in the shallowest part of the screen section (Horn and Harter, 2009; Viers et al., 2012; Gailey, 2017).

For pollutants that are present in groundwater at several orders of magnitude above their regulatory limits, dilution is a poor control mechanism to attenuate the pollutant signature in the final mixed water delivered by the well. The main nitrogen compound in groundwater, nitrate, however, is typically present at background concentrations that can be as high as 1-2 mg N/L. The regulatory limit of 10 mg N/L (for drinking water purposes) is less than one order of magnitude above such background levels. Typical nitrate pollution found in groundwater due to fertilizer and other source typically ranges from 10 mg N/L to as much as 50 mg N/L, in few cases as high as or exceeding 100 mg N/L. Mixing within a well therefore has significant potential for attenuation of higher concentration spikes that occur over only a small fraction of the total inflow to the well screen.

Because wells mix water of varying recharge age (spanning typically several years to decades), an accounting of nitrogen dynamics at temporal scales of less than one year is not necessary to understand potential impacts to groundwater users, as long as total nitrogen fluxes, including short-term spikes are integrated into the mass balance and accounted for. For this work, we therefore consider the annual (one-year) nitrogen fluxes into and out of a control volume, averaged over a 15 year period. This greatly simplifies the accounting of nitrogen fluxes as nitrogen storage changes and nitrogen flux variations at temporal scales of less than 15 years are accounted for implicitly, but their specific temporal dynamics do not need to be predicted.

Given that, at the scale of the Central Valley, no significant measurable increases in soil organic matter have been recorded over the past 65 years, and neglecting potential overall decreases in soil organic matter (leading to nitrogen leaching and emissions), soil nitrogen storage change over the 65 year period of this assessment and over each of the five 15 year periods of assessment is conservatively considered to be negligibly small:

$$\Delta \text{NStorage} = 0$$

It then follows that, for the 15 year averaging period:

$$\text{NInputs} = \text{NOutputs}$$

Substituting the individual nitrogen flux terms into the above mass balance equation and re-arranging, we obtain the following equation for the potential nitrogen loading to groundwater:

$$N_{GW\_nondirect} = N_{deposition} + N_{irrigation} + N_{synthetic} + N_{landApplied} + N_{manureSale} - N_{harvest} - N_{runoff} - N_{AtmLosses}$$

All the terms on the right-hand side of the above equation have been estimated for the Central Valley at various spatial scales over the period of interest (mid-20th century to early 21st century). The above equation is then used to estimate potential groundwater nitrate-N loading.

11.2.3 Area of Interest, Spatial Discretization: The Control Volume

Our area of interest is the area overlying the Central Valley aquifer system, which underlies the floor of the Central Valley. The extent of the Central Valley aquifer system is defined by the California Department of Water Resources (CDWR) Bulletin 118. While the boundaries have recently been slightly modified (CDWR, 2016), we use the Bulletin 118 (2003) boundaries for this assessment. The Central Valley is here defined to include the Redding Area basin (5.06), the Sacramento Valley basin (5-21), several basins surrounding the Sacramento-San Joaquin Delta (Suisun-Fairfield Valley, 2-03, Pittsburg Plain, 2-04, Clayton Valley, 2-05, Ygnacio Valley, 2-06, and Arroyo del Hambre Valley, 2-31), and the San Joaquin Valley basin (5-22).

The area of interest intersects with 20 counties that we group into 3 regions (also see Task 1):

- Sacramento Valley (SCV):
  - Butte
  - Colusa
  - Glenn
  - Placer
  - Sacramento
  - Shasta
  - Solano
  - Sutter
  - Tehama
  - Yolo
  - Yuba
- (Northern) San Joaquin Valley (NSJV or SJV):
  - Contra Costa
  - Madera
  - Merced
  - San Joaquin
  - Stanislaus
- Tulare Lake Basin (TLB):
  - Fresno
  - Kern
  - Kings
  - Tulare

We perform the mass balance at several different horizontal scales of the control volume and over all control volumes overlying the Central Valley aquifer system:

- 50 m x 50 m scale ("raster cell" or "pixel" scale), which corresponds to the resolution of landuse and crop cover in the CAML landuse map of the Central Valley

- County
- Region
- Central Valley
- All lands belonging into a specific group of agricultural crops ("crop group"), within a county, region, or within the Central Valley (see Task 9)

11.2.4 Landuse Maps

The mass balance analysis is performed separately based on two different sets of data describing the amount of land area occupied by the specific crops listed in Table 9.1: one mass balance is computed for the land area of each crop reported in the county agricultural commissioner reports (ACR), and another mass balance is computed for the land area using CAML mapped areas, which includes all agricultural landuses but also various urban, industrial, and natural landuses. CAML is based on a 50 m (164 ft) rasterization of vector maps. A raster cell belongs to the landuse area located at the center of the raster cell. Boundaries of individual agricultural fields are therefore represented only to the nearest 50 m raster cell boundary, which leads to small errors in the total area reported for each crop within counties, groundwater basins, or regions, when compared to the original DWR maps used for generating CAML.

The ACR crop acreage data are collected independent of the 2005 and 1990 DWR landuse surveys that are contained in CAML. ACR data used represent averages for the 5 year periods, whereas CAML data represent snapshots of landuse at the time of the DWR landuse survey. This leads to sometimes significant differences in the total county acreage of individual crops (Viers et al., 2012). Importantly, the ACR provides total acreage, but not the location of a crop within a county. Hence, the ACR-based mass balance approach is used only at the county, region, and Central Valley scale, by crop and by crop-group. Only the CAML based mass balance analysis is performed at all spatial scales listed above.

The landuse maps described in Tasks 2 and 10 provide basis for the 50 m raster-scale mass balance analysis. Several sources of potential groundwater nitrogen loading were mapped separately from the CAML based landuse maps. Additional GIS layers that were generated as part of our work include percolation basins and land application areas associated with wastewater treatment plants (WWTPs) and food processors (FPs), dairy corrals (animal holding areas), dairy manure lagoons, dairy cropland used for liquid and solid manure applications, golf courses, and urban areas, all mapped across the entire Central Valley. The specific mapping methods are explained in the landuse specific sub-sections under this Task chapter.

The mapped location of these landuses reflect the 2005 period, but are used in raster-based simulations unaltered in all other periods as well. Significant additional digitization efforts will be needed in the future to account for historic changes in the spatial extent of specific landuses. The only exception to this approach is "urban" landuse, which is mapped separately for each period. Simulated landuse areas (land application areas for some dairies, all WWTPs, all FPs, and all biosolids applications) are using the facility specific application area total for the 2005 period, but the simulated location of the area changes based on period-specific agricultural land distribution (simulated areas are simulated separately for each period). The subsections for each of these landuses below explain how historic potential nitrate loading to groundwater was adjusted to account for historic changes in human and animal population in the Central Valley.

Some of these individual landuses may overlap (e.g., “golf course” may overlap with “urban”). For raster-scale nitrogen flux simulations, individual pixels with overlapping landuses are only assigned one landuse. The highest priority ranking landuse in the following list of GIS maps is assigned to raster pixels that match multiple landuses. Pixels that do not belong in any of the special landuse classes listed here are assigned their CAML landuse category, in any given period:

1. mapped percolation basins (2009 aerial imagery)
2. mapped dairy manure lagoons (not used in the 1945 and 1960 period) (2009 aerial imagery)
3. mapped dairy corrals and animal holding areas (not used in the 1945 and 1960 period) (2009 aerial imagery)
4. mapped dairy and dairy cropland areas (not used in the 1945 and 1960 period) (2011/2012 assessor’s parcel numbers reported to the Central Valley Regional Water Board)
5. mapped golf courses (2010 CAML)
6. mapped urban (separately for 1945, 1960, 1975, 1990, 2005)
7. simulated dairy cropland areas for dairies with no spatial information (not used in 1945 and 1960; separately simulated for 1975, 1990, 2005)
8. simulated WWTP effluent application areas (separately for 1945, 1960, 1975, 1990, 2005)
9. simulated FP effluent application areas (separately for 1945, 1960, 1975, 1990, 2005)
10. simulated biosolids application areas (separately for 1945, 1960, 1975, 1990, 2005)
11. all others: CAML landuse (separately for 1945, 1960, 1975, 1990, 2005)

11.3 Work Description: Nitrogen Leaching from Leguminous Crops: Alfalfa and Clover

We do not apply the mass balance approach to estimate nitrogen leaching from alfalfa (CAML code 1601) and clover (CAML code 1602). The largest nitrogen flux into these legume crops is the amount of nitrogen fixed by bacteria from atmosphere within the root zone of alfalfa. The uncertainties in the amount of N fixation by these legume crops relative to harvested nitrogen, and relative to (small amounts of) fertilizer nitrogen (synthetic or manure) applied, is too uncertain to arrive at reasonable N leaching estimates. Rather, we used field measurements of N leaching from alfalfa, reported in the literature, as the final estimate of groundwater N leaching from alfalfa and clover fields. Specifically, we used a reported value of 30 kg N/ha/yr (27 lb N/ac/yr) (Letey et al., 1979; Robbins et al., 1980). Manure is typically not applied to fields growing alfalfa except an unknown amount of solids that is sometimes applied prior to planting or after the last cutting in the fall. Little is known about nitrate leaching from alfalfa, which is most often grown in rotation with other field crops (corn, winter grain), particularly near dairies. More research is needed to better understand the potential, if any, of alfalfa leaching to groundwater under various management practices. The approach used here is largely the same as that used by Viers et al. (2012), where it was applied to the Tulare Lake Basin and the Salinas Valley.

11.4 Septic Systems

11.4.1 Introduction

Septic systems, in the technical industry also referred to as onsite wastewater treatment systems, are designed to treat domestic wastewater and for the prevention of human exposure to pathogens. Like other wastewater systems, the discharge contains nitrogen that is subject to potential discharge into groundwater. Viers et al (2012) examined the relative contribution of septic systems, regionally and locally to assess their potential impact on groundwater nitrate levels. Their analysis was focused on the Tulare Lake Basin and the Salinas Valley. Here, the analysis of potential nitrogen loading to groundwater from septic systems is expanded to include the entire Central Valley.

The methodology used to map potential nitrogen leaching to groundwater from septic systems relied on a two-step process. The first step was a literature review of nitrogen release to groundwater from septic systems. The literature review was used to determine the nitrogen discharge rate from a typical single household septic system. In a second step, we estimated the spatial distribution of septic systems and their density across the Central Valley.

11.4.2 Work Description: Nitrogen in Septic Systems

The primary purpose of septic system design is to control pathogen emissions into groundwater, to the land surface, or into surface waters, and to minimize the risk for human exposure. Exposure to soil microbial activity and filtration processes during leaching of septic effluent are the primary attenuation mechanisms for pathogens. Nitrogen removal is not typically considered in septic system design. About 10-20% of nitrogen discharged from households into septic system is removed incidentally through retention of solids in the septic tank, volatilization of NH_3, and denitrification either to N_2 (complete) or N_2O (incomplete) (Siegrist et al. 2000). Nitrogen removal during the leaching process, after leaving the septic tank, has been found to be as high as 15% (Cuyk et al., 2001) or, under other site conditions, may be neglibly small (Brown 1984).

Tchobanoglous et al. (2003) estimated that the daily nitrogen excretion per adult is 13.3 grams. For our analysis, we assume that approximately 15% of that nitrogen is either retained in the septic tank or volatilizes from the tank or from the septic leachfield (Siegrist et al. 2000). We conservatively (worst case) assume that the remaining 85% nitrogen leaving the septic system is subject to potential leaching into groundwater (Wheelan 1988). The potential groundwater nitrogen loading from septic systems is therefore assumed to be 11.3 grams of nitrate-nitrogen per person per day (4.125 kg N per person per year).

To determine the spatial loading rate of nitrogen in kilograms per hectare, the per person groundwater loading is multiplied with the population density of the number of persons on septic systems per hectare.

11.4.3 Work Description: Septic System Densities

Households on septic systems have been reported as part of the 1990 U.S. Census. Similar national surveys, however, have not been implemented since then. The Census results are reported at the spatial resolution of census block groups, which are similar in population size, but vary in spatial extent – smaller in densely populated urban areas typically serviced by urban wastewater systems, and larger in sparsely populated areas, which are more likely to contain households on septic systems. The 1990 Census dataset found 665,913 households on septic systems in California. This dataset consists of 21,330 block group polygons ranging in size from less than 0.5 hectare (less than 1 acre) to 1 million ha (2.5 million acres). Each block group is attributed with an estimate of the number of households within it that discharge their sewage to “sewer”, “septic, or “other”. Here, we ignored the “other” group assuming that waste discharge from that group was negligible.

Since the Census covers the entire state, many census block groups include areas that are uninhabited, resulting in underestimation of population density in actually inhabited areas, and thus underestimation of septic system density as well. Similarly, urban areas within a census block that are actually covered by a sewer system service area are not excluded from the census block in an unadjusted density estimation, which further dilutes (lowers) an unadjusted density estimate`.

To adjust the spatial density within block groups, a spatial analysis is needed of the areas within each block group most likely featuring a septic system. For this, a first step taken was to use a statewide layer of land ownership that was queried for non-private lands. Non-private lands were removed from the Census data block groups (which are available as a digital map), which resulted in approximately 50% of statewide areas being eliminated (Table 11.1). However, this approach has two short-comings: excluding public lands eliminates public lands housing, e.g., for park staff, forest service staff, likely a negligible factor within the Central Valley. Second, the private lands dataset does not distinguish between residential and commercial or agricultural lands, where the latter two are unlikely to be occupied by septic systems. A residential zoning digital map layer would further enhance the quality of the septic system location estimate. Such a dataset does exist, but it is privately developed and would have to be obtained through ParcelQuest Incorporated at a cost of about $5000 (for a statewide dataset).

Table 11.1: Land area by number of septic systems per acre using 1990 Census Bureau data.

	Acres in CA	
Systems per acre	1990 unmodified	1990 minus public lands
< 0.5	101,186,807	47,185,112
< 1.5	119,392	136,165
< 2.5	11,312	10,418
< 3.5	1,631	3,037
< 4.5	359	383
< 5.5	0	272
< 10	0	69
≥ 10	0	25

Alternatively, the 2010 U.S. Census provides the number of occupied households at the spatially smaller block level but did not estimate sewer or septic system coverage. The 2010 Census also better reflects population density for the 2005 period of interest in this study than the 1990 Census. The 710,145 California blocks in the 2010 Census ranged in size from less than 0.5 ha (less than 1 acre) to over 1.3 million hectare (Mha) (over 330,000 acres). The 2010 household density in each block was calculated as the number of occupied households (Census 2010) divided by the area of the block, not considering private vs. public lands. Occupied households were used, rather than all housing units, to reflect the actual loading rate from residential septic systems.

To estimate the 2010 density of septic systems, we assume:

- The fraction of persons on septic systems per total population is equal to the fraction of households on septic systems per total households (Figure 11.1).
- The fraction of households on septic systems per total households was unchanged between 1990 and 2010.

The fraction of households on septic systems was obtained from 1990 Census by taking the ratio of the number of households on septic systems in a given census block group and the total number of households in that census block group. The total population per block was obtained from the 2010 census. The spatial extent of the 1990 census block groups was intersected with the spatial extent of the 2010 census blocks, using ArcGIS 10®. The resulting spatial dataset consists of spatial polygons that replicate boundaries of both intersected datasets. For each polygon, the 2010 number of persons on septic systems was obtained by multiplying the 2010 population density in each polygon with the 1990 fraction of households on septic systems in that polygon:

$$(PS/ha)_{2005} = (PS/P)_{1990\ Census} * (P/ha)_{2010\ Census}$$

where:

- ha = area in hectare
- yr = year
- PS = persons on septics (assumed to be equal to the fraction of households on septic systems among all househholds)
- P = total persons

The amount of potential nitrogen loading to groundwater from septic systems [kg N/ha/yr) was obtained by multiplying the number of persons on septic systems per hectare, PS/ha, with 4.1245 kg N/yr (11.3 g N/person/day).

This process does not account for areas of each polygon that are not inhabited by people, as a result of the intersection of 1990 Block Groups and 2010 Blocks. It spreads the rate over the entire polygon, which may include large amounts of agricultural or other landuses. For the 0.25 ha raster-scale simulations with GNLM, the potential nitrogen loading to groundwater from septic systems represents a block average rate and is considered in addition to any other loadings from a raster cell including raster cells designated as “urban”, “percolation basin”, “lagoon”, or “corral”.

This methodology also does not account for suburban or rural housing developments with centralized sewer systems that were built between 1990 and 2010. To avoid gross overestimation of the number of persons on septic systems and of septic systems N leaching, the maximum density of 32.44 persons per hectare (13.13 persons per acre, 32.44 persons per ha) on septic systems, observed in the 1990 Census data, is assumed to also not be exceeded in 2005 or later. Higher densities obtained using 2010 household densities are assumed to be due to new housing developments with centralized sewer systems. The maximum loading can therefore not exceed the 1990 maximum of 134 kg N/ha/yr.

11.4.4 Results and Discussion: Septic System Density and Regional Septic Nitrogen Leaching to Groundwater

Statewide, the intersection of the 1990 block-groups and the 2010 blocks produced 1,009,776 polygons, of which 365,837 were calculated to have at least a fraction of a septic system. The density of septic systems varied from 0.00007 SS/km^2 to 48,795.6 SS/km^2. A total of 1,538,357 or roughly 12.23% of households in the state (based on 2010 estimate from US Census of 12,577,498 occupied households statewide). That is a little higher than the expected rate of about 10%.

In the Central Valley, nearly 10% of the land area is over the arbitrary threshold of 40 septic systems per square mile (Table 11.2). One percent of land area (about 30,000 ha) has more than 256 systems per square mile.

Table 11.2. Land area with septic system densities below the threshold of 40 system per square mile (0.154 systems per ha), up to twice the threshold (0.308 systems per hectare) and higher thresholds. Potential groundwater nitrate loading is computed by assuming an average of 2.89 persons per household and septic system and a potential groundwater N loading of 4.12 kg N/ha/yr per person.

		Central Valley	
System Density	**Potential Groundwater Loading [kg N/ha/yr**	**Hectare (Acres)**	**% of region**
Under 40/sq.mi.	<1.8	2,703,108 (6,679,518)	90.3%
40-80/sq.mi.	1.8 - 3.7	158,835 (392,491)	5.3%
80-256/sq.mi.	3. 7 - 11.7	97,630 (241,248)	3.3%
256-512/sq.mi.	11.7 – 23.5	16,960 (41,910)	0.6%
Over 512/sq.mi.	>23.5	13,808 (34,120)	0.5%

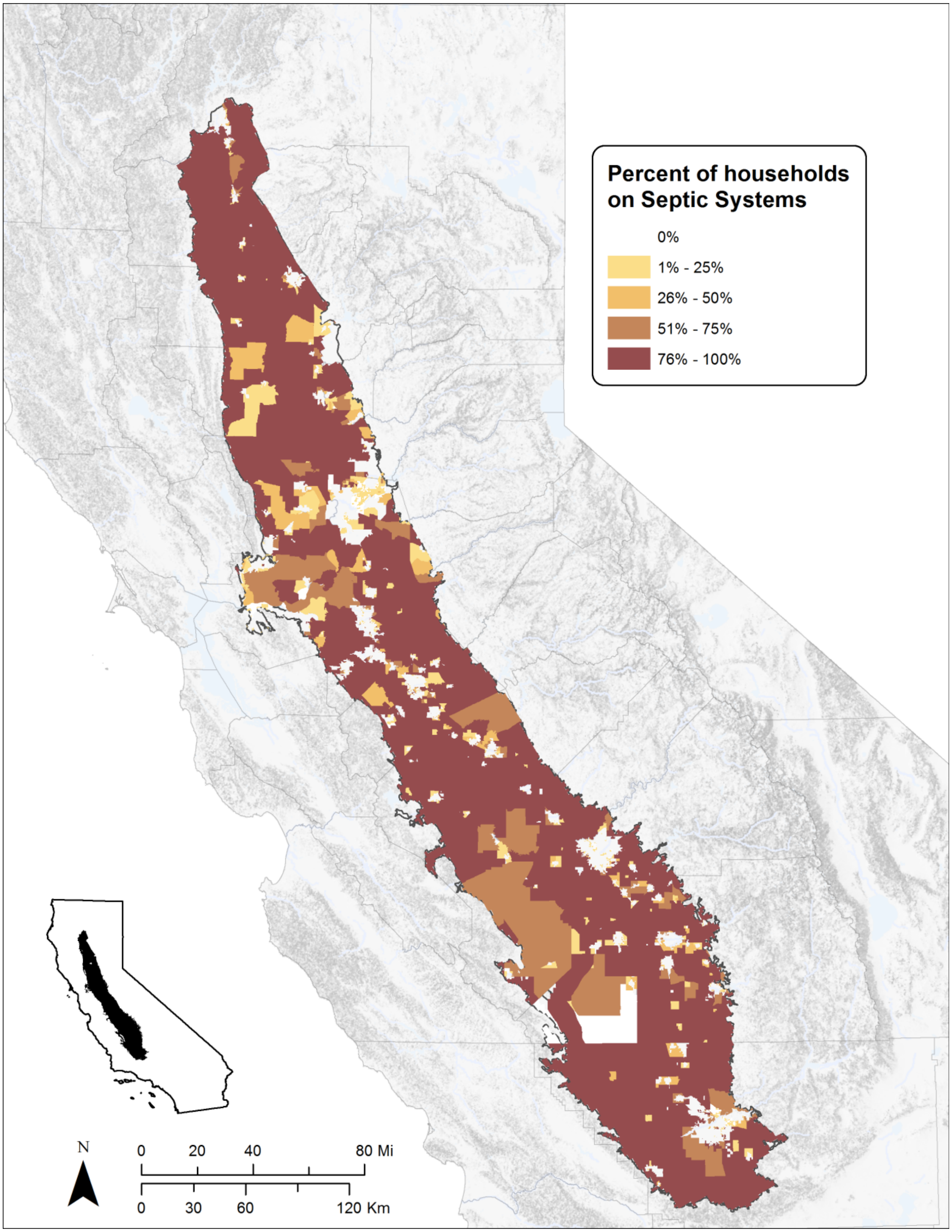

Figure 11.1: Percent of households on septic systems, by blockgroup, from 1990 census data, in the study area.

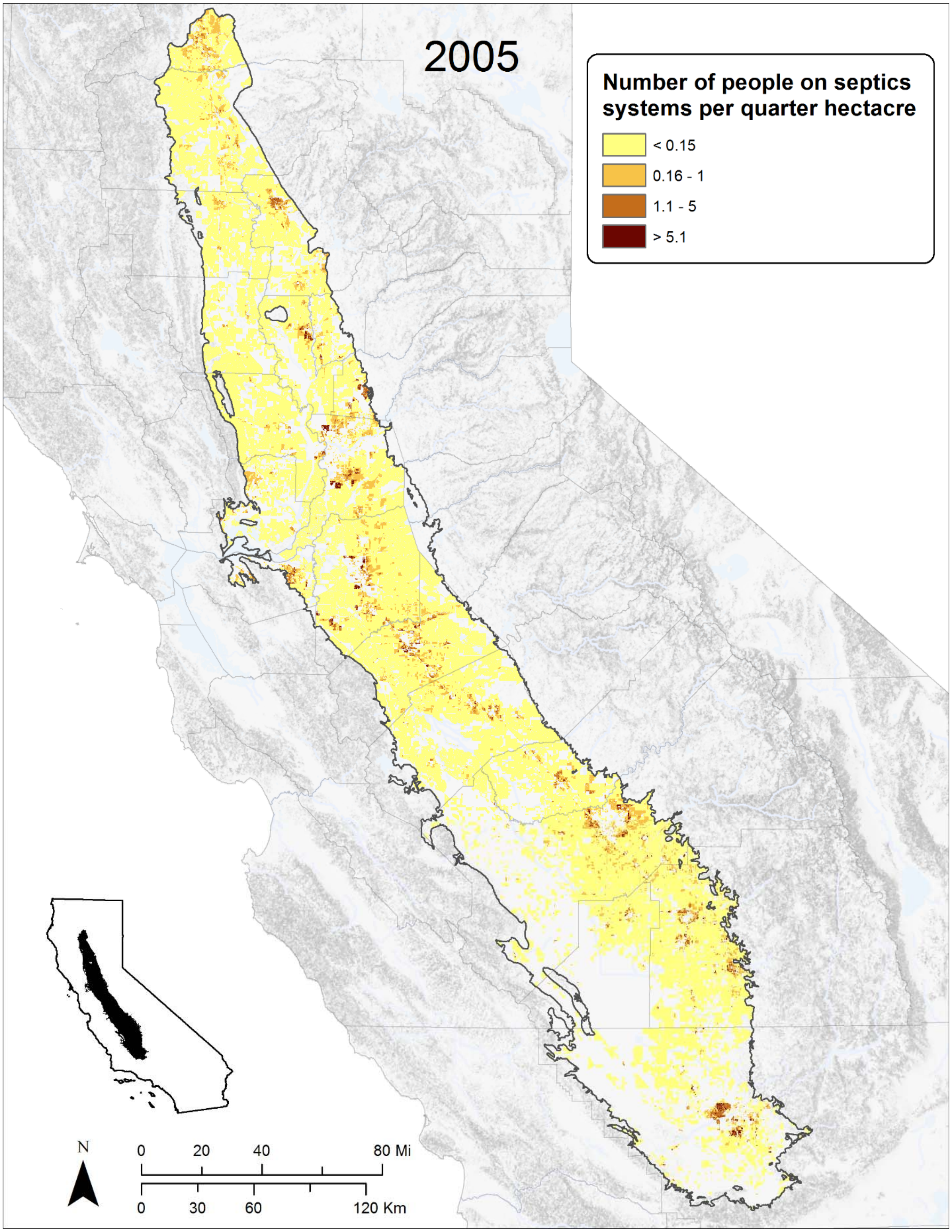

Figure 11.2. Number of people on septic systems per raster cell (i.e., per 0.25 hectare), in the study area.

The system densities range from zero systems per hectare in city centers and some nearly unpopulated rural areas to over 21 persons (7 septic systems) per hectare in many peri-urban areas (Figure 11.2). Due to the specific method used for the 2010 septic systems density, a few of the densities are unrealistically high (the highest value is over 200 systems per ha). This is likely because some areas, especially in peri-urban regions, have seen significant development between 1990 and 2010 with commensurate development of urban wastewater collection systems to central wastewater treatment plants. Newly sewered areas remain unaccounted for in the method used here. Increases in housing density, e.g., new developments, produce increases in septic system density with this septic system density estimation method. As described in Section 11.4.3, the maximum leaching rate is therefore assumed to not exceed the amount estimated for 1990, 134 kg N/ha/yr.

The septic N leaching mapped in Figure 11.3 includes 3.00 million ha (out of 5.29 million ha) with at least some septic N leaching. Of 477,000 ha classified as "urban" in the 2005 landuse map (Figure 2.2), 250,000 ha have some septic N leaching, averaging 13.9 kg N/ha/yr (1.16 households per ha). On 25,000 ha of urban landuse the septic N leaching rate exceeds 18.6 kg N/ha/yr (90^{th} percentile), while 12,500 ha exceed a leaching rate of 44.0 kg N/ha/yr (95^{th} percentile). Total estimated septic N leaching is 5.565 Gg N/yr, of which 3.471 Gg N/yr are from "urban" landuses and 2.094 Gg N/yr occur in non-urban, rural areas. In rural areas, average leaching rates amount to 0.76 kg N/ha/yr or 1 household per 15.6 ha (1 household per 38.5 acres). Septic leaching estimates for earlier periods (Table 11.30) are obtained by scaling 2005 estimates proportional to total population changes in the Central Valley relative to 2005.

Outside Central Valley city boundaries, which includes some landuses classified as "urban" (Figure 2.2), the spatial analysis of census blocks and block groups yielded 103,275 polygons, of which approximately half (53,330) contained at least some fraction of its population on septic systems. The total area of these polygons was nearly 3 Mha (2,990,340 ha). The average household size was 2.89 persons per household: 700,870 persons in 242,850 households on septic systems. Assuming one septic system per household, the average septic system density is 0.081 systems per ha (1 system per 12.3 ha).

Although the highest rate of septic system use is in the most rural areas – areas furthest away from urban areas (Figure 11.2), the lower population densities in these areas result in low total densities of septic systems. We found that the highest densities of septic systems occurred in peri-urban (rural sub-urban) areas near cities, but outside the service areas of the wastewater systems that served those cities (Figure 11.2).

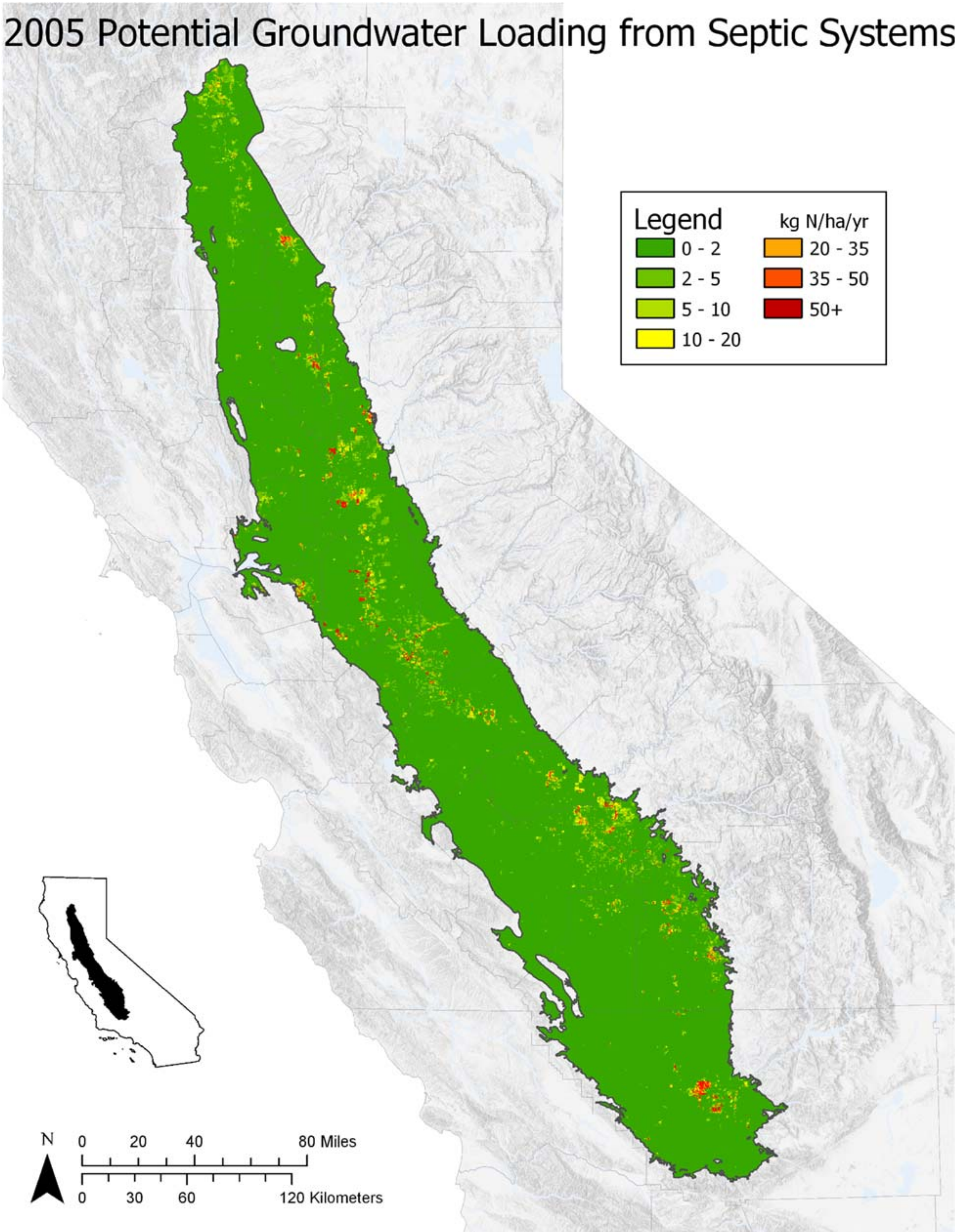

Figure 11.3: Potential septic system nitrogen leaching rates within the study area for the 2005 period.

11.4.5 Septic Systems Analysis: Conclusions

Septic system nitrogen leaching in "urban" landuse areas contribute about 3.5 G N/yr to groundwater leaching, while rural residences in the Central Valley contribute about 2.1 Gg N/yr to groundwater (total: 5.6 Gg N/yr). In rural and urban areas outside city limits, total septic system contribution to potential nitrate loading of groundwater from about 700,000 residents on septic systems is 2.9 Gg/yr.

Across the Central Valley, septic systems contribute between 1% and 2% of all potential nitrogen loading to groundwater. While a small potential source in the context of the Central Valley, the contribution of septic systems to domestic well nitrate pollution can be significant, as shown in the well survey of Ransom et al. (2015). Especially in areas of high septic systems density, surrounding cities, with highest densities observed around the cities of Fresno and Bakersfield, nitrate loading to groundwater may be in the range of 10 - 50 kg N/ha (9 – 45 lb N/ac) or even higher. Even where septic system densities are low, significant risks exist for septic systems leaching to affect a domestic well, as both are typically co-located on the same property (Bremer et al., 2012).

It is important to note that this analysis is providing an upper (highest possible) estimate of septic sewer leakage due to the assumption that all daily human waste is collected by the domestic septic system. In reality, residents spend some of their time outside the home, e.g., at their workplace, and some of the human waste will be collected in municipal sewer systems. The fraction of actual waste collected per septic system is therefore not known. Another significant uncertainty in the analysis here is the rate of septic system to central sewer system conversion in urban landuse areas, particularly within city limits, which make up more than half of the total estimated 2010 septic systems in the Central Valley.

11.5 Nitrogen Leaching from Urban Landuses

11.5.1 Introduction: Urban Sources of Nitrogen Leaching to Groundwater

Urban population and urban landuses are an integral part of the nitrogen cycle. Globally, the urban population and its need or food, consumer products, and transportation directly or indirectly drives most of the global reactive nitrogen cycle, including the loss of nitrate to groundwater in both agricultural and urban areas (Davidson et al., 2011; Sutton et al, 2011; Tomich et al., 2016).

The major sources of nitrogen leaching to groundwater within urban areas that are considered here include:

- Turf areas and other vegetated landscapes of urban areas that may receive nitrogen fertilizer, including golf courses
- Sewer systems collecting liquid waste from private household and industrial urban users
- Landfills
- Disposal of waste effluent or biosolids from wastewater treatment plants (WWTPs) and food processors (FPs):
    - in percolation basins or
    - via land application to agricultural lands

These urban sources of nitrogen are described and discussed in detail in Viers et al. (2012) and in Tomich et al. (2016). Our methodology for computing Central Valley groundwater nitrogen loading from urban sources and for estimating the amount of urban effluent discharged to agricultural lands is based on the methodology and findings described for the Tulare Lake Basin and Salinas Valley in chapters 5 and 6 of Viers et al., (2012). Here, we include a brief review and detail the methods used in this project to estimate groundwater nitrogen loading from urban areas and present the results for the Central Valley. This section is divided into three major subsections: mapping (11.5.2), diffuse sources of urban N (11.5.3 – 11.5.4), and WWTP and FP disposal of nitrogen to percolation basins and land application (11.5.5 – 11.5.7).

11.5.2 Work Description: Mapping of Urban Areas

Urban landuses are defined variably in mapping efforts and typically include industrial, urban housing, school, commercial, traffic, and other urban landuses, including vacant urban lands. We relied on external information sources to define urban areas in the Central Valley.

Urban areas for the "2005" period were obtained by combining urban areas identified in the 2002 Multi-Source Land Cover (MSLC) map produced by the California Department of Forestry and Fire Protection and the Farmland Mapping and Monitoring Program (FMMP) maps generated by the California Department of Conservation (see chapter 2). Urban areas are obtained by taking the union of all "urban" pixels (at 50 m resolution, see chapter 2) in the MSLC map and in the FMMP map, except any pixels that are classified as belonging to an agricultural landuse in either the MSLC or the FMMP (agricultural identification trumps urban identification between the two maps).

Urban areas for the “1990” period were reconstructed similarly (see Task 2). Urban areas were identified solely based on the 1992 NLCD map, a raster layer at 30 meter resolution. Urban areas for earlier periods were back-casted following the methods described under Task 10.

Golf course locations were identified from the CDWR landuse surveys used for generating the 2010 CAML layer. Some locations were adjusted to remove overlapping mapped dairy cropland area, dairy lagoons, or dairy corrals.

11.5.3 Work Description: Urban Sources of Nitrogen Leaching to Groundwater

Vegetated urban landscapes such as lawns, turf areas, and golf courses that receive nitrogen fertilizer, like agricultural landscapes, are subject to nitrogen leaching. Typically, between one-eight and one-quarter of the urban landscape may be turf areas. Golf courses, which are known to receive relatively high amounts of fertilizer, typically account for only about one-tenth or less of urban turf areas. Review of urban fertilizer use and research on nitrate leaching from turf and golf course areas indicated minimal losses of nitrogen to groundwater, when considering the total urban area. Here we adopt the approach in Viers et al., (2012) and assume that a representative leaching rate due to fertilizer applications from all areas designated as “urban” or “golf courses” is 10 kg N/ha/yr ((8.9 lb N per acre per year).

The remaining urban-related sources of groundwater nitrate are related to urban waste management. Sources of nitrogen in urban waste include human consumption of foods, household products, and pets. The per capita rates of food consumption and the ultimate fate of that food (wastewater treatment vs. disposal in landfills) are relatively well characterized in many areas (see the section on septic systems). Household use of N containing products that affect urban waste N is more difficult to estimate. One class of compounds is synthetically produced from the same ammonia feedstock as fertilizers. These synthetic compounds include nylon, polyurethane, and acrylonitrile butadiene styrene plastic. Many households also use products like shampoo and detergents that contain synthetic N. Pet waste from dogs and cats is also a part of urban N dynamics. Though pet waste can pose a detriment to quality of surface waters, often for pathogenic reasons, its role in nitrate leaching to groundwater is comparatively minor, as this material is either disposed of in the landfill or is largely deposited on turfgrass where it is unlikely to leach to groundwater because of the high N retention in turfgrass soils.

Waste generated in urban areas is managed along two pathways: solid waste collection for landfill disposal, and liquid waste (wastewater) collection via sewer systems for treatment in wastewater treatment facilities and disposal into streams (surface water discharge), percolation basins (direct groundwater recharge), or application to agricultural lands (effluent and biosolids land application). Here, we also consider food processing facilities, which – like WWPTs – may dispose of nitrogen-rich waste by disposal of wastewater to percolation basins or by application of effluent and biosolids to agricultural lands. Landfills, diffuse pollution from leaky urban sewer systems, and percolation basins associated with WWTPs and FPs are considered here for their nitrogen leaching to groundwater within urban areas. Land application of effluent and biosolids from WWTPs and FPs contributes to the N balance and potential nitrogen loading to groundwater of affected agricultural lands.

Landfills are the final point of disposal for solid waste from households and industrial uses in urban areas. Loading of nitrate to groundwater may occur from landfills and could be significant for landfills with active composting facilities or biosolids applications depending on their management practices. However, most landfills have sophisticated liners to minimize leaching and all facilities are regulated by local enforcement agencies. Given findings from previous studies (e.g., Hater et al. 2003, Wakida & Lerner 2006, Viers et al., 2006), we considered nitrate leachate contamination from landfills in this study to be comparatively negligible. No nitrogen leaching rate was assigned to landfills.

Sewer systems collect wastewater from individual urban household, some urban stormwater runoff, and from urban industrial landuses. Aging infrastructure and insufficient maintenance of sewer systems can result in leakage from sewer pipes, leading to infiltration of raw sewage containing nitrogen into the surrounding soil and ultimately into underlying groundwater. Poorly fitted pipes, aging collection systems, sanitary sewer overflows, and unsuitable piping materials all contribute to the leakage of raw sewage. Chapter 5 of Viers et al. (2012) reviewed information in the literature and interviewed industry representatives to estimate nitrogen loading from sewer leakage in southern Central Valley and Salinas Valley cities. Here we adopt the approach in Viers et al. (2012) and assume that, on average across all urban landuses (not including golf courses), the nitrogen leaching rate to groundwater attributable to leaky sewer system is a nominal 10 kg N/ha/yr (8.9 lb per acre per year).

11.5.4 Results and Discussion: Diffuse Urban Sources of Nitrogen Leaching to Groundwater

The combined diffuse nitrogen loading to groundwater in urban areas, from leaky sewer systems and from fertilizer applications to the vegetated urban landscape is 9.5 Gg N per year (10,500 tons per year). The valley's counties with the largest urban areas – Sacramento, Fresno, and Kern County – contribute 1.6, 1.2, and 1.2 Gg N per year (1700, 1300, and 1300 tons N per year) (Table 11.3). Estimated nitrogen loading to groundwater from golf courses is 66 Mg per year (73 tons per year). Each of the three regions has a similar land area in golf courses – about 2,200 ha (5,400 acres) (Table 11.4).

Table 11.3: Urban area (not including golf courses) and estimated urban nitrogen loading from leaky sewer systems and from fertilizer applications to groundwater for the 2005 period, by county, region, and for the entire Central Valley. The estimated combined, uniform leaching rate in urban areas is 20 kg N per ha per year (17.8 lb per acre per year).

County / Region	Urban Area (ha)	Urban Area (acres)	Urban Nitrogen Loading to Groundwater (Mg N per year)	Urban Nitrogen Loading to Groundwater (tons per year)
Butte	15,487	38,270	310	341
Colusa	4,463	11,028	89	98
Glenn	4,298	10,620	86	95
Placer	15,292	37,787	306	337
Sacramento	77,986	192,707	1560	1719
Shasta	15,127	37,380	303	333
Solano	19,163	47,353	383	422
Sutter	6,206	15,334	124	137
Tehama	8,742	21,601	175	193
Yolo	15,159	37,458	303	334
Yuba	7,147	17,661	143	158
Sacramento Valley	**189,069**	**467,198**	**3781**	**4168**
Contra Costa	24,973	6,1710	499	551
Madera	9,306	22,994	186	205
Merced	19,051	47,075	381	420
San Joaquin	42,105	104,043	842	928
Stanislaus	31,550	77,961	631	696
San Joaquin Valley	**126,984**	**313,783**	**2540**	**2800**
Fresno	58,879	145,492	1178	1298
Kern	58,394	144,295	1168	1287
Kings	16,065	39,696	321	354
Tulare	27,763	68,604	555	612
Tulare Lake Basin	**161,100**	**398,087**	**3222**	**3552**
Central Valley	**477,152**	**1,179,069**	**9543**	**10519**

Table 11.4: Golf course area and estimated urban nitrogen loading from golf course fertilizer applications to groundwater for the 2005 period, by county, region, and for the entire Central Valley. The estimated average leaching rate golf courses is 10 kg N per ha per year (8.9 lb per acre per year).

County / Region	Golf Course Area (ha)	Golf Course Area (acres)	Golf Course Nitrogen Loading to Groundwater (Mg N per year)	Golf Course Nitrogen Loading to Groundwater (tons per year)
Butte	283	699	2.83	3.12
Colusa	47	117	0.47	0.52
Glenn	27	66	0.27	0.29
Placer	145	358	1.45	1.60
Sacramento	1010	2496	10.10	11.14
Shasta	108	267	1.08	1.19
Solano	147	364	1.47	1.62
Sutter	136	337	1.36	1.50
Tehama	79	195	0.79	0.87
Yolo	203	501	2.03	2.23
Yuba	130	321	1.30	1.43
Sacramento Valley	**2315**	**5720**	**23.15**	**25.52**
Contra Costa	347	856	3.47	3.82
Madera	292	722	2.92	3.22
Merced	311	767	3.11	3.42
San Joaquin	867	2143	8.67	9.56
Stanislaus	331	819	3.31	3.65
San Joaquin Valley	**2148**	**5307**	**21.48**	**23.67**
Fresno	729	1801	7.29	8.04
Kern	868	2144	8.68	9.56
Kings	200	493	2.00	2.20
Tulare	370	914	3.70	4.08
Tulare Lake Basin	**2166**	**5352**	**21.66**	**23.87**
Central Valley	**6629**	**16379**	**66.29**	**73.07**

11.5.5 Nitrogen in Wastewater Treatment Plants and Food Processors - Introduction

Wastewater treatment plants and food processors generate large amounts of nitrogen contained in wastewater and biosolids. The disposal of those wastes to percolation basins and agricultural land application areas may lead to leaching of nitrogen to groundwater. The application of wastewater and biosolids to agricultural land also provides an opportunity to recycle nitrogen from urban uses in agricultural food production. Land application of effluent from WWTPs and FPs can be an effective way to reuse water and nutrients, using natural processes in the soil and irrigated crops as a final stage of treatment. However, with inappropriate land application groundwater can be degraded. When discharges run the risk of negatively impacting groundwater, existing land application processes can be modified or facilities can be improved and potentially expanded to optimize operations and/or treat wastewater to a higher quality (Dzurella et al. 2012).

The quantity and type of waste disposal varies from facility to facility and is subject to significant variability and associated with specific land parcels. Unlike nitrogen loading from other urban sources (turf, golf courses, leaky sewer systems), the groundwater N loading associated with WWTPs and FPs was estimated individually by facility and assigned to specific land parcels. We examined WWTPs and FPs for their potential nitrogen disposal in percolation basins or to agricultural lands by inspection of available reports and waste discharge permits for specific facilities. For this project, the investigation of Viers et al. (2012) was extended from the Tulare Lake Basin to include WWTPs and FPs in the entire Central Valley. Methods and results are described in the next section.

Influent nitrogen levels typical of domestic WWTPs (raw sewage) may vary from 20 to 100 mg N/L (Table 11.5). Although influent nitrogen levels vary with community water use, the annual mass loading of an individual treatment facility is directly related to the population served. Nitrogen loading from human waste can range from 2 – 15 g/capita/day (Henze, Loosdrecht, & Ekama 2008); according to (Crites & Tchobanoglous 1998b), the typical amount of excreted nitrogen is 13.3 g/capita/day. Concentrations are not dependent on the size of WWTPs, but WWTPs serving larger populations generally discharge the greatest amount of total nitrogen (larger flows).

Table 11.5. Typical composition of domestic wastewater. (Source: Metcalf & Eddy 2003; Wisconsin Department of Natural Resources 2006; Henze et al. 2008.)

	Low	Medium	High
	mg/L as N		
Ammonia – N	12 – 20	25 – 45	50 – 75
Organic – N	8	15	35
Total – N	20 – 30	40 – 60	85 – 100

Effluent nitrogen levels from WWTPs are dependent on the level of treatment (Viers et al., 2012).

Wastewater from FPs is characterized by the specific processing operations of the facility and by the food type; as such, waste volume and nitrogen content can vary widely between facilities. Steps in food processing can include peeling, trimming, washing, mechanical operations, cooling, heating, canning, pureeing, juicing, blanching, cooking, drying/dehydrating, and cleaning of machinery and the facility (Liu 2007).

FP waste may be discharged to an existing municipal or industrial wastewater treatment plant, where appropriate treatment is already in place. An often less costly alternative for FPs is the land application of food processing waste. However, to avoid degradation of groundwater, it is vital *"that wastes are* *applied to fields at reasonable rates, such that organic matter is broken down, [and] nutrients are taken up by crops or consumed by soil microorganisms…"* (Central Valley Regional Water Quality Control Board 2005, p. 4). Reuse of food processing discharge through land application is a common disposal option for many types of food processing wastes and is well documented (Crites et al. 2000; Central Valley Regional Water Quality Control Board 2005; United States Environmental Protection Agency 2006; Brown and Caldwell and Kennedy/Jenks Consultants 2007). Land application of wastewater is common for a wide range of FP categories including brewery, vegetable and fruit canning and frozen foods, dairy, meat processing, and winery wastewaters (Crites et al. 2000). In-plant treatment of food processing waste prior to discharge is dependent on food processor type and wastewater characteristics. Depending on the disposal method, different waste streams within the plant can be handled separately or they can be combined to meet disposal requirements. Some facilities discharge to onsite septic systems as well. Importantly, unlike in WWTPs, discharge of waste from FPs may be highly seasonal.

Solid wastes from food processing operations are often reused as animal feed; however, certain solids can be composted and land applied as a soil amendment, a practice similar to leaving plant residual on a field after harvest. According to the Central Valley Regional Water Board (Central Valley Regional Water Quality Control Board, Daniel Benas, Environmental Scientist, Compliance and Enforcement Unit 2011):

- Most FPs screen wastewater for solids before effluent is discharged.
- Solid wastes from food processing are often sold as animal feed.
- A small number of FPs dry solid wastes and apply to land as a soil amendment.

11.5.6 Work Description: Accounting for WWTP and FP Nitrogen Disposal to Land and Percolation Basins in the Central Valley

Information on the quantity, nitrogen content, and fate of wastewater and biosolids from WWTPs and FPs was obtained predominantly from publically available permits and reports. The Central Valley Regional Water Quality Control Board (Central Valley Regional Water Board) (Region 5) oversees the permitting, monitoring and enforcement of regulations relevant to waste dischargers in the Central Valley (State Water Resources Control Board 2011a). The Federal Clean Water Act (CWA) requires a permit for discharge to surface waters administered through the National Pollutant Discharge Elimination System (NPDES) (United States Environmental Protection Agency 2011a). Important to this study, the California Porter-Cologne Water Quality Control Act of 1968 provides more extended state authority and mandates all groundwater dischargers, not only surface water dischargers, to file a report of waste discharge with the appropriate Regional Water Board. Unless a waiver[4] is granted, subsequent waste discharge requirements (WDR), issued by the Board, provide the guidelines that must be followed to protect beneficial water uses and maintain or improve water quality in accordance with the Regional Basin Plan (Brown and Caldwell and Kennedy/Jenks Consultants 2007). Non-compliance or violation of WDRs can result in the Regional Water Board mandating measures for remediation. Monitoring and Reporting Programs (MRPs) are delineated in WDRs to facilitate ongoing protection of water resources; monthly and annual monitoring reports are submitted to the Regional Water Board to ensure continued compliance with WDRs. Requirements for the disposal of approved solid wastes, including biosolids from WWTPs, are also dictated by WDRs.

Liquid discharges from WWTPs and FPs were examined, accounting for discharges to both irrigated agriculture and percolation basins. Biosolids production was detailed in Viers et al. (2012) for the Tulare Lake Basin (TLB), which includes Fresno, Tulare, Kings, and Kern Counties. The total mass of nitrogen, total nitrogen concentration in discharges, and application rates (kg/ha/yr) were estimated based on collected data. To assess the distribution of N loading from these sources, information on discharge location and land area was collected and the corresponding spatial distribution of N loading from these sources was mapped.

The list of facilities in the Central Valley was expanded from the list generated for the TLB (Viers et al., 2012). The primary sources were a State Water Resources Control Board master list and the California Integrated Water Quality System Project (CIWQS) online database, with facilities extracted by county. Supplemental information was extracted from the U.S. EPA's Facilities Registry System (FRS) and, for food processors, the Hilmar Supplemental Environmental Project (Hilmar SEP)(Rubin et al. 2007). Facilities were geo-located and mapped; facilities outside of the project boundaries were excluded. For both WWTPs and FPs, any Waste Discharge Requirement (WDR) Reports available online were collected.

The Central Valley Regional Water Board (2006) found that "approximately 250 wineries plus an unknown number of other food processors discharge to land, but have not submitted Reports of Waste Discharge (RWDs), as required by the CWC. […] 212 processors discharge to land, and are regulated under individual WDRs issued pursuant to the California Water Code (CWC); […] 62 processors discharge to land and are enrolled under Order No. R5-2003-0106, the Waiver of Waste Discharge Requirements for Small Food Processors".

Due to the large number of WWTPs in the Central Valley, we only collected data for 90% of each region's design flow (avoiding numerous very small systems, e.g. trailer parks, etc.). The design flows for all

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[4] In accordance with California Water Code Section 13269 state and regional boards can waive WDRs for individual dischargers under the under the following conditions (CWC Section 13269):
1) "The state board or regional board determines, after any necessary state board or regional board meeting, that the waiver is consistent with any applicable state or regional water quality control plan and is in the public interest."
2) "A waiver may not exceed five years in duration, but may be renewed…"
3) "The waiver shall be conditional and may be terminated at any time by the state board or a regional board."
4) "Monitoring requirements shall be designed to support … the waiver's conditions;" however, "the state board or a regional board may waive the monitoring requirements … for dischargers that it determines do not pose a significant threat to water quality."

WWTPs in each region were collected and summed. Starting with facilities having the largest design flow, WWTPs were added to the final list until 90% of the total design flow was included (see **Error! Reference source not found.**4 for flow rate by facility). WDRs unavailable online were collected directly from the Regional Water Boards, in the Rancho Cordova and Fresno jurisdictions. Monthly and annual water quality monitoring reports (SMRs) were provided by the Central Coast Regional Water Board for all required facilities. SMRs for Central Valley facilities were reviewed at the Central Valley Regional Water Board office in Fresno and Rancho Cordova and nitrogen levels in discharge were extracted from these reports on site. To ensure current information and to fill data gaps, WWTPs were surveyed via email and telephone. For this report, we did not extend the biosolids information from Viers et al. (2012), where available biosolids information for Fresno, Tulare, Kings, and Kern County was collected through communications with individual facilities and through contact with Lauren Fondahl from U.S. EPA Region 9.

For FPs in the Central Valley, information was extracted from a database developed as part of the Hilmar Supplemental Environmental Project (Hilmar SEP) by Hydrogeophysics, Inc. (Rubin et al., 2007). The Hilmar database is based on WDRs and monitoring reports filed with the Central Valley Regional Water Board from 2003 to 2005. WDRs and monitoring data were provided by the Central Coast Regional Water Board, as available, for FPs in the Salinas Valley.

Collected information includes: population served (WWTPs); design flow and actual flow; relative flow to recharge basins, surface water and irrigated agriculture; seasonal variation in flow and nitrogen levels; acreage of irrigated agriculture and/or percolation basins; nitrogen concentration in discharge (ammonia, organic nitrogen, nitrate, TKN, and total nitrogen, as available); fate and volume of biosolids; and treatment for nutrient removal (if any). Fifty WWTPs and 132 FPs were included in the analysis (Figure 11.4). Facilities with unknown actual flow were excluded from the dataset.

Not all of the above information was available for all facilities. Modeling lacked sufficient correlation for the SCV and NSJV for concentration. To fill data gaps, missing information was modeled based on the reported results of other facilities as follows:

- Unknown N concentration of discharge
  - FP: Correlation between N concentration in discharge and total flow by type of FP in the TLB, average values of same processing type for the type for all remaining counties
  - WWTP: Correlation between N concentration in discharge and total flow of WWTP in the TLB, average values for all remaining counties
- Unknown relative flow to recharge basins and irrigated agriculture
  - 50 – 50 split of flow to recharge basins and irrigated agriculture
- Unknown acreage of recharge basins and irrigated agriculture
  - Correlation between flow and acreage for recharge basins (WWTPs and FPs considered separately) for the TLB, average values for all remaining counties

While we attempted to obtain data for all FP facilities for which reporting is required, we were only able to capture actual flow values for approximately 60% of known facilities (137 of 238 total facilities, 29%

of SCV facilities and 62% and 63% of the NSJV and TLB region's facilities respectively). As the northern Sacramento Valley has relatively few food processors, we declined pulling records from the Redding SWRCB office (18 facilities within Tehama, Glenn, Colusa, and Butte counties), and the Fresno office for Merced and Madera counties only including facilities within these counties that had reports available online or from the Hilmar SEP database. Food processor data were pulled from electronic or paper records at the SWRCB Rancho Cordova office for Yolo, Yuba, Sutter, Solano, Sacramento, Placer, Contra Costa San Joaquin, and Stanislaus counties, while the TLB county data was pulled directly from Jenson et al (2012).

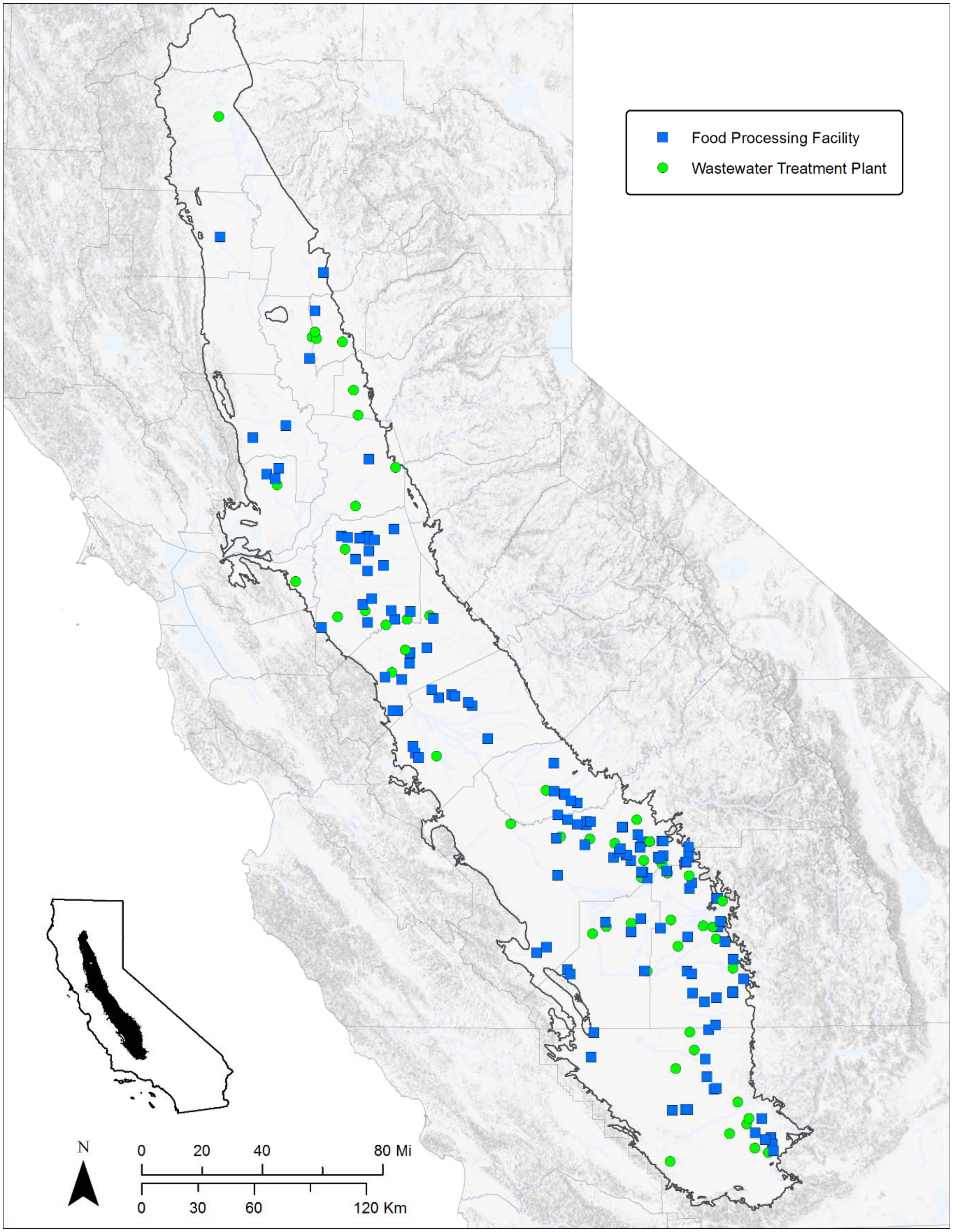

Figure 11.4: Location of included wastewater treatment plants and food processing facilities in the central valley (FPs with an active discharge permit and known flow, and the largest WWTPs comprising 90% of design flow in each basin were included in this analysis, see Appendix Tables 4 and 5 for facility specific information). (Source: California Water Boards.)

11.5.7 Results and Discussion: WWTP and FP Nitrogen Disposal to Land and Percolation Basins in the Central Valley

Results reflect an extension of the work by Viers et al. (2012) to the Central Valley region. Like the earlier work, there are a number of limitations to the results presented:

- Effluent nitrogen monitoring data were not available for all facilities.
- The service population of WWTPs was not always available resulting in an estimation of population served from various sources, some of which may be outdated.
- When information was unavailable from the most reliable source, information from alternative sources was used to fill data gaps. For some facilities available information was limited or completely unavailable. The reliability and accuracy of data varied with source (from most certain to least certain):
    - From recent monitoring reports and direct contact with facilities
    - From recent monitoring reports and recent WDRs
    - From recent WDRs
    - From old WDRs
    - Modeling to fill data gaps
    - No data available
- Small WWTPs (the WWTPs representing the final 10% of flow) were excluded from data collection to focus data collection efforts and to account for the largest nitrogen sources.
- Data for facilities operating with old permits may be outdated and data were unavailable for some facilities with pending permits.
- Effluent nitrogen levels were the focus of this analysis to determine the relative contribution of facilities to N loading; however, there is uncertainty in the estimation of leached nitrogen levels from applied nitrogen levels.
- In the surveying of WWTPs, some facilities indicated that additional fertilizer may be applied to supplement the nitrogen in land applied discharges. The extent of such practices and the impact to groundwater are unknown.
- Regarding the estimation of N loading from the land application of biosolids, the nitrogen content of biosolids varies (2 – 10%). Unless reported otherwise, the nitrogen content of biosolids was assumed to be approximately 3.3%, in accordance with Metcalf & Eddy (2003).
- The impact of evaporation and surface water recharge to groundwater were excluded.
- N loading was assessed based on annual averages (of flow and N concentration). Seasonal variation may be a significant factor in the N loading from WWTP and FP facilities due to changes in applied water characteristics as well as irrigation and fertilization practices.

Summary of results

Of the 72 WWTP facilities reviewed, 31% discharge to surface waters, equating to 54% of SCV design flow (66% of count) and 46% of NSJV design flow (44% of count) (of the 90% of the total). The remaining 50 facilities discharge 5.1 Gg N as nitrate to the environment, potentially leached to groundwater (2 Gg via irrigation and 3 Gg via ponds). Forty percent of the reporting WWTPs discharge to both percolation basins and irrigated agriculture; 32.5% only to percolation basins and 27.5% discharge only to irrigated agriculture. Of the 132 FP facilities in our analysis, 70% discharge to irrigation only, 23% to percolation basins only, and 7% discharge to both irrigation and percolation basins.

As shown in Figure 11.4 and Table 11.6, of those facilities included in analyses, there are more facilities in the TLB than in the SCV and NSJV combined (both WWTPs and FPs), and similarly the total load is concentrated in the TLB region, accounting for 74% of all 7.2 Gg applied annually from these sources, 50% of the total food processors load, and 84% of all N discharged from wastewater treatment facilities (Figures 11.5 and 11.6).

Of 238 total food processing facilities, data for actual flow was available for 137 facilities included in our analyses, equal to 58% representation overall, 29% of SCV facilities and 62% and 63% of the NSJV and TLB region's facilities respectively. The number of facilities excluded due to lack of actual flow data is highest in those counties lacking on-site water board office data collection efforts: Butte, Colusa, Glenn, Tehama, Merced and Madera (on site data inspection was only carried out for facilities that fall within the water board's Rancho Cordova office and TLB counties within their Fresno jurisdiction). Within the SCV, 23 known facilities were excluded from Redding jurisdiction counties, and in the NSJV, 17 known facilities in Merced and Madera counties were excluded due to lack of actual flow data.

For WWTPs, the much higher number of facilities in the TLB is partially due to the much higher number of surface dischargers in the SCV and NSJV regions. Additionally, the total number of WWTP facilities in the NSJV is also constricted due to several facilities with very large design flows. These high design flow facilities reduce the number of facilities captured within 90% of total regional design flow. Among all regions, the average design flow is 9.7 MGD, and the median 3.5 MGD. In the NSJV there is a facility with a design flow of 70 MGD, a surface discharger with a design flow of 55 MGD, and 3 additional facilities designed for between 15 and 20 MGD. The actual flow of many facilities is much less than the design, for example, the facility designed for 70 MGD is treating 17 MGD only. In the SCV the scarcity of facilities is primarily due to the greater proportion of surface dischargers (66%) and the lower number of facilities in general.

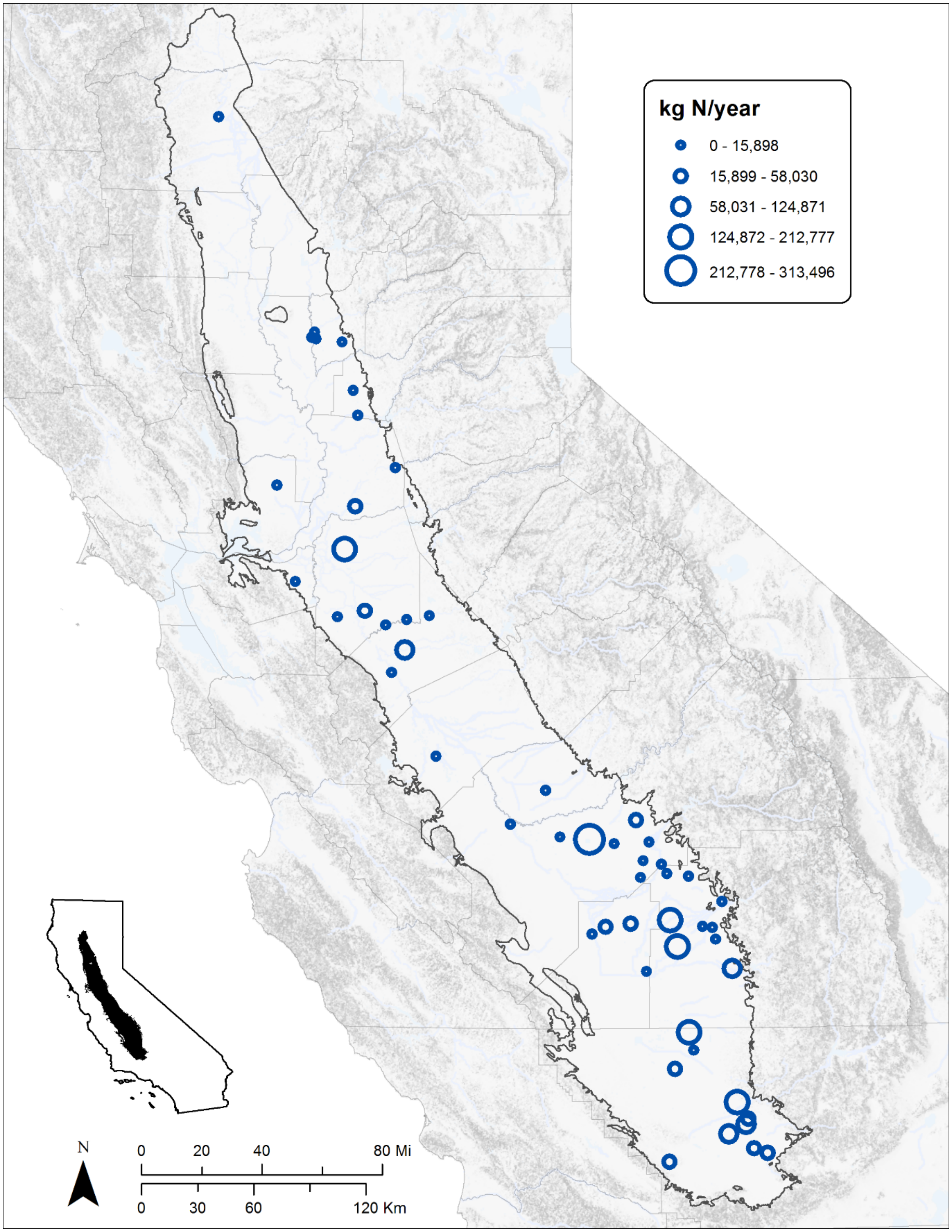

Figure 11.5 2. Estimated total nitrogen discharge [kg N/year] from Central Valley wastewater treatment plants to percolation basins and to land application (see Appendix Table 4 for facility specific information). (Source: California Water Boards, Contact with Facilities, WDRs, SMRs.) [1 kg = ~2.2 lb, 1 hectare = 2.47 acres.]

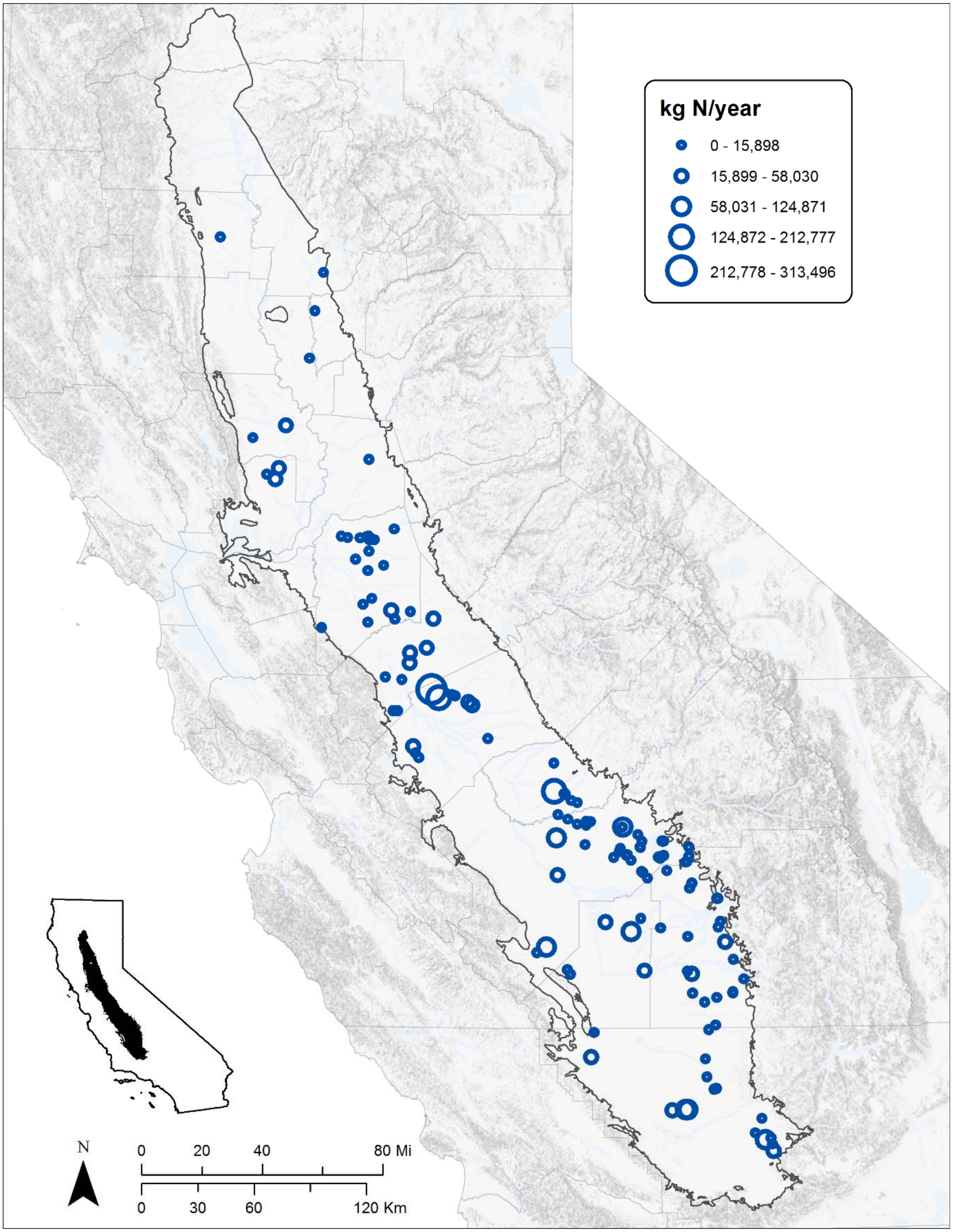

Figure 11.6. Estimated total nitrogen discharge [kg N/year] from Central Valley food processors to percolation basins and to land application (see Appendix Table Error! Reference source not found.**5 for facility specific information). (Source: California Water Boards, Contact with Facilities, WDRs, SMRs.) [1 kg = ~2.2 lb, 1 hectare = 2.47 acres.]**

Table 11.6: Number of and metric tons (Mg) N applied annually from facilities discharging to land or percolation ponds in the central valley: Data was available for approximately 60% of known food processing facilities. Of wastewater treatment plants constituting 90% of total design flow in the study area, 22% of these are surface dischargers and excluded from this dataset. 1 metric ton = 1 Mg = 1.1 tons.

County / Region	Total Mg N/yr	Total irrigation Mg N/yr	Total percolation Mg N/yr	FP Mg N/yr	FP count	WWTP Mg N/yr	WWTP count
Butte	8	8	-	8	1	-	-
Colusa	-	-	-	-	-	-	-
Glenn	14	-	14	14	1	-	-
Placer	0.2	0.2	-	-	0	0.2	1
Sacramento	33	33	-	12	1	22	1
Shasta	-	-	-	-	-	-	-
Solano	61	41	20	41	3	20	1
Sutter	144	-	144	7	1	137	1
Tehama	0.3	0.3	-	-	-	0.3	1
Yolo	17	17	-	17	2	-	-
Yuba	63	13	50	0.2	1	63	2
Sacramento Valley	**341**	**114**	**228**	**100**	**10**	**242**	**7**
Contra Costa	-	-	-	-	-	-	-
Madera	182	172	10	172	7	10	1
Merced	616	485	131	614	10	2	1
San Joaquin	439	241	198	72	19	367	5
Stanislaus	309	240	69	115	8	194	3
(Northern) San Joaquin Valley	**1,546**	**1,137**	**410**	**973**	**44**	**574**	**10**
Fresno	2,728	650	2,079	348	34	2,380	10
Kern	1,374	1,226	148	454	17	920	10
Kings	319	245	74	167	7	152	4
Tulare	863	540	324	100	20	764	9
Tulare Lake Basin	**5,285**	**2,661**	**2,624**	**1,069**	**78**	**4,216**	**33**
Central Valley	**7,172**	**3,911**	**3,261**	**2,141**	**132**	**5,031**	**50**

A rough estimate of required nitrogen for the highest demand crops is 250 kg/ha/yr (~225 lbs/acre/yr), or 500 kg/ha/yr (~450 lbs/acre/yr) for double cropping (see Appendix Table 3). Facilities exceeding these rates risk leaching. As shown in Table 11.7, food processors in the valley discharge an average of 272 kg N/ha/yr as irrigation water, greater than the 250 kg N/ha needed by even the most nitrogen demanding crop, and for WWTPs the average nears this level as well (210 kg N/ha/yr).The average application rate on irrigated land exceeds even the double cropping threshold of 500 kg/ha in Stanislaus county WWTPs, and in Madera and Merced county FP operations. The Sacramento and Stanislaus county FP average and

Tulare county WWTP average rate to irrigated fields exceed 250 kg/ha. The average regional application rate in the NSJV is near 500 kg/ha for both FPs and WWTPs. There are 23 food processors that exceed irrigation application rates of 250 kg/ha/yr, including 9 that exceed 500 kg/ha/yr (up to 4172 kg/ha/yr). In the NSJV, of the 9 facilities that exceed 250 kg/ha/yr, the average rate is 1468 kg/ha/yr . Of the 5 facilities that exceed 500 kg/ha, the average rate is 2256 kg/ha/yr, rates usually associated with percolation ponds. Of the 132 facilities in our analysis, the 23 operations that apply N to irrigated fields above 250 kg/ha/yr account for 31% of the total load (578 of 1,868 metric tons per year).

Percolation pond application rates (kg/ha/yr) are higher than disposal to irrigated fields due to their generally smaller area. To ponds, the average rate for WWTPs is 1245 kg/ha/yr and for FPs 1764 kg/ha/yr. However, the significantly high SCV average rate of over 3000 kg/ha is due to a single dairy processing facility in Glenn county that averages 5408 kg N/ha/yr. Without this facility the county would average similar to others. This facility is also responsible for the very high average concentration for the SCV region (as discussed below, see Table 11.7).

Table 11.7: Total area (ha) and average annual discharge rates (kg N/ha/yr) to irrigated fields and percolation ponds, representing approximately 60% of food processing facilities in the study area and those wastewater treatment facilities that discharge to land or ponds within 90% of total design flow in the study area.

County / Region	WWTP				FP			
	Irrigation		*Percolation*		*Irrigation*		*Percolation*	
	Average kgN/ha/yr	Sum ha	Average kgN/ha/yr	Sum ha	Average kgN/ha/yr	Sum ha	Average kgN/ha/yr	Sum ha
Butte	-	-	-	-	55	149	-	-
Colusa	-	-	-	-	-	-	-	-
Glenn	-	-	-	-	-	-	5,408	3
Placer	3	85	-	-	-	-	-	-
Sacramento	159	138	-	-	383	30	-	-
Shasta	-	-	-	-	-	-	-	-
Solano	-	-	304	65	159	322	-	-
Sutter	-	-	2,450	56	-	-	1,022	7
Tehama	1	283	-	-	-	-	-	-
Yolo	-	-	-	-	28	323	-	-
Yuba	46	283	725	67	4	57	-	-
Sacramento Valley	**52**	**790**	**1,160**	**187**	**126**	**881**	**3,215**	**10**
Contra Costa	-	-	-	-	-	-	-	-
Madera	-	-	79	130	624	222	-	-
Merced	12	166	-	-	773	3,725	1,455	90
San Joaquin	408	421	2,465	103	211	626	856	17
Stanislaus	902	138	1,711	47	491	810	-	-
(Northern) San Joaquin Valley	**441**	**725**	**1,418**	**279**	**525**	**5,383**	**1,155**	**108**
Fresno	132	1,742	2,355	939	161	3,048	306	61
Kern	255	8,259	754	130	218	2,389	910	93
Kings	27	7,138	330	240	121	1,308	42	8
Tulare	317	2,113	1,188	389	164	599	2,429	99
Tulare Lake Basin	**138**	**19,253**	**1,157**	**1,698**	**166**	**7,344**	**922**	**260**
Central Valley	**210**	**20,767**	**1,245**	**2,165**	**272**	**13,608**	**1,764**	**377**

As shown in Table 11.8, the average effluent concentration is significantly higher from food processors than from wastewater treatment facilities (average 63 mg N/L and 11 mg N/L respectively). Effluent discharge to percolation ponds can be a concern above 10 mg/L. There are 25 facilities discharging to ponds exceeding this concentration, 80% of which are in the TLB counties. There are 15 total facilities with very high effluent concentrations over 100 mg/L, 9 located in the TLB, 4 in the NSJV, and 2 in the

SCV. Of these, 5 discharge to percolation ponds, both SCV facilities, and 3 of the TLB facilities. The possibility of direct recharge from percolation basins makes concentration especially relevant, where the combination of a highly concentrated effluent applied to a small area is of concern.

Average concentration for FPs appears abnormally high in the SCV region. Recall that the SCV region food processors are poorly represented (29%) due to lack of actual flow data. The singe Glenn county facility accounted for (a dairy processor) releases considerably concentrated effluent (468 mg N/L), and the single facility in Sacramento county releases 132 mg N/L, both to percolation ponds. The two combine to bring the regional average quite high. Although there are high concentrations in some TLB and NSJV facility's effluent, for example, up to 900 mg/l in the TLB, the average values for these counties are much lower due to the high number of lower concentration facilities. If more SCV facilities were included in our analysis, the average concentration would likely go down, although the high figures for these facilities are still of concern.

Table11.8: County, region, and study area average N concentration (mg N/L) in discharge from food processors (FP) and wastewater treatment plants (WWTP) included in this study.

County	FP average mg N/L	WWTP average mg N/L
Butte	20	-
Colusa	-	-
Glenn	468	-
Placer	-	0.7
Sacramento	28	14
Shasta	-	-
Solano	27	12
Sutter	132	18
Tehama	-	13
Yolo	7	-
Yuba	19	13
Sacramento Valley	**100**	**10**
Madera	37	1.4
Merced	49	0.5
San Joaquin	33	14
Stanislaus	16	15
(Northern) San Joaquin Valley	**34**	**7**
Fresno	85	17
Kern	44	20
Kings	55	12
Tulare	36	15
Tulare Lake Basin	**55**	**16**
Central Valley	63	11

Discharge information by food processor type is listed in Table 11.9. Nearly half of the annual N load (Mg/yr) originates from winery (27%) and tomato processing (19%) operations. While meat and dairy operations contribute less to the overall load, they tend towards more highly concentrated effluent. The highest concentrations on record are found in a meat processing facility and a dairy processing facility (900 and 468 mg N/L respectively). However, of the remaining 13 facilities discharging effluent greater than 100 mg N/L, only 2 are meat or dairy operations, the rest are wine and fruit and nut operations. Of the 25 facilities discharging to percolation ponds with concentrations over 10 mg/L, the majority (68%) are fruit and nut processing facilities, 20% wine processors, and the remaining 3 facilities are meat, dairy and vegetable processors.

Table 11.9: Total kgN/yr, average and median concentration and flow for different types of food processing facilities. MGD= million gallons per day.

	SUM kg N/yr	Average mg N/L	Median mg N/L	Average MGD	Median MGD
Wine	546,025	56	31	0.13	0.06
Tomato	399,641	24	21	0.89	0.72
Vegetables	323,826	15	14	1.01	0.75
Meat	312,141	153	53	0.39	0.11
Dairy	240,396	197	102	0.61	0.25
Fruit+Nut	235,345	44	42	0.08	0.02

11.6 Dairy Sources of Nitrogen

11.6.1 Groundwater Nitrogen Loading from Dairy Corrals

Work Description: Most animal feedlots and corrals in the Central Valley are associated with dairy facilities. In addition, there are several mostly small feedlots and one large feedlot (Harris Ranch). Feedlots and corrals are characteristically an un-vegetated, bare soil area where cattle spend all (dry-lot dairy) or part (freestall dairy) of their time. Nitrogen in animal waste deposited in the corral area and bedding materials imported into the corral area (dried solid waste, compost, or dry plant materials) contain nitrogen that may be susceptible to leaching. Chapter 4 of Viers et al. (2012) provides an extensive review of the potential for corral areas to leach to groundwater. They found that reported leaching rates vary from 75 kg N/ha/yr to 1,000 kg N/ha/yr. For the Groundwater Nitrogen Loading Model (GNLM), we assumed a constant leaching rate of 183 kg N/ha/yr (163 lb N/ac/yr) to groundwater (Viers et al., 2012). This is based on using an average recharge rate of 305 mm/yr (12 in/yr) and an average corral leachate nitrate concentration of 270 mg/L. It represents a value near the lower end of the range reported in the literature.

For the simulation of historic nitrate loading from corrals, we used a very simplified conceptual scenario of the historic development of corral loading: nitrate loading in corrals is assumed to have been constant since the 1975 period. Prior to the 1970s, contributions from (much smaller) corral areas are assumed to have been negligibly small with the dairy herd mostly on pasture.

For this project, we mapped all open dairy corrals located in the Central Valley using a 2007 list of dairy addresses provided by the Regional Water Quality Control Board. We also employed California Department of Water Resources land use surveys[5] for individual counties and 2009 aerial photography provided by the Department of Conservation Farmland Mapping and Monitoring Program[6] (FMMP) as the basis for manually digitizing the actual open corral area in dairies. Only locations already delineated as dairy parcels were searched for corrals or lagoons. Some batch topological cleanup was done to make sure there was no issue with overlapping features, self-intersection, etc. Some validation on features was done manually, but not on the entire dataset. The data may include some features that are missing and/or misidentified.

Data/Results and Discussion: Most of the dairy facilities are in the San Joaquin Valley and Tulare Lake Basin with few facilities in the Sacramento Valley. The total mapped corral area in the Central Valley is 12,244 ha (over 30,000 acres) with an estimated loading rate of 2.2 Gg N/yr (2,500 tons N/yr). Two-thirds of the corral area is in the Tulare Lake Basin, about 7,600 ha (19,000 acres), with an estimated loading rate of 1.4 Gg N/yr (1,500 tons N/yr). Much of the remaining third of dairy corrals is in the San Joaquin Valley (

[5] http://www.water.ca.gov/landwateruse/lusrvymain.cfm
[6] http://www.conservation.ca.gov/dlrp/fmmp/Pages/Index.aspx

Table 11.101Table 11.10). Beef lot corrals that are not mapped here may contribute an additional 5% to 10% of the total shown in Table 11.10.

Table 11.101. Corral area and the estimated N loading to groundwater. The numbers of dairies reflect 2007-2009 conditions. Results are based on total rasterized area, which is adjusted by multiplying county rasterized area by the ratio of actual total Central Valley mapped area (12,244 ha) : rasterized area (18,292 ha). The larger rasterized area is due to mapping any 50 m raster cell containing mapped corral area as a "corral" raster cell, unless the raster cell also contains a lagoon, in which case a raster cell will be mapped as a "lagoon". Corral nitrogen loading to groundwater is assumed to be 183 kg N/ha/yr (163 lb N/ac/yr).

Period: 2005	No. of Facilities	Corral Area (ha)	Corral Area (acres)	Corral Nitrogen Loading to Groundwater (Mg N per year)	Corral Nitrogen Loading to Groundwater (tons per year)
Butte	4	5.5	13.6	1.0	1.1
Colusa	-	-	-	-	-
Glenn	47	n/a	n/a	n/a	n/a
Placer	1	5.2	12.8	0.9	1.0
Sacramento	39	70	173	13	14
Shasta	1	-	-	-	-
Solano	3	27.9	69.1	5.1	5.6
Sutter	1	-	-	-	-
Tehama	27	38	94	7	8
Yolo	3	10.0	24.8	1.8	2.0
Yuba	4	8	20	2	2
Sacramento Valley	**130**	**165**	**408**	**30**	**33**
Contra Costa	-	-	-	-	-
Madera	49	543	1343	99	110
Merced	318	1727	4267	316	348
San Joaquin	130	553	1367	101	112
Stanislaus	292	1635	4039	299	330
San Joaquin Valley	**789**	**4458**	**11015**	**816**	**899**
Fresno	104	1130	2793	207	228
Kern	53	1288	3182	236	260
Kings	149	1444	3568	264	291
Tulare	310	3759	9289	688	758
Tulare Lake Basin	**616**	**7621**	**18831**	**1395**	**1537**
Central Valley	**1535**	**12244**	**30254**	**2241**	**2470**

Given the wide range of reported leaching rates at individual sites, varying about one order of magnitude, the estimated county and region nitrogen loading to groundwater from corrals is associated with significant uncertainty. In the San Joaquin Valley, many of the corrals are located over relatively shallow water table, particularly in the area west of Highway 99, east of the San Joaquin River, and north of the Merced River. There, loading rates may often be higher than 183 kg N/ha/yr (163 lb N/ac/yr). In contrast, many of the Tulare Lake Basin corrals are located over a relatively thick unsaturated zone.

Given the lower precipitation in the Tulare Lake Basin relative to rest of the Central Valley, loading rates may be in the lower range of values reported due to significant attenuation in the unsaturated zone.

Although unknown sources of nitrogen loading to groundwater in the corral area include leaking underground pipelines for manure recycling within the production facility area, these here are not considered to contribute substantially to the above stated range of total loading rates from corrals.

Nitrogen Sequestration in Corrals: Significant amounts of nitrogen are stored in the corral and the uppermost soil. In Viers et al. (2012) we considered a number of studies (Miller et al., 2008; Vaillant et al., 2009) to provide four independent estimates of the potential magnitude of soil nitrogen storage in the immediate subsurface below dairy corrals. These ranged from 7.5 Mg N/ha (3.3 tons N/ac) to 37 Mg N/ha (17 tons N/ac). For the Central Valley, this suggests corral nitrogen storage in the range from 90 Gg N (100,000 tons N) to 450 Gg N (500,000 tons), accumulated over a 30 year period or longer. The corresponding annual contribution to soil N storage in Central Valley corrals may be as high as 3 – 15 Gg N/yr (3,300 – 17,000 ton N/yr) – higher or much higher than the estimated leaching rate to groundwater, 2.2 G N/yr (2,500 tons N/yr). Due to the warm, dry climate in California, it is more likely that soil N storage is in the lower part of this range.

11.6.2 Nitrogen Loading Rates from Dairy Lagoons

Work Description: Like corrals, most liquid manure lagoons in the Central Valley are associated with dairy facilities. Dairy lagoons are unlined or clay-lined, earthen containments to collect wastewater and manure-contaminated runoff from the corral and animal housing areas of the dairy. Many dairies employ one or several of various solid separation processes to minimize the amount of solids waste collected into the lagoon. This includes settlement basins, weeping walls, and other mechanical solids separators. Liquid manure waste is stored in the lagoon. Lagoon effluent is reused on the dairy for flushing concrete free-stall lanes in the animal holding area. Lagoon effluent is ultimately recycled by direct application to cropland, typically within the immediate vicinity of the dairy animal holding areas. Liquid manure application is typically by gravity from the lagoon into an irrigation system, although other forms of manure spreading are also used.

Nearly all of Central Valley dairy lagoons were built prior to the issuance of the Dairy General Order in 2007. Prior to 2007, regulatory requirements for the construction of liquid manure lagoons were governed under California Water Code Title 27, which required that lagoons are lined with soil containing at least 10% clay (for a review of the guidelines, see Brown et al. 2003). The soil liners typically develop a thin, but highly effective sludge layer that controls the seepage rate from the lagoon (Ham 2002).

Dairy lagoons are subject to leaching, even if only at relatively slow rates. Chapter 4 in Viers et al. (2012) provides an extensive review of nitrogen leaching to groundwater from dairy lagoons. Literature and field data suggested that rates may range from less than 200 kg N/ha/yr (178 lb/ac/yr) to over 3,650 kg N/ha/yr (3,260 lb/ac/yr). In 2015, the Central Valley Representative Dairy Monitoring Program published a follow-up study for which field work was completed on 17 dairy lagoons located throughout the Central Valley. Seepage rates from these lagoons were found to range from less than 0.2 mm/d to 2.2 mm/d. Mean and median seepage rates were found to be 1.1 and 0.7 mm/d, respectively, close to the NRCS lagoon construction guidelines of 0.9 mm/d. Importantly, based on typical nitrogen concentrations, the average nitrogen leaching rate to groundwater was found to be 1171 kg N/ha/yr (1045 lb N/acre/yr). We used this average to compute groundwater nitrogen leaching from all dairy lagoon areas in the Central Valley.

For computer simulations of historic loading to groundwater, we assume that lagoon loading to groundwater was constant in time since 1970, despite the increasing cattle numbers. Prior to 1970, we assume that no lagoons existed in the Tulare Lake Basin. Prior to 1970 and the passing of the Porter-Cologne Act in 1968, few lagoons existed, and many of the animals grazed on pasture for significant portions of the year.

The total area of dairy lagoons in the Tulare Lake Basin was mapped in the same manner as the open corral area: using a 2007 database of dairy addresses provided by the Regional Water Quality Control Board the latest Department of Water Resources land use surveys for Central Valley counties to locate all dairies, and 2009 aerial photos provided by the Department of Conservation Farmland Mapping and Monitoring Program (FMMP) as the basis for manual digitization of corrals and lagoons (see previous section).

Data/Results and Discussion: More than 4,400 individual lagoons were identified on over 1,300 dairy facilities. Their total mapped area is 2,378 ha (5877 ac). Projecting the lagoons onto a raster map with 50 m x 50 m raster cells yielded a significantly larger area, 6373 ha (15748ac): The mapping rule, projecting digitized GIS shapefile lagoon objects onto the 50 m raster grid identified any raster cell overlapping with a lagoon as a “lagoon”. Yet, lagoons are relatively small compared to the raster cells, and have a typically long and narrow shape. This resulted in the much larger “lagoon” area in the raster grid used for GNLM. The GNLM area and corresponding loading estimates were therefore multiplied by the ratio 2378/6373 to obtain properly scaled results (Table 11.11).

Table 11.11: Lagoon area and estimated N loading to groundwater from storage lagoons based on the average leaching rate measured on Central Valley dairies, 1171 kgN/ha/yr (1045 lb N/ac/yr). Lagoon area was obtained from the GNLM raster grid area for lagoons in each county and scaled by the average ratio of mapped lagoon area : rasterized lagoon area (2385 ha : 6373 ha).

Period: 2005	No. of Facilities	Lagoon Area, (ha)	Lagoon Area, (acres)	Lagoon Nitrogen Loading to Groundwater (Mg N per year)	Lagoon Nitrogen Loading to Groundwater (tons per year)
Butte	4	0.9	2.3	1.1	1.2
Colusa	-	0	0	0	0
Glenn	47	n/a	n/a	n/a	n/a
Placer	1	0.7	1.8	0.9	1.0
Sacramento	39	21	52	24	27
Shasta	1	0	0	0	0
Solano	3	1.6	3.9	1.9	2.0
Sutter	1	0	0	0	0
Tehama	27	15	38	18	20
Yolo	3	1.1	2.8	1.3	1.4
Yuba	4	5	12	6	7
Sacramento Valley	**130**	**46**	**113**	**54**	**59**
Contra Costa	-	0	0	0	0
Madera	49	96	237	112	124
Merced	318	428	1058	502	553
San Joaquin	130	161	397	188	207
Stanislaus	292	427	1056	500	552
San Joaquin Valley	**789**	**1112**	**2748**	**1302**	**1435**
Fresno	104	136	336	159	176
Kern	53	178	439	208	229
Kings	149	252	624	296	326
Tulare	310	654	1617	766	845
Tulare Lake Basin	**616**	**1220**	**3016**	**1429**	**1575**
Central Valley	**1,535**	**2378**	**5877**	**2785**	**3070**

We note that low nitrate (and ammonium) concentrations found in monitoring wells constructed in the Tulare Lake Basin adjacent to relatively old manure storage lagoons (Harter et al., 2013) suggests that, under conditions of deep water table (> 20 m below ground surface), either significant denitrification occurs or lateral movement across perching layers distributes the nitrogen across a larger recharge area.

Nitrogen Sequestration in Lagoons: Lagoons, like corrals, may store significant amounts of nitrogen either in a sludge layer at the bottom of the lagoon or in the subsurface below the lagoon. The organic nitrogen stored in the sludge layer or the lagoon is potentially stored there for long periods of time (years to decades) while the lagoon is operating. Following the methodology proposed in Viers et al. (2012), total storage within the lagoon and in the unsaturated zone below the lagoon, across all 2,378 ha (5,877 ac) of Central Valley lagoons amounts to a total sequestration of 51 Gg N (56,000 tons N) over a period of 30 years or more. The annual nitrogen sequestration rate associated with lagoons is therefore on the order of 1.7 Gg N/yr (1,900 ton/yr). The combined annual rate of nitrogen sequestration on dairy facilities (corrals and lagoons) is on the order of 10 Gg N/yr (11,000 ton/yr) – less than 5% of the estimated amount of nitrogen land applied as manure (see next section).

11.6.3 Nitrate Loading Rates in Irrigated Crop Fields with Manure Applications

Work Description: Dairies in the Central Valley no longer maintain significant acreages of irrigated pasture land for cattle grazing (a practice common prior to the 1970s). Instead, animals are confined to corrals and freestalls, while agricultural land surrounding the animal production facility is used for the production of forage crops other than pasture. The most common forages in the Tulare Lake Basin are alfalfa (*Medicago sativa*), corn (*Zea mays*), sudangrass (*Sorghum bicolor* subsp. *drummondii*), and winter grains including triticale (*Triticale hexaploide*), oats (*Avena sativa*), wheat (*Triticum aetivum*), and barley (*Hordeum vulgare*). Liquid and solid manure from the animal holding areas are recycled to forage crops managed by the dairy, except alfalfa fields. Alfalfa, a leguminous crop capable of fixing nitrogen directly from atmospheric sources, may receive some solid manure prior to planting or after the last cutting in the fall, but generally receives little or no manure water application and only small amounts of fertilizer application. Dairies also manage vineyards, cotton, and other crops, which may be used for some (limited) manure application.

Dairy croplands and other cropland areas receiving manure may also be subject to synthetic fertilizer applications, irrigation water nitrate application, and atmospheric deposition of nitrogen. Like wastewater effluent and biosolids from WWTPs and FPs, dairy manure applied to agricultural lands is an input to the mass balance analysis of nitrogen fluxes in the agricultural landscape (see Section 11.2). Our previous work (Viers et al., 2012) showed that a mass balance approach, though not exact, provides a valuable approximation of groundwater nitrate losses from manure applications. Over the past decade, this has led to the introduction of manure management practices that directly account for the nitrogen-fertilizer value of manure by measuring the amount and nitrogen-content of manure applied to fields, by timing the manure applications, and by including manure into the overall field fertilization schedule.

The 2007 Dairy General Order issued by the Central Valley Regional Water Quality Control Board requires dairies to fully account for the nitrogen content of land applied manure and other nitrogen sources, while meeting a nitrogen application ratio (ratio of total nitrogen applied to total nitrogen removed in the harvest) of 140%–165%. Historically—prior to the 2007 Dairy General Order—manure (liquid or solid) was typically applied during the spring and during the fall fallow seasons between harvest of summer/winter crops and planting of winter/summer crops on fields with corn and winter grains.

To estimate the amount of manure generated by a dairy facility, we here principally relied on the number of total adult cows on a dairy, as the total nitrogen excretion of dairy cows is relatively well known, with some uncertainty and variability among dairies. From the number of adult cows, the total N excretion was computed. After excretion, nitrogen is subject to volatilization and other atmospheric losses and to export of manure to off-dairy cropland. The remaining nitrogen is land-applied. Nitrogen land-applied via manure application to a dairy's cropland is obtained by subtracting atmospheric losses and nitrogen in manure exports from the total nitrogen exreted on a dairy. The following sections describe further details.

Number of Adult Cows on a Dairy Facility: The Central Valley Regional Water Board, since 2007, regulates nitrogen management and applications on dairy facilities in the Central Valley (Central Valley Regional Water Quality Control Board, Order R5-2013-0122). As part of the dairy order, individual facilities submit annual nitrogen reports to the Regional Water Board. We used two resources to estimate the number of adult cows on a dairy. First, a spreadsheet was obtained from the Central Valley Regional Water Board in 2010, also used by Viers et al. (2012), which lists the "ECR Total Mature Cows (2007)", the "2008 Total Mature Cows (7/08)" and the "2009 Total mature Cows (7/09)". The spreadsheet that is applied here and in Viers et al. (2012) is referred to as the "RB5 2010 dairy database". We also digitized the number of milking cows and the number of dry cows from the paper copies of the dairy annual reports available at the Regional Water Board offices in Fresno and Rancho Cordova. This latter resource is here referred to as the "UCD Dairy Annual Report Database v2012" (where 'v2012' refers to the version of the database).

The UCD Dairy Annual Report Database v2012 was the preferred source of information, but not all dairies reported numbers in all years. We sought to determine a representative number of adult cows for the 2005 period by using the number of cows that most closely represents the years 2003-2007 from the data we had available. To do this, we first determined the number of adult cows, for each dairy and each year between 2007-2011, using the first available of the following list of potentially available data:

1. Number of milking cows plus number of dry cows from the dairy annual report for the respective year
2. If the number of dry cows is not available: 120% times the number of milking cows reported in the dairy annual report for the respective year. This formula assumes that each milking cow is dry for 2 out of 12 months
3. If none of the above is available: ECR Total Mature Cows (2007)
4. If none of the above is available: 2008 Total Mature Cows (7/08)
5. If none of the above is available: 2009 Total Mature Cows (7/09)
6. If none of the above is available: no record for number of adult cows available for the respective year

The above algorithm generated a number of adult cows (or an empty record) for each of the five years between 2007 and 2011. The final "period 2005 number of adult cows" on a dairy was determined from the earliest year in this array for which there was not an empty record. For most of the 1565 facilities in the UCD Dairy Annual Report Database v2012, this was the number determined from the above algorithm for the year 2007. For all subsequent computations described here, it was then assumed that an adult cow is lactating for 305 days and that it is dry for 60 days each year.

Historic Number of Dairy Cattle: We also compiled data from USDA National Agricultural Statistics Service. Animal census data are available for 1950, 1992, 2002, and 2007. We assumed that 1950 data were representative of the 1945 period. For all other periods, we linearly interpolated the number of adult dairy cows reported for each of the Central Valley counties in the census years to 1960, 1975, 1990, and 2005 (Table 11.12).

Total N Excretion from a Dairy Facility's Herd: Daily N excretion from lactating cows and dry cows follows the method described in Chapter 4 of Viers et al. (2012): "[…] daily N excretion from lactating cows and dry cows is 462 g N d^{-1} and 195 g N d^{-1}, respectively (UC Committee of Consultants – Harter, 2007). This amounts to 153 kg N/yr (336 lbs/yr) excreted per adult cow, consistent with Pettygrove et al. (2010). To estimate the N excretion from support stock, we used the ratios in Table 1 of Pettygrove et al. (2010), which suggest that 25 kg N/yr (56 lbs/yr) are excreted by support stock for every adult cow, which – according to their Table 1 – excretes 148 kg N/yr (326 lbs/yr). Their computation was based on the assumption that, on average, each dairy has 0.17 calves (0-6 months) and 0.5 heifers (6 months to 24 months) per adult cow. We adopted the EPA estimate of 1.4 support stock per milk cow (lactating cows[7]) or 1.17 support stock per adult dairy cow, and scaled the Pettygrove et al. (2010) support stock excretion rate to 45 kg N/yr (101 lbs/yr) for the 1.17 support stock per adult dairy cow. Per adult cow, and including support stock, the total excretion rate is therefore 198 kg N/yr (437 lbs/yr)."

Historic N excretion rates by county and from individual dairies were estimated based on historic changes in Central Valley herd size and California (statewide) milk production per milking cow, both obtained from USDA agricultural census data for 1950, 1992, 2002, and 2007; and based on historic fraction of milk nitrogen to feed nitrogen intake (milking cow nitrogen use efficiency) representative for the Central Valley.

Future N excretion rates are based on the assumption that the 2005 number of milking cows remains constant, that milk production per head increases at the same rate as that for 1992-2007, obtained from the USDA agricultural census data for 1992, 2002, and 2007, and that feed to milk nitrogen use efficiency will also increase at the same rate as over the past 60 years - by one percentage point every 15 years.

[7] In the EPA database, lactating cows are referred to as "milking cows" to which "dry cows" are added to obtain the total number of "adult cows"

Table 11.12: Historic number of milking cows, by Central Valley county, reported in USDA NASS census data for 1950, 1992, 2002, and 2007 and interpolated to the central (3rd) year of each five-year period. The table also shows three ratios used to compute the relative amount of dairy animal N excretion in the Central Valley (CV, last row): Ratio of historic period number of milking cows relative to 2005, ratio of historic period California milk production per milking cow relative to 2005, and the fraction of milk nitrogen relative to feed nitrogen intake, by historic period.

County / Region	1945	1960	1975	1990	2005
Butte	9558	7598	4659	1719	1513
Colusa	2970				
Glenn	18032	18407	18969	19531	24505
Placer	5477				
Sacramento	21774	21842	21944	22046	23578
Shasta	5694	4608	2979	1350	297
Solano	5672	5043	4100	3156	4736
Sutter	6396	5008	2927	845	
Tehama	9110	8676	8025	7374	5069
Yolo	4726				2414
Yuba	4726	4041	3015	1988	3942
Sacramento Valley	**94135**	**75225**	**66617**	**58010**	**66055**
Contra Costa	3640				
Madera	15851	19008	23744	28479	78385
Merced	70438	95030	131918	168807	303920
San Joaquin	47994	58282	73714	89146	128418
Stanislaus	83876	103149	132058	160967	216226
(Northern) San Joaquin Valley	**221798**	**275469**	**361434**	**447399**	**726949**
Fresno	41634	52393	68530	84668	126097
Kern	11954	18984	29529	40073	125684
Kings	28814	46592	73259	99926	184172
Tulare	46777	97205	172848	248490	539620
Tulare Lake Basin	**129180**	**215175**	**344166**	**473158**	**975573**
Central Valley	**445,114**	**565,868**	**772,217**	**978,567**	**1,768,577**
CV No. of milking cows, relative to 2005, *#milkC*	0.252	0.320	0.437	0.553	1.000
CA Milk protein production per cow, relative to 2005, *milkN*	0.334	0.456	0.634	0.862	1.000
CV milk N as fraction of feed N, *milkNUE*	0.21	0.22	0.23	0.24	0.25
CV dairy animal N excretion, relative to 2005, $f\_N\_excr_{period\ l}$	0.105	0.173	0.309	0.504	1.000

The ratios of historic excretion rates to the 2005 excretion rate estimated from these census data is used to scale the 2005 excretion rate at the facility, county, region and Central Valley scale back to 1945, 1960, 1975, and 1990 (Table):

$$f\_N\_excr_{period\ i} = \frac{[\#\text{MilkC} * \text{MilkN} * (1 - \text{MilkNUE})/\text{MilkNUE}]_{year\ i}}{[\#\text{MilkC} * \text{MilkN} * (1 - \text{MilkNUE})/\text{MilkNUE}]_{2005}}$$

where:

- *year i*: the third year of each five-year period *i* considered in this report, i.e., 1945, 1960, 1975, 1990, 2005, 2020, 2035, 2050.
- $f\_N\_excr_{period\ I}$: Central Valley dairy adult cow nitrogen excretion rate in period *i* as a fraction of period 2005 N excretion
- *#MilkC*: total number of milking cows in the Central Valley, NASS census data
- *MilkN*: California average milk production per head, NASS census data
- *MilkNUE*: estimated average Central Valley ratio of milk nitrogen content to feed nitrogen intake per head

Actual changes in adult dairy cow numbers on individual facilities are not considered. For the spatially distributed simulations with GNLM, we also do not consider county-to-county variations in historic dairy herd growth and fluctuations. These could be considered in future versions. Instead, the simplifiying assumption was made that adult dairy cow numbers on all 2005 dairy facility locations grew at the same rate from 1945 to 2005.

Data/Results and Discussion: The estimated nitrogen excretion rate from dairy cattle in the Central Valley has risen exponentially throughout the six decades considered. Higher annual nitrogen excretion is driven by the growth in the Central Valley dairy herd size and the growth in per cow milk production.

The Central Valley dairy herd quadrupled over the 60 year period between 1945 and 2005. It doubled in size over a 40 year period between the late 1940s and the late 1980s. After 1980, growth accelerated and was particularly pronounced between the late 1980s and early 2000s, a period during which herd size doubled again in less than two decades. Herd growth was somewhat more pronounced in the Tulare Lake Basin than in the San Joaquin Valley. Growth abruptly levelled off in the mid-2000s. The number of dairy cows has remained stable since then, although the number of facilities has been decreasing. The Sacramento Valley on the other hand has historically featured only a relatively small number of dairies. There, the number of milking cows has fluctuated, but overall has been relatively steady throughout the six decades.

The milk production per milking cow has also increased by about 300% since 1945. Since nitrogen excretion rates are proportional to milk production, higher milk production per cow has also significantly affected the increase in nitrogen excretion. A simultaneous improvement in milk nitrogen to feed nitrogen intake has kept excretion rates from increasing even further.

Overall, total nitrogen excretion rates from the Central Valley dairy herd has increased by about 1200% from less than 40 Gg N/yr (4,400 tons N/yr) in the 1940s to 472 Gg N/yr (520,000 tons N/yr) in 2005 (Table 11.14Table). Until the 1960s, much of the nitrogen excretion in the study area is assumed to have occurred on irrigated pasture where plant uptake rates absorbed most of the manure nitrogen entering the root zone. However, since the early 1970s, liquid and solid manure is collected and land applied on crops. Since then, the amount of nitrogen that needs to be land applied – in direct proportion to the amount of nitrogen excreted - has increased five-fold. Manure nitrogen now stands to be about one-third of the total nitrogen applied to agricultural lands in the San Joaquin Valley and Tulare Lake Basin.

Table 11.13. Estimate of historical manure nitrogen excretion rates in the Central Valley based on USDA NASS California census data on milk production per head of cattle (hd) and total number of milk cows in the Central Valley.

Year	Milk Production [kg/hd/yr] (lbs/hd/yr)	Milk Nitrogen [kg N/hd/yr] (lbs/hd/yr)	Milk : Feed Intake Nitrogen Ratio	Excretion Rate [g N/milk cow/d] (lbs/milk cow/day	Number of Adult Dairy Cows in the CV	Total Excretion Ratio, relative to 2005	Total N Excretion in the CV [Gg N/yr] (tons N/yr)
1945	3,243 (7,150)	17 (37)	21%	173 (0.38)	445,114	0.105	36.9 (40,700)
1960	4,432 (9,770)	23 (51)	22%	223 (0.49)	565,868	0.173	60.4 (66,600)
1975	6,154 (13,566)	32 (70)	23%	292 (0.64)	772,217	0.309	108 (119,000)
1990	8,372 (18,456)	43 (95)	24%	376 (0.83)	978,567	0.504	176 (194,000)
2005	9,709 (21,404)	50 (111)	25%	413 (0.91)	1,768,577	1	350 (386,000)
2020	11,263 (24,831)	58 (128)	26%	432 (0.95)	1,768,577	1.118	392 (431,000)
2035	13,431 (29,612)	69 (153)	27%	489 (1.08)	1,768,577	1.268	444 (490,000)
2050	14,986 (33,039)	78 (171)	28%	520 (1.15)	1,768,577	1.347	472 (520,000)

Notes: The increase in milk N to feed N intake ratios is estimated to fit 1973 Committee of Consultant N excretion rate for California and approximate historic conditions. The number of cows in 1945 was assumed to be identical to the 1950 census data. The number of cows in 1960, 1975, and 1990 were estimated by linear interpolation of the 1950 and 1992 national agricultural census data. Similarly, the 2005 number of cows was estimated by linear interpolation of the 2002 and 2007 national agricultural census data. The historical total excretion rates for the Central Valley are based on the 2005 estimated N excretion and the N excretion ratio.

Table 11.14. Number of 2007 adult dairy cows, by county, in the UCD Dairy Annual Report Database v2012 (see text). Nitrogen volatilization, area of and nitrogen in land application of manure on cropland controlled by dairy facilities, and nitrogen reported as exported from dairy facilities in 2007. We assume that exported nitrogen is applied to agricultural cropland in the county. The total land area of crops considered for exported manure land application in each county is listed as the "exported manure land application area". The first table uses metric units, the second table (Table 11.15) uses American units.

County / Region	Number of Adult Cows, UCD Dairy Annual Report Database v2012	Nitrogen volatili-zation from manure, Mg N/yr	Dairy Facility Land Application Area, ha	Manure Nitrogen in Dairy Facility Land Application, Mg N/yr	Exported Manure Land Application Area, ha	Exported Manure Nitrogen, Mg N/yr
Butte	-	-	-	-	-	-
Colusa	-	-	-	-	-	-
Glenn	24714	1465	2027	2296	111157	95
Placer	800	60	353	98	0	0
Sacramento	18312	1388	2528	2140	81374	125
Shasta	-	-	-	-	-	-
Solano	3335	235	137	383	0	0
Sutter	550	1	39	2	0	0
Tehama	-	-	-	-	-	-
Yolo	2974	213	213	334	146948	13
Yuba	3320	256	405	262	38631	156
Sacramento Valley	**54005**	**3619**	**5703**	**5516**	**378110**	**388**
Contra Costa	-	-	-	-	-	-
Madera	111492	7251	6262	9905	151050	1926
Merced	294888	20227	23641	28608	231807	4395
San Joaquin	111419	7846	8791	10828	235494	1974
Stanislaus	220588	15370	16556	20729	157805	4349
(Northern) San Joaquin Valley	**738387**	**50695**	**55249**	**70069**	**776155**	**12644**
Fresno	129469	9682	15035	10679	538063	5118
Kern	178918	15200	24769	20286	388208	4514
Kings	179174	13592	31908	17394	233346	4782
Tulare	548163	41816	41120	50276	306434	17950
Tulare Lake Basin	**1035724**	**80290**	**112831**	**98635**	**1466051**	**32364**
Central Valley	**1828116**	**134603**	**173782**	**174220**	**2620316**	**45396**

Table 11.15: Same as Table 11.14, but in American units (short-tons, acres).

County / Region	Number of Adult Cows, UCD Dairy Annual Report Database v2012	Nitrogen volatile-zation from manure, tons N/yr	Dairy Facility Land Application Area, acres	Manure Nitrogen in Dairy Facility Land Application, tons N/yr	Exported Manure Land Application Area, acres	Exported Manure Nitrogen, tons N/yr
Butte	-	-	-	-	-	-
Colusa	-	-	-	-	-	-
Glenn	24714	1615	5009	2531	274675	104
Placer	800	66	872	108	0	0
Sacramento	18312	1530	6247	2359	201079	138
Shasta	-	-	-	-	-	-
Solano	3335	259	339	422	0	0
Sutter	550	1	97	2	0	0
Tehama	-	-	-	-	-	-
Yolo	2974	235	526	369	363115	14
Yuba	3320	282	1001	289	95459	172
Sacramento Valley	**54005**	**3989**	**14092**	**6080**	**934328**	**428**
Contra Costa	-	-	-	-	-	-
Madera	111492	7993	15473	10918	373251	2123
Merced	294888	22297	58417	31534	572806	4844
San Joaquin	111419	8649	21722	11936	581918	2176
Stanislaus	220588	16943	40910	22850	389944	4794
(Northern) San Joaquin Valley	**738387**	**55882**	**136523**	**77238**	**1917920**	**13937**
Fresno	129469	10673	37152	11771	1329581	5642
Kern	178918	16755	61204	22362	959281	4975
Kings	179174	14983	78846	19174	576610	5272
Tulare	548163	46094	101608	55420	757215	19786
Tulare Lake Basin	**1035724**	**88504**	**278810**	**108727**	**3622687**	**35675**
Central Valley	**1828116**	**148375**	**429424**	**192045**	**6474935**	**50040**

Atmospheric nitrogen losses from manure prior to land application: Following Viers et al. (2012), "atmospheric losses of nitrogen from the total mass of nitrogen excreted are assumed to be 38%, which is based on a 2003 EPA draft report on ammonia emissions from manure (EPA 2003). This estimate is near the upper end of the range of atmospheric losses provided by the University of California Committee of Consultants (Harter 2007), which suggested that these losses may range from 20% to 40% of excreted N. We use the higher number to account for the fact that a significant number of dairies in the Tulare Lake Basin are drylot dairies, where atmospheric N losses tend to be higher than on freestall dairies."

Atmospheric losses of nitrogen from the animal holding area, lagoons, and on-site dry manure storage amounts to 135 Gg N/yr (148,000 tons N/yr) using the above approach. Tulare Lake Basin emissions are 80 Gg N/yr (89,000 tons N/yr), San Joaquin Valley N emissions are 51 Gg N/yr (56,000 tons N/yr), while 4 Gg N/yr (4,000 tons N/yr) are emitted in the Sacramento Valley (Tables 11.14 and 11.15).

Manure nitrogen exports from a dairy facility: Exported manure is here determined by analyzing dairy manure export data reported by individual dairy facilities in dairy annual reports for 2007, 2008, 2009, and 2011. The data were digitized from printed reports available at the Regional Water Board offices in Fresno and Rancho Cordova and added to the UCD Dairy Annual Report Database v2012. The data record retrieved from the annual reports into the database are the pound of nitrogen exported in manure from the dairy (where reported).

To determine a representative amount of N exported in the 2005 period, we focused on year 2007 records for each dairy. On a few dairies, the reported nitrogen exported in 2007 was larger than the amount of nitrogen available after subtracting 38% from the estimated nitrogen excretion on a dairy. In that case, we instead used the median amount of N exported from a dairy facility across all years between 2007 and 2011 for which N export was reported to be non-zero. If the median exported N was also larger than 62% of estimated nitrogen excreted on a facility, the amount of N export was reduced from the reported amount to 62% of the estimated nitrogen excreted, leaving no nitrogen for land application on the dairy (62% of estimated nitrogen excreted is exported and 38% is assumed to go to atmospheric losses).

Manure nitrogen applied on cropland managed by dairy facilities ("dairy cropland")

The amount of nitrogen available for land application within a dairy facility, *Nmanure*, is the computed for each dairy as the amount of N excreted minus the amount of N in atmospheric losses prior to land application minus the amount of N exported from the dairy facility.

In the Central Valley, the estimated amount of manure nitrogen land applied on cropland considered to be part of a dairy facility and managed by the dairy ("dairy cropland") is 174 Gg N/yr (192,000 tons N/yr) on approximately 174,000 ha (429,000 acres). This yields a Central Valley average application rate of manure N on dairy cropland of 1,000 kg N/ha/yr (890 lb N/ac/yr). More than half of this dairy cropland land application occurs in the Tulare Lake Basin, at 99 Gg N/yr (109,000 tons N/yr). In the San Joaquin

Valley, land application of manure on dairy cropland is estimated to be 70 Gg N/yr (77,000 tons N/yr). Only about 6 Gg N/yr (6,000 tons N/yr) of manure is applied on dairy cropland in the Sacramento Valley (see Table 11.15). The San Joaquin Valley has the least amount of reported land application area per adult dairy cow resulting in a higher dairy cropland manure N application rate than elsewhere – over 1250 kg N/ha/yr (over 1100 lb N/ac/yr). In the Sacramento Valley, application rates are similar to Central Valley average. The Tulare Lake Basin has the most land application area per adult dairy cow resulting in an average land application rate just under 900 kg N/ha/yr (under 800 lb N/ac/yr).

11.7 Nitrogen Mass Balance: Crop Group, County, Region, and Central Valley Scale Analysis using Agricultural Commissioner Reports (ACR) Data

11.7.1 Work Description: Total N applied and N use efficiency (ACR)

Typical (recommended) N application rates (*Nfertilizer* rate, see Task 5) for each crop were multiplied by each period's mean crop area within a county (see Task 4) to determine the total *Nfertilizer* applied at the crop, county and regional level. Period crop total *Nfertilizer* means were aggregated into crop groups (as defined in Task 4) at the regional level.

Crop N requirements can be met by both synthetic and organic N sources. Many field and grain crops, especially in the vicinity of dairy operations, receive manure as a source of nitrogen (see section 11.6). Farmers using dairy lagoon water on their fields typically reduce synthetic fertilizer applications to account for a portion of the crop N requirements. While more N may be available from dairy manure to meet crop needs, uncertainty about short- and long-term release of plant available forms of N from organic sources, dairy farmers have preferred use of synthetic N sources in addition to manure N to grow crops.

We use two different approaches to account for the reduction of synthetic fertilizer application where dairy manure is available. For the analysis in this section, which is based on on ACR data and does not account for any spatially distributed crop or manure distribution within a county, we use the following procedure: Manure exports from dairies (*Nexport*) are typically solids and used as a soil amendment on a wide range of agricultural crops. We assume the N in this waste fraction is applied only in addition to typical N application rates (*Nfertilizer*). We assume that dry manure is exported in the 1975, 1990, and 2005 periods.

To account for manure nitrogen applications on dairy cropland in the 1975-2005 periods (*Nmanure*), we adjusted the total *Nfertilizer* within a county and by crop based on preliminary estimates of how much of the crop's fertilizer demand (*Nfertilizer*) may feasibly be met by dairy manure N without jeopardizing yield (Viers et al., 2012). Crops receive either liquid lagoon waste, solid waste, or both. A large fraction of manure applied on dairy cropland is in liquid form. Within the spatial scales considered here (crops, county), we do not distinguish crop acreages that are managed by dairies or by other farms. Instead, we here distribute *Nmanure* to all cropland within a county typically associated with manure – and particularly with liquid manure – land application, not just on dairy cropland. We assume that *Nmanure* will meet a certain percentage of those crops' county total *Nfertilizer*, if that much manure is available (less otherwise):

- 10% for grains (barley, wheat, oats, and miscellaneous grain and hay crops)
- 50% for corn, sorghum, sudangrass, cotton, sunflower, sugar beets, and miscellaneous field crops

While many of these crops are predominantly grown on dairies, significant areas of these crops are located off-dairy and not likely to utilize dairy manure as part of their fertilizer regime. As a result, the estimates obtained from this procedure may significantly overestimate manure contribution to

Nfertilizer, thus underestimating synthetic fertilizer applications to these crops. Furthermore, while pasture receives (sometimes very high) levels of dairy waste, we did not distribute manure to pasture in the 1975-2005 periods due in part to poor area reporting of this landuse in the agricultural commissioner's reports.

Total N from dairy manure sources and from synthetic fertilizer used in each county was calculated as the sum of exported solid manure, the estimated synthetic N application (the adjusted *Nfertilizer* of each crop), and any excess *Nmanure* not utilized in meeting field and grain crop N needs, *Nfertilizer*. For the 1945-1960 we assumed pasturelands received 100% of dairy waste and thus did not adjust field and grain crop's typical application rates, *Nfertilizer*, for those periods.

On the crop group level, within each county, *Nmanure* is distributed to four crop groups (corn/sorghum/sudan, cotton, other field crops receiving manure, and grain and hay) based on the fraction that each crop contributes to the total *Nfertilizer* within a crop group. Similarly, *Nexport* (exported manure) were distributed to these crop groups based on the fraction of these crops' *Nfertilizer* within their crop group's total *Nfertilizer*. As with the crop estimates, crop group synthetic N and total N applied are conservative due to the assumption that county-wide production of each crop group receives dairy waste, which is offset somewhat by neglecting on-dairy pasture disposal. For *Nmanure* and *Nexport* we used the data described in section 11.6.3 (also see Viers et. al. 2012, and Rosenstock et.al. 2014).

We define nitrogen use efficiency (NUE) as the total N harvested, divided by total N applied. For the ACR based data analysis here, we ignore nitrogen sources other than synthetic N and manure N: county, crop, or crop group contribution of atmospheric nitrogen deposition or irrigation water nitrogen. These will be considered in the more detailed GNLM analysis (see 11.8). NUE was analyzed at the crop/county level and aggregated into regions and crop groups.

11.7.2 Results and Discussion: Total N applied and N use efficiency (ACR)

As shown in Figure Table 11.16, and Figure 11.8, while harvest rates have increased steadily and linearly over time, the rate of increase of estimated total synthetic N applied has declined since 1990. This is partly due to increased N use efficiency in some crops, increased production of inherently more efficient crops. It is also due to the exponential increase in dairy cow numbers and manure N production (see 11.6), which – in this model - reduces synthetic N requirements in crops receiving this organic N source. There is currently also an excess of land-applied manure N in the system that cannot be absorbed by crops, despite relatively conservative assumptions that would maximize the utilization of *Nmanure* toward meeting *Nfertilizer* requirements. While the synthetic N use rate in the Central Valley has increased by only 26 Gg N/yr between 1990 and 2005, manure application rates have increased by 116 Gg N/yr over the same time period. Even in the Sacramento Valley where dairy operations are relatively scarce, manure production has increased due to higher per animal milk production (Table 11.7).

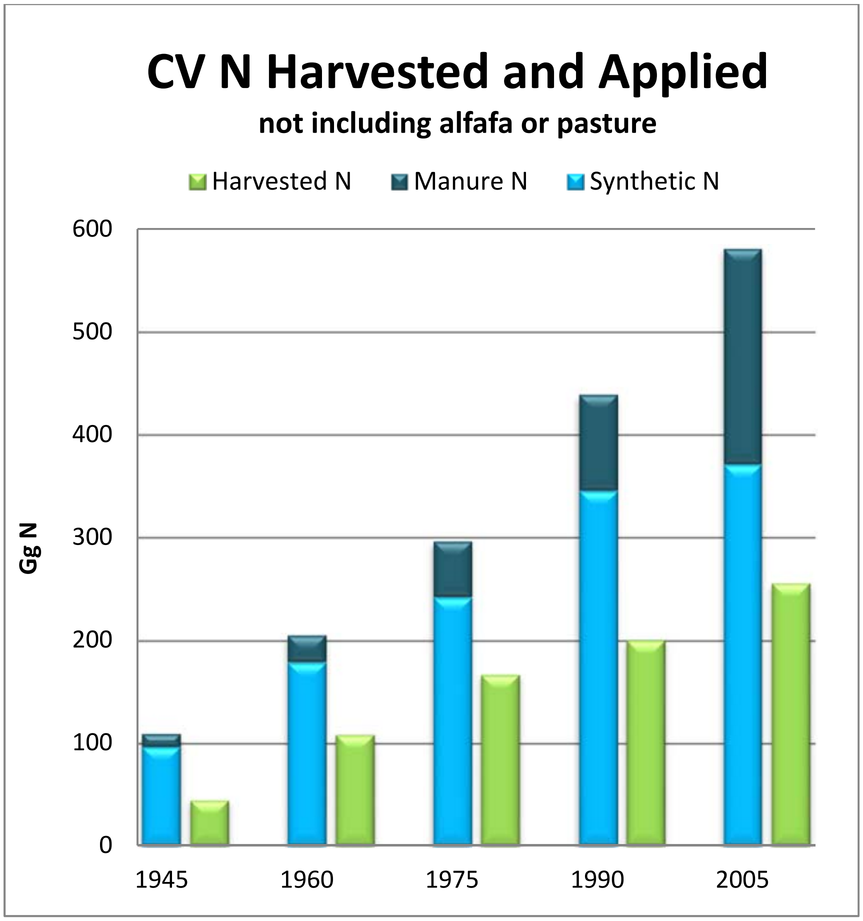

Figure11.7: 1945-2005 total Gg harvested N and total N applied (inclusive of synthetic and manure N) in the Central Valley, not including alfalfa and pasture. One Gg = 1,100 tons.

The nitrogen use efficiency (NUE, defined as the ratio of N harvested by total synthetic and manure N applied) computed for all crops that do not receive manure has increased from 33% in 1945 to 53% in 2005. However, across all crops, including those that receive manure, while synthetic N application increased by only 7% from 1990 to 2005, manure applications have increased by 35%, and while NUE increased sharply between 1945 to 1960, the average regional and Central Valley NUE has since returned to near 1945 levels (as of 2005, Figure). Even with a 28% increase in harvested N from 1990 to 2005, NUE decreased by 4% in that same time period, due largely to the exponential increase in manure N. From 1990 to 2005, the NUE in the Sacramento Valley, where manure N is much less prominent, remains stable rather than declining. By 2005 the overall NUE in the Sacramento Valley is nearly 10% higher than the two other, dairy-intensive regions (57% compared to 42% in the NSJV and 41% in the TLB (Table). We note that the NUE obtained here, based on ACR data and the aforementioned assumptions about manure nitrogen use, does not account for the additional applications from wastewater treatment and food processing facilities, well water used for irrigation and atmospheric deposition.

Table 11.16: Total regional N harvested and applied: synthetic, manure, and total Gg N, periods 1945-2005. Nfertilizer represents the sum of typical N application rates applied to the area of each crop. Synthetic N is based on replacing a portion of Nfertilizer with liquid on-dairy manure applications to field and grain crops 1975-2005. Exported dry manure is assumed as in addition to typical N application rates. Total N applied sums synthetic N, exported dry manure, and any excess liquid on-dairy manure not used in meeting grain and field crop N requirements. NUE is defined here simply as N harvest/Total N appliedAll figures exclude alfalfa and pasture. One Gg = 1,100 tons. SCV: Sacramento Valley, NSJV: (northern) San Joaquin Valley, TLB: Tulare Lake Basin, CV: Central Valley.

Gg N	1945	1960	1975	1990	2005
SCV Nfertilizer	29	57	82	100	96
SCV Synthetic N applied	29	57	82	98	92
SCV Manure N applied	0.4	1	2	3	7
SCV Total N applied	29	57	82	100	99
SCV N harvested	14	37	52	57	56
SCV NUE	50%	64%	64%	57%	57%
NSJV Nfertilizer	27	43	63	98	123
NSJV Synthetic N applied	27	43	63	85	106
NSJV Manure N applied	5	10	20	34	77
NSJV Total N applied	27	43	63	119	182
NSJV N harvested	12	23	39	51	76
NSJV NUE	39%	43%	53%	43%	42%
TLB Nfertilizer	41	78	128	196	213
TLB Synthetic N applied	41	78	128	163	173
TLB Manure N applied	8	16	32	57	127
TLB Total N applied	41	78	128	219	300
TLB N harvested	18	50	75	93	123
TLB NUE	37%	53%	54%	42%	41%
CV Nfertilizer	96	178	273	395	432
CV Synthetic N applied	96	178	242	345	371
CV Manure N applied	13	26	54	94	210
CV Total N applied	96	178	273	439	581
CV N harvested	45	109	167	201	256
CV NUE	41%	53%	57%	46%	44%

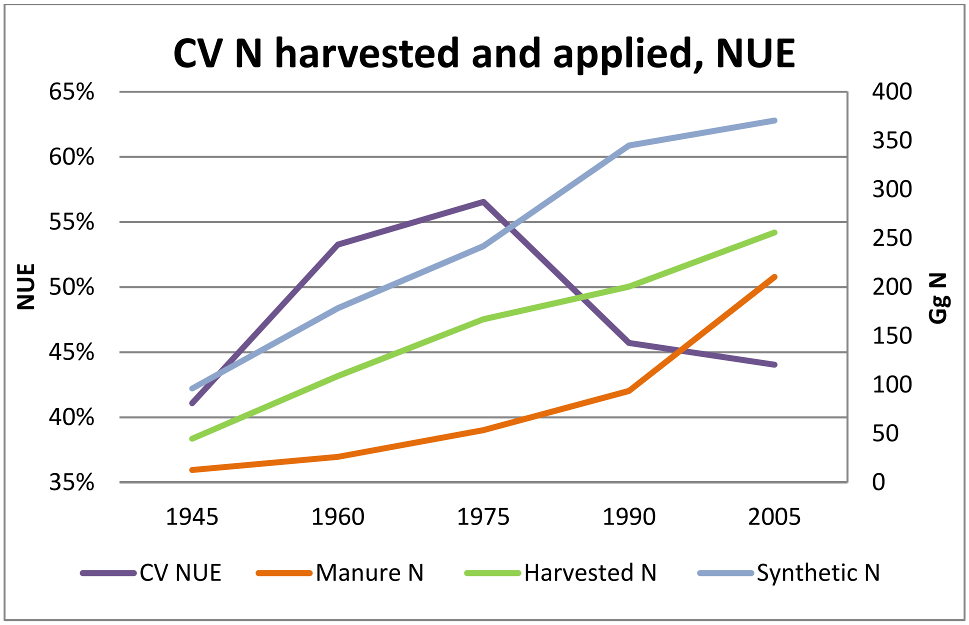

Figure 11.8: 1945-2005 change in overall NUE across all crops, Gg N harvested and manure and synthetic N applied in the Central Valley (excluding alfalfa and pasture), 1945-2005. One Gg = 1,100 tons.

NUE varies significantly between crops groups (Figure 11.8Figure and Appendix Table 1). Tree fruit are the least efficient crops in general although their NUE has increased significantly since 1945. Nuts and grapes make better use of applied N, and NUE has shown a general increase over time. For rice, an inherently efficient crop, NUE has not increased over time. The vegetable and berry crop group includes many crops. When analyzed as a crop group, NUE does not increase significantly (except between 1990 and 2005, which coincides with an increase in the use of drip irrigation and other management practices that reduce nitrate leaching, see Task 12). However, many individual crops within that crop group show a trend toward higher NUE, e.g., processing tomatoes. Of vegetables with relatively high area in the CV, potatoes are the most efficient (2005 NUE: 76%) followed by tomatoes and onions/garlic (2005 NUE: 67% and 64% respectively). The NUE varies regionally within the same crop group as well. For example, NUE for grapes and rice is similar between the three regions, while nuts range from 44% in the Sacramento Valley to 61% in the Tulare Lake Basin (2005 period).

All crops that are subject to receiving dairy manure (corn, sorghum, sudangrass, cotton, miscellaneous other field crops, and grain and hay) have seen a sharp decline in efficiency from 1975 to 2005. This follows the introduction of, and increasing use of confined animal feeding operations for milk production (section 11.6). Transporting the liquid fraction of manure is not possible over long distances and the increased disposal on crops near the dairy operation is responsible for the reduced NUE in these crops since 1975.

Note however that the efficiencies shown in Figure for field and grain crops (including the cotton and corn groups) are quite conservative, due to our distributing manure to 100% of the county area of these crops. Many of these crops are grown far from dairy operations and do not actually receive manure. Our spatial analysis, used for the GNLM (see 11.8), addresses this shortcoming by explicitly considering cropping areas under dairy management and cropping areas not under dairy management. The analytical method used here, to the degree it attributes manure use to a larger-than-actual crop area, can also be interpreted as a potential future scenario that would distribute available N (liquid or solid) across all county wide cropping areas (not just dairy areas) of crops typically used for such manure applications. The assessment shows that NUE is low even for this more optimal manure N distribution than currently practiced.

The analysis also shows that some of the historic application or harvest rates are highly uncertain. Some crops show high NUE for 1945, 1960, and 1975 (prior to manure applications). An NUE above 70-80% is considered by most agronomists a best-case scenario, especially when only considering manure and synthetic N contributions to a field. In the Central Valley, high NUE rates are expected to have been obtained in only some crop systems. Yet, our estimates using ACR data shows high NUE for both field crops and rice during the early periods (Figure 11.9). Rice is generally an inherently efficient crop, grown in paddies, where anaerobic and aerobic zones exist, allowing for a dynamic nitrification-denitrification cycle, but such high efficiency has never been reported. As for field crops, while leguminous dry beans do exceed 100% efficiency due to their nitrogen fixation, efficiency above 100% was also calculated for sugar beets in most periods. As for rice, sugar beets are an inherently efficient crop, but 100% NUE is not possible realistically. Hence, the high efficiencies shown in Figure 11.9 appear highly uncertain.

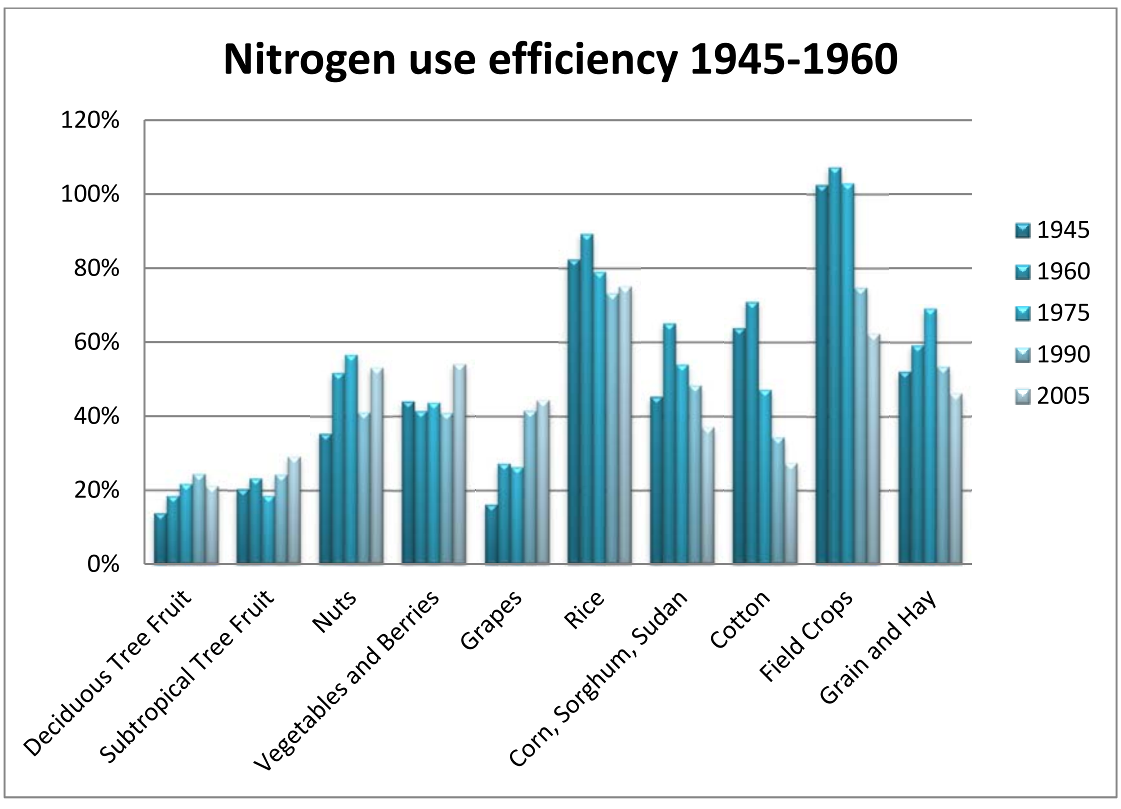

Figure11.9: Crop group nitrogen use efficiency, 1945-2005. In this calculation NUE only includes N applied from synthetic fertilizer and manure. Wastewater treatment facility and food processing waste is not included, nor atmospheric deposition and any N in well water used for irrigation. With the exception of legumes, values over 70% should be viewed with skepticism.

11.8: The Groundwater Nitrogen Loading Model for the Central Valley (GNLM-CV) - Raster-Based Nitrogen Mass Balance Analysis at the 50 Meter Scale

11.8.1 Work Description: GNLM_CV methodology for land application of dairy manure

Identification of Appropriate Cropland Areas: In GNLM, land applied dairy manure nitrogen is applied spatially to cropland associated with a specific dairy. For the spatially distributed analysis, the specific location for land application and their crops need to be identified, separately for each dairy.

For the years prior to the 2007 Dairy General Order, little is known about the actual distribution of cropland applied manure nitrogen including:

- The distribution across crops (crop categories)
- The distribution between on-dairy cropland and off-dairy cropland
- The distribution within county of origin and outside of the county of origin
- The relative contribution of synthetic fertilizer and manure nitrogen to meet applied fertilizer needs

Most manure is land applied to forage crops, particularly corn, which – on dairies - is often double-cropped with winter grain. Manure is also likely being applied to grain and hay crops (see Section 11.7). Dried or composted manure solids may be applied as soil amendment to other crops including perennial crops. Limited amounts of manure are applied to alfalfa, typically before seeding, and occasionally at the end of the season. Until recently (including the 2005 period), manure has been applied effectively as a soil amendment, in addition to synthetic fertilizer. Under the 2007 Dairy General Order, dairies are required to account for both, synthetic nitrogen and manure nitrogen as well as other sources of nitrogen (e.g., irrigation water) in their nutrient management planning.

We obtained data from the Central Valley Regional Water Quality Control Board that lists assessor's parcel numbers of land area associated with a dairy and its cropland ("RB5 APN Database v2015"). For all but the four Tulare Lake Basin counties and Madera County, the data was created in 2012 and extracted from 2011 dairy reports. Data were entered by Regional Water Board staff into a spreadsheet and merged with GIS parcel data to create shapefiles. This data is the best available for Central Valley dairy facility and cropland locations, but is limited based on the reliability of the data. For the Tulare Lake Basin and Madera County, the Regional Water Board staff used 2012 dairy reports. We note that the two datasets obtained from Central Valley Regional Water Board are not considered accurate survey document and cannot be used for legal determination. Here they are used for mapping, simulation, and illustrative purposes only.

We use the RB5 APN Database v2015 to identify the spatial extent of the parcels accessible by dairies for manure application. The APN parcel map is overlaid with the CAML landuse map through GIS analysis to determine the parcels in the landuse layer with cropland suitable for dairy manure land application (assumed to be mostly liquid manure), as indicated by a "1" in column "Dairy Manure" in Table 11.17.

For dairies in the UCD Dairy Annal Report Database v2012 (see Section 11.6) for which no APN data were listed in the RB5 APN database v2015, we determine the specific land parcels used by a dairy for land application of manure through spatial simulation: Using the total crop acreage reported by individual dairies in the UCD Dairy Annal Report Database v2012 , a computer program was written to identify all 50 m x 50 m pixels in the CAML map nearest to the dairy address that represent crops identified as crops receiving dairy manure on dairies, up to the total land area used by the dairy for manure application (indicated by a “1” in column “Dairy Manure” in Table 11.17).

Due to the simulation procedure and the use of the CAML, the simulation may not extend to entire land parcels or fields. Instead, simulated application areas are effectively circular areas around the address of a dairy, identifying all cropland to which liquid manure is typically applied. Also, the simulation did not allocate all land considered to belong to a specific dairy at once. Rather, the algorithm that we developed allocated one raster cell per dairy at a time, looping over all Central Valley dairies, before allocating the next 50 m x 50 m raster cell. This may generate interwoven raster cells that alternately belong to different dairies, where dairies are located near each other (Viers et al., 2012). While this, in some cases, creates unrealistic representation of individual dairy’s land application area, it minimizes the distance over which manure N is distributed from a dairy when multiple dairies without known land application area are nearby each other (Figure 11.10).

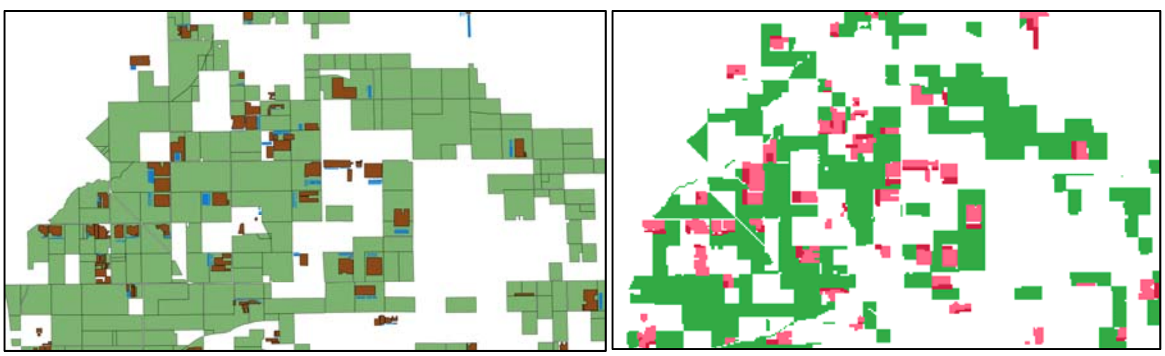

Figure 11.10: Left: Example detail of mapped lagoons (blue), corrals (brown), and dairy cropland (receiving land application of manure, green). Right: The corresponding rasterized map used for GNLM simulations with lagoons in dark red, corrals in red and land area receiving manure in green (smaller than the green area on the left, as it excludes nut and tree crops, vegetables, and some other crops found in the CAML map in areas identified as dairy cropland). The smallest resolution of the raster grid are cells with 50 m x 50 m.

Crops Used for Manure Application: In GNLM, as mentioned above, only some crops are considered to receive manure land applications. Exported dairy manure nitrogen is assumed to be mostly in form of manure solids or composted that is hauled off dairy and used as soil amendment. Manure N land applied on dairy cropland is assumed to include large amounts of liquid manure. Liquid manure is typically not applied to a number of crops that do receive organic soil amendments including dry dairy manure. For GNLM, the crops identified for receiving manure on dairy cropland (not exported, “1” in column “Dairy Manure” of Table 11.17) are a subset of crops receiving exported manure N (“2” in column “Dairy Manure” of Table 11.17).

Table 11.17: Agricultural and non-agricultural landuses, their DWR/CAML code and whether or not they are considered for dairy manure, WWTP effluent, FP effluent, and biosolids application: "Dairy Manure" value 1 indicates that the crop is considered "dairy cropland" if located within land parcels identified by dairies. These crops also receive manure exported from dairies within the same county. "Dairy Manure" value 2 indicates crops receiving dairy manure only if exported from dairies within the same county. Crops that are considered to receive WWTP effluent, biosolids, or FP effluent are indicated by a "1" in the respective column.

Landuse or Crop	Landuse Group	DWR/ CAML Code	Dairy Manure	WWTP Effluent and Biosolids	FP Effluent
Eucalyptus	Shrub/Forest	77	0	1	1
Citrus and Subtropical (Also Miscellaneous subtropical and jojoba)	Subtropical	300	2	0	1
Grapefruit	Subtropical	301	2	0	1
Lemons	Subtropical	302	2	0	1
Oranges	Subtropical	303	2	0	1
Dates	Subtropical	304	0	0	1
Avocados	Subtropical	305	2	0	1
Olives	Olives	306	2	0	1
Kiwis	Subtropical	308	2	0	1
Eucalyptus	Shrub/Forest	310	0	0	1
Deciduous Fruits and Nuts	Tree Fruit	400	2	0	1
Mixed deciduous (Apples)	Tree Fruit	401	2	0	1
Apricots	Tree Fruit	402	2	0	1
Cherries	Tree Fruit	403	2	0	1
Peaches and Nectarines	Tree Fruit	405	2	0	1
Pears	Tree Fruit	406	2	0	1
Plums	Tree Fruit	407	2	0	1
Prunes	Tree Fruit	408	2	0	1
Figs	Tree Fruit	409	2	0	1
Almonds	Nuts	412	2	0	1
Walnuts	Nuts	413	2	0	1
Pistachios	Nuts	414	2	0	1
No Access	No data	500	0	0	0
Field Crops (includes Flax, Hops, Castor Beans, Miscellaneous Field, and Millet)	Field Crops	600	1	1	1
Cotton	Cotton	601	1	1	1
Safflower	Field Crops	602	2	1	1
Sugar Beets	Field Crops	605	1	1	1
Corn (Field and Sweet)	Corn, Sorghum, Sudan	606	1	1	1
Grain sorghum	Corn, Sorghum, Sudan	607	1	1	1
Sudan	Corn, Sorghum, Sudan	608	1	1	1
Beans (dry)	Field Crops	610	2	0	1
Sunflowers	Field Crops	612	1	1	1
Grain and Hay (includes miscellaneous)	Grain and Hay	700	1	1	1
Barley	Grain and Hay	701	1	1	1
Wheat	Grain and Hay	702	1	1	1
Oats	Grain and Hay	703	1	1	1
Idle â€“ Cropped Past 3 Years	Barren	901	0	0	1
Idle â€“ New Lands	Barren	902	0	0	1
Pasture	Pasture	1600	1	1	1
Alfalfa	Alfalfa, Clover	1601	2	1	1
Clover	Alfalfa, Clover	1602	2	1	1

Landuse or Crop	Landuse Group	DWR/ CAML Code	Dairy Manure	WWTP Effluent and Biosolids	FP Effluent
Mixed pasture	Pasture	1603	1	1	1
Native Pasture	Native Pasture and Grassland	1604	0	1	1
Induced high water table native pasture	Native Pasture and Grassland	1605	0	1	1
Miscellaneous grasses	Native Pasture and Grassland	1606	0	1	1
Turf farms	Pasture	1607	0	1	1
Rice (includes rice & wild rice subclasses)	Rice	1800	2	0	1
Farmstead (with residence)	Farm	1901	0	0	0
Livestock feedlot operation	Farm	1902	0	0	0
Dairy farm	Farm	1903	0	0	0
Poultry farm	Farm	1904	0	0	0
Farmstead (without residence)	Farm	1905	0	0	0
Truck,Nursery, Berry Crops (includes cole mix, mixed, and misc. truck crops)	Vegetables and Berries	2000	2	0	1
Artichokes	Vegetables and Berries	2001	2	0	1
Asparagus	Vegetables and Berries	2002	2	0	1
Beans (green)	Vegetables and Berries	2003	2	0	1
Carrots	Vegetables and Berries	2006	2	0	1
Celery	Vegetables and Berries	2007	2	0	1
Lettuce	Vegetables and Berries	2008	2	0	1
Melons, squash, cucumbers	Vegetables and Berries	2009	2	0	1
Onions and garlic	Vegetables and Berries	2010	2	0	1
Peas	Vegetables and Berries	2011	2	0	1
Potatoes	Vegetables and Berries	2012	2	0	1
Sweet Potatoes	Vegetables and Berries	2013	2	0	1
Spinach	Vegetables and Berries	2014	2	0	1
Tomatoes (processing)	Vegetables and Berries	2015	2	0	1
Flowers, nursery, Christmas tree farms	Vegetables and Berries	2016	0	0	1
Bush berries	Vegetables and Berries	2019	2	0	1
Strawberries	Vegetables and Berries	2020	2	0	1
Peppers	Vegetables and Berries	2021	2	0	1
Broccoli	Vegetables and Berries	2022	2	0	1
Cabbage	Vegetables and Berries	2023	2	0	1
Cauliflower	Vegetables and Berries	2024	2	0	1
Brussels Sprouts	Vegetables and Berries	2025	2	0	1
Greenhouse	Industrial	2027	0	0	1
Urban landscape	Urban	2130	0	1	1
Lawn - irrigated	Urban	2131	0	1	1
Golf course	Urban	2132	0	1	1
Ornamental landscape	Urban	2133	0	1	1
Cemeteries - irrigated	Urban	2134	0	1	1
Vineyards (includes table grapes, wine grapes, and raisins)	Vineyards	2200	2	0	1

Distribution of Manure across the Landscape: The total amount of N used for land application on an individual dairy's cropland (cropland managed by a dairy) is obtained from the number of adult dairy cows on a dairy as described above, using the UCD Dairy Annual Report Database v2012 (see above). The land area considered for land application ("dairy cropland") are those CAML pixels with crops considered to be receiving manure if located on a dairy (including liquid manure, "1" in column "Dairy Manure" of Table 11.17) that are overlapping with or are located within parcels associated with a dairy's reported APNs (see above).

In GNLM, all manure applications, are distributed proportional to typical fertilizer N applied to the particular crop grown on a specific field. The amount of manure N applied to a dairy cropland raster pixel *i*, $NlandApplied_i$, is:

$$NlandApplied_i = \frac{Nfertilizer_i}{\sum_{i=1}^{n} Nfertilizer_i} \cdot \sum_{dairy} NlandApplied$$

where *n* is the total number of dairy cropland raster pixels on a dairy, $Nfertilizer_i$ is the typically applied fertilizer nitrogen (see Task 5) applied to the specific crop in raster cell *i* , and ∑NlandApplied is total amount of manure N land applied on a specific dairy.

On dairy cropland, the synthetic fertilizer applied, $Nsynthetic_i$, is reduced by no more than 50% from *Nfertilizer* (the amount of typically applied fertilizer) to account for the nitrogen applied as manure:

$$Nsynthetic_i = \min\left(\frac{Nfertilizer_i}{2}, [Nfertilizer_i - NlandApplied_i]\right)$$

Where manure N applied exceeds 50% of the typical fertilizer N applied, it is still considered to be applied albeit in excess of the typical annual fertilizer application needs, $Nfertilizer_i$.

The sum of exported dairy manure from all dairies within a county *j*, $Nexport_j$, is uniformly distributed to all cropland area, $AreaNexport_j$, within county *j* identified as receiving either exported manure only ("2" in columns "Dairy Manure" of Table 11.17) or as receiving on-dairy manure or exported manure ("1" in Table 11.17):

$$NmanureSale_{i,j} = \frac{Nexport_j}{AreaNexport_j}$$

where $NmanureSale_{I,j}$ is the exported manure nitrogen application rate [kg N/ha/yr] in raster cell *i* receiving exported manure in county *j*. In the current version of GNLM, $AreaNexport_j$ does not distinguish between dairy cropland and non-dairy cropland. Hence, dairy cropland is receiving the same rate of exported manure as other off-dairy cropland within county *j*, in addition to *NlandApplied*. While this does not reflect actual conditions, *NmanureSale* is generally only a small fraction of *NlandApplied*, thus not affecting the potential groundwater nitrogen loading significantly.

Historic Simulation of Manure Nitrogen Application to Cropland: For the historic simulations of spatially distributed nitrogen applications to cropland, we assume that until the late 1960s, manure nitrogen is not land applied but excreted on irrigated pasture. Hence, for modeling purposes, dairy manure from any dairy application source or location (cropland, lagoon, or corral) is assumed to not contribute to groundwater nitrate loading prior to the 1970s. In the 1975 representative period, land application of manure is assumed to be limited to cropland belonging to a dairy. The amount of manure N land applied within a dairy in periods 1975 and 1990 is computed using the Central Valley dairy animal N excretion ratio relative to 2005, $f\_N\_excr_{period\ l}$. No manure is exported from dairy-owned land prior to 1980. After 1980, exports of manure are assumed to gradually increase. GNLM assumes that the full amount of export is only reached in 2005. Between 1980 and 2005, the fraction of manure exported from dairies increases linearly from zero to the amount specified for 2005. Data are not available to determine the actual location of cropland receiving dairy manure prior to the 2005 period. Here, we simulate the dairy cropland area for each historic period by identifying the location of crops receiving dairy manure from that period's landuse distribution among the (time-invariant) APN parcels that belonged to a specific dairy in 2005.

Data and Simulation Limitations: Both, the APN data obtained from the Regional Water Board and the land areas simulated as being dairy cropland (on dairies without APN parcels identified) are subject to potential errors. APN parcel identification may be incorrect and simulated locations of dairy cropland parcels are only a spatial approximation, although the total land area corresponds to reported land areas for manure land applications. Parcels receiving manure may also change from year to year. It is unclear, whether the data provided by an individual dairy facility represent the acreage used in 2007 only or the complete acreage of all crops typically used for manure applications, even if only on a rotating basis. Furthermore, the CAML land use cover used for the spatially distributed, field-by-field nitrogen loading mass balance analysis, represents only a snapshot of cropping conditions that are often transient from year to year and may not be the actual cropping conditions of 2007. Hence, the intersection of eligible dairy cropland in CAML and APN parcels may yield a smaller than actual land application area.

The simulation process is a conceptual spatial approximation of complex processes in space and time involving people and land. The complexity of these processes is difficult to capture for current conditions, let alone under historic conditions, for which data cannot be collected retroactively. We emphasize that our approach is not designed to predict historic and current loading rates with high accuracy for each field or even for each individual dairy. Instead, our approach is designed to recreate the approximate conditions across all dairies in the study area, while preserving general spatial patterns of N fluxes driven by the variety of crops grown, and by the variability in management practices between dairies, as expressed by animal numbers and land base. The simulation algorithm described in this section was selected to provide overall consistency in the conceptual approach, given the lack of historic landuse and land ownership data for more detailed modeling input.

11.8.2 Work Description: GNLM-CV Methodology for Mapping and Simulating WWTP and FP Nitrogen Disposal to Agricultural Land and Percolation Basins

Percolation Basins: While our combined database identified approximately 900 WWTP and FP facilities, we here consider only the largest of them, 182 facilities. Of these facilities, about 75 facilities are known to have percolation basins. It was not possible to use existing databases to identify and map the spatial location and extent of individual percolation basins accurately.

We therefore chose to digitize the approximate location of percolation basins on these facilities using 2005 NAIP imagery and imagery available on Google Earth to digitize obvious or about obvious percolation basins based on facility address. One or multiple percolation basins may have been identified at each individual facility.

Importantly, we did not attempt to digitize to percolation basin area in the database. Instead all of the following areas in the immediate vicinity of a WWTP or FP facility were digitized: percolation basins, containment basin (whether or not they were lined was not distinguishable from aerial photos), and treatment basins. Fields are not designated as percolation basins in the digitization process unless it was obvious from the aerial photography that they are used for waste percolation (as opposed to land application). Facilities for which the application rates exceeded 2,000 kg N/ha/yr, a second round of digitization was undertaken to ensure that all possible percolation basin area was identified. Percolation basins outside of the study area were not included. Percolation basins located on study area boundaries were included.

The vectorized shapefile of the percolation basin is projected onto the 50 m raster grid and the total N loading to a percolation basin (kg N/year) is assigned to all raster grid cells designated as a facility's percolation basin area.

WWTP, FP, and biosolids land application areas: Using the WWTP and FP information in Section 11.5, we identify the total land area (ha) that each facility is using for land application of effluent or biosolids. We simulated the approximate land application area using the 50 m raster based landuse maps: Crops that were considered to typically receive WWTP effluent, FP effluent, or biosolids (identified in Table 11.17) were selected by finding the nearest raster cells occupied by any of these crops, until the full specified area available from the database was met or exceeded (up to 0.25 ha error). Application areas of individual facilities may interlace (but not overlap) with one another: the simulation algorithm selects one raster cell for each facility at a time, rotating among all facilities before selecting the next raster cell for a facility. This results in partially interlaced circular application areas. Simulations ensured that the simulated areas did not overlap with mapped percolation basins, golf courses, urban areas, lagoons, corrals, or dairy cropland areas by excluding these known areas from the search algorithm. For biosolids, we only mapped the 8 facilities in the TLB reported in Viers et al. (2012) and did not expand our database to SJV or Sacramento Valley.

Effluent that is applied to "golf" or "urban" will not affect groundwater leaching from those landuses. But it will not need to be applied to agricultural land area, where it would be increasing potential groundwater nitrogen loading. Four WWTPs therefore had their land application area set to zero prior to simulating land application area (W-4 Brentwood, W-37 Roseville, W-42 Rancho Murietta, W-75 Beale).

The simulation of nitrogen application to WWTP, FP, and biosolids land areas follows the same approach as the application of exported manure nitrogen. The total land applied N from a facility *j*, $Nfacility_j$, is uniformly distributed to all of its cropland application area, $AreaNfacility_j$, identified as receiving either WWTP effluent, biosolids, or FP effluent ("1" in Table XX):

$$NlandApplied_{i,j} = \frac{Nfacility_j}{AreaNfacility_j}$$

where $NlandApplied_{i,j}$ is the effluent or biosolids nitrogen application rate [kg N/ha/yr] in raster cell *i* receiving effluent or biosolids from facility *j*. Effluent and biosolids are here considered to be used as soil amendments and do not affect the amount of synthetic fertilizer N applied (*Nsynthetic* = *Nfertilizer*). Importantly, the land application area simulated for facility *j* does not also receive effluent or biosolids from other facilities or exported dairy manure N. It is also not located on land identified as dairy cropland.

11.8.3: Work Description: GNLM-CV Simulation

The potential groundwater nitrogen loading model for the Central Valley, GNLM-CV, computes the potential nitrogen available for leaching to groundwater, *NGW_nondirect*, from the landscape and root zone mass balance equation developed in Section 11.1, at the scale of individual 50 m x 50 m raster cells, separately for each of the periods identified in Section 11.2:

$$N_{GW\_nondirect} = N_{deposition} + N_{irrigation} + N_{synthetic} + N_{landApplied} + N_{manureSale} - N_{harvest} - N_{runoff} - N_{AtmLosses}$$

GNLM-CV spatially integrates the vegetated and natural landscape mass balance accounting with the potential groundwater nitrogen losses from sources for which no mass balance was computed, *NgwDirect*:

- urban areas (section 11.5.3)
  - 10 kg N/ha/yr (8.9 lb N/ac/yr) from synthetic fertilizer contributions plus
  - 10 kg N/ha/yr (8.9 lb N/ac/yr) from wastewater pipeline leakage
- golf courses (section 11.5.3)
  - 10 kg N/ha/yr (8.9 lb N/ac/yr)
- dairy corrals (section 11.6.1)
  - 183 kg N/ha/yr (163 lb N/ac/yr) adjusted for the ratio of raster cell to actual area
- dairy lagoons (section 11.6.2)
  - 1171 kg N/ha/yr(1045 lb N/ac/yr) adjusted for the ratio of raster cell to actual area
- alfalfa cropland (section 11.2)
  - 30 kg N/ha/yr (26.8 lb N/ac/yr)

- clover cropland (section 11.2)
    - 15 kg N/ha/yr (13.4 lb N/ac/yr)

All raster cells in the Central Valley are assigned to only one of these landuse types (vegetated/natural landscape, alfalfa, clover, urban, golf course, etc.). Raster cells are assigned either *NGW_nondirect* or *NgwDirect*, but not both. The final total potential groundwater nitrogen loading at a raster cell is computed using:

$$N_{GW} = N_{GW\_nondirect} + N_{gwDirect} + N_{septic}$$

In areas designated as urban with *Nseptic* larger than 10 kg N/ha/yr, 10 kg N/ha/yr of wastewater pipeline leakage (accounted for in *NgwDirect*) is subtracted from *Ngw* to avoid double-counting.

11.8.4: Results and Discussion: GNLM-CV Simulation

Cropland Area: The GNLM simulation includes over 3 million ha of mostly irrigated cropland (not including pasture) in 2005. Almost all of that land has been production for at least four decades (1975: 2.6 Mha). In 1945, only little over half to this area was growing crops (1.7 Mha) and in 1960 about three-quarter of the current irrigation cropland was in production (2.4 Mha).

Table 11.18: Historic and current cropland areas (from the landuse data in DWR, CAML, and – for 1945, 1960, 1975 – from the county Agricultural Commissioner's reports).

	Area [kha]					Area [thousand acres]				
Landuse Group	**1945**	**1960**	**1975**	**1990**	**2005**	**1945**	**1960**	**1975**	**1990**	**2005**
Alfalfa, Clover	257	372	293	264	304	634	920	723	653	750
Corn, Sorghum, Sudan	60	203	238	175	222	149	501	588	432	549
Cotton	143	308	425	483	311	353	760	1050	1195	769
Field Crops	98	205	183	282	202	243	507	452	696	500
Grain and Hay	657	722	579	294	383	1624	1783	1430	727	947
Nuts	45	65	151	320	492	111	160	372	791	1216
Olives	7	9	11	16	20	18	23	26	39	50
Rice	97	120	175	231	280	240	297	431	571	691
Subtropical	19	18	53	77	97	47	44	132	191	240
Tree Fruit	76	74	92	154	185	188	184	228	380	457
Vegetables and Berries	120	158	183	248	273	297	391	452	613	675
Vineyards	154	141	178	249	307	381	348	441	616	758
TOTAL	**1735**	**2394**	**2560**	**2794**	**3076**	**4286**	**5917**	**6326**	**6904**	**7602**

Table 11.18 shows the historical development of acreages among crop groups. In 1945, grain and hay was the largest crop group, at nearly 0.7 Mha, but declined to nearly half in 2005. Alfalfa (and some clover) also was a large crop in 1945 and has kept a steady area of 0.25-0.35 Mha. By 2005, nuts are the

leading crop grown in the Central Valley (almost 0.5 Mha). Other crop groups are similarly large – being harvested on 0.2 to 0.4 Mha each. Subtropical fruit (oranges, lemons) are the smallest crop group, at less than 1 Kha. For 1945 through 1975, the cropping areas follow the acreages reported by the Agricultural Commissioner Reports (Task 4). For 1990 and 2005, the cropland areas are determined by DWR landuse surveys. Alfalfa, nuts, vegetables and berries, and vineyards are expanding in area. Cotton has steadily lost land area to other crops.

All Areas Associated with Major Nitrogen Flux Components in the GNLM-CV Simulation: There are nearly 5.3 million hectare of land area in the study area of which – since the 1970s - about two-third is agricultural, irrigated cropland. The remainder of the land are natural landscape, grasslands and pasture, and nearly 10% are urban areas (476,000 ha, see Section 11.5).

The following four tables list historic, current, and simulated future land areas associated with the various nitrogen fluxes tabulated later in this section: Land areas simulated for atmospheric deposition, for atmospheric losses, and for potential groundwater nitrogen loading (pGW-N) include all 5.3 million ha of land area in the Central Valley. Nitrogen in irrigation water, synthetic fertilizer applications, and in harvest consider all irrigated cropland, including alfalfa and pasture (but not native pasture, grassland, or native vegetation). There is a small difference in the cropping area for synthetic fertilizer applications and the area considered to be harvested. The difference in land area corresponds to the "pasture" landuse (CAML codes 1600 and 1603), for which GNLM considers the harvested amount (145 kg N/ha/yr), but the synthetic fertilizer application is set to zero and hence the area is not counted toward the area in the tables below. *Nirrigation* applies to all cropland. It is slightly smaller than the harvested area due to some land areas overlying groundwater basins for which no groundwater irrigation concentration was specified. Land applied areas include dairy cropland and cropland associated with WWTP effluent, FP effluent, and biosolids application.

The tables list the area with non-zero potential groundwater nitrogen loading from harvested cropland, $N_{GW\_nondirect}$ ("pGW cropland"). The area is not as large as the harvested cropland area due to some cropping areas being accounted for otherwise: this includes all alfalfa and clover, which fall under the $N_{gwDirect}$ category ("pGW fixed rate lands"). For those, a fixed potential groundwater nitrogen loading rate was assigned, 30 and 15 kg N/ha/yr, respectively, included in the area for "pGW fixed rate lands". Note that "pGW cropland" does include pasture unless explicitly mentioned otherwise. Later in this section we provide separate analysis that exclude pasture, but include alfalfa and its leguminous nitrogen fixation as part of the cropland analysis.

The landuses assigned a fixed potential groundwater nitrogen loading rate ("pGW fixed rate lands"), i.e., urban, golf courses, dairy corrals, dairy lagoons, WWTP/FP percolation basins, alfalfa, and clover are listed separately. The area assigned to those in 2005 is 815,000 ha, of which nearly 480,000 ha are urban and 300,000 ha are alfalfa and clover. Finally, the tables include a group "pGW All", which is the sum of pGW cropland, pGW fixed rate lands, and potential groundwater nitrogen loading from septic systems. The latter is not confined to landuses designated as either urban or agricultural, but may include other landuses.

Table 11.19a-d: Land areas associated with various nitrogen fluxes in GNLM-CV for a) Central Valley, b) Sacramento Valley, c) (Northern) San Joaquin Valley, and d) Tulare Lake Basin, at the 50 m raster cell scale.

Central Valley	1945	1960	1975	1990	2005	2020	2035	2050
	[kha]	[kha]	[kha]	[kha]	[kha]	[kha]	[kha]	[kha]
Atm. Deposition	5289	5289	5289	5289	5289	5289	5289	5289
Irrigation	0	2390	2554	2919	3195	3195	3195	3195
Pot. Synth. Fertilizer	1734	2394	2560	2788	3071	3071	3071	3071
Synth. Fertilizer	1734	2394	2560	2788	3071	3071	3071	3071
Land Applied	46	46	151	177	179	179	179	179
Manure Sale	0	0	0	2409	2614	2614	2614	2614
Pot. Harvest	1735	2395	2560	2924	3202	3202	3202	3202
Harvest	1735	2395	2560	2924	3202	3202	3202	3202
Atm. Losses	4916	4732	4705	4631	4473	4473	4473	4473
pGW cropland	1291	1797	2412	2685	2759	2730	2728	2727
pGW fixed rate lands	373	557	583	657	815	815	815	815
pGW All	3520	3872	4178	4334	4458	4450	4450	4450

Sacramento Valley	1945	1960	1975	1990	2005	2020	2035	2050
	[kha]	[kha]	[kha]	[kha]	[kha]	[kha]	[kha]	[kha]
Atm. Deposition	1798	1798	1798	1798	1798	1798	1798	1798
Irrigation	0	705	725	796	893	893	893	893
Pot. Synth. Fertilizer	538	707	730	743	840	840	840	840
Synth. Fertilizer	538	707	730	743	840	840	840	840
Land Applied	2	2	6	7	7	7	7	7
Manure Sale	0	0	0	346	378	378	378	378
Pot. Harvest	538	708	730	801	900	900	900	900
Harvest	538	708	730	801	900	900	900	900
Atm. Losses	1726	1667	1643	1622	1556	1556	1556	1556
pGW cropland	362	437	632	679	762	762	762	762
pGW fixed rate lands	72	131	154	175	242	242	242	242
pGW All	1286	1328	1427	1448	1504	1504	1504	1504

San Joaquin Valley	1945	1960	1975	1990	2005	2020	2035	2050
	[kha]	[kha]	[kha]	[kha]	[kha]	[kha]	[kha]	[kha]
Atm. Deposition	1308	1308	1308	1308	1308	1308	1308	1308
Irrigation	0	566	583	732	802	802	802	802
Pot. Synth. Fertilizer	535	568	583	665	743	743	743	743
Synth. Fertilizer	535	568	583	665	743	743	743	743
Land Applied	6	6	43	54	58	58	58	58
Manure Sale	0	0	0	710	775	775	775	775
Pot. Harvest	535	569	583	732	802	802	802	802
Harvest	535	569	583	732	802	802	802	802
Atm. Losses	1163	1143	1140	1126	1071	1071	1071	1071
pGW cropland	392	462	642	718	668	645	643	642
pGW fixed rate lands	145	165	168	182	237	237	237	237
pGW All	1030	1063	1118	1145	1148	1142	1142	1142

Tulare Lake Basin	1945	1960	1975	1990	2005	2020	2035	2050
	[kha]	[kha]	[kha]	[kha]	[kha]	[kha]	[kha]	[kha]
Atm. Deposition	2183	2183	2183	2183	2183	2183	2183	2183
Irrigation	0	1119	1246	1391	1500	1500	1500	1500
Pot. Synth. Fertilizer	662	1119	1246	1380	1488	1488	1488	1488
Synth. Fertilizer	662	1119	1246	1380	1488	1488	1488	1488
Land Applied	38	38	102	117	114	114	114	114
Manure Sale	0	0	0	1353	1462	1462	1462	1462
Pot. Harvest	662	1119	1246	1391	1500	1500	1500	1500
Harvest	662	1119	1246	1391	1500	1500	1500	1500
Atm. Losses	2026	1922	1922	1883	1847	1847	1847	1847
pGW cropland	537	898	1138	1289	1329	1323	1323	1323
pGW fixed rate lands	156	261	261	300	336	336	336	336
pGW All	1203	1482	1633	1741	1807	1805	1805	1805

Nitrogen Fertilizer Applications, by Crop Group: In 2005, the total amount of synthetic fertilizer applied, *Nsynthetic*, after accounting for manure applications (which reduces the typical amount of synthetic fertilizer applications, *Nfertilizer*, on dairy cropland), is estimated by GNLM to be 504 Gg N/yr in the Central Valley. The largest share of that synthetic fertilizer - about one-third - is for about 600,000 ha of forage crops (155 Gg N/yr for corn, sorghum, sudan, grain and hay crops), and over 20%, goes to about 500,000 ha of nut crops, predominantly almonds (112 Gg N/yr). More than half of the synthetic fertilizer is therefore applied to one-third of the cropland – that with some of the most nutrient-rich crops. Cotton (59 Gg N/year), rice (41 Gg N/yr), and vegetables (55 Gg N/yr) are the next largest users.

In contrast, the largest synthetic fertilizer users in the 1975 period were forage crops and cotton. In the 1940s – albeit with significant uncertainty – grain and hay crops may have been the leading synthetic fertilizer consumers. Overall demand for synthetic fertilizer has risen about 5-fold between the 1940s and the 2000s, from nearly 100 Gg N/yr to over 500 Gg N/yr. For the 1990 and 2005 period, the amount of synthetic fertilizer use estimated by GNLM is significantly larger than that obtained by using the ACR acreages – for 2005, the GNLM estimate is nearly 20% higher (504 Gg N/yr compared to 432 Gg N/yr of "*Nsynthetic*", see section 11.7.2 above). The difference is due to the different cropping areas estimated by the ACR versus the DWR-based landuse surveys in CAML (Note: the same crop-specific rates are used for the ACR analysis and the GNLM analysis).

The 2005 top synthetic fertilizer users are also the most intensively grown crops: corn, sudan, and sorghum have an average application rate of 381 kg N/ha/yr. The rate is this high, because GNLM assumes and accounts for double-cropping with winter-grain during winter and spring in the 1990 and 2005 period (Appendix Table 3). Winter grain in rotation with summer corn/sorghum/sudan is not accounted for in the "Grain and Hay" group. Nuts (227 kg N/ha/yr) and vegetables (205 kg N/ha/yr) are the next-most intensive users of synthetic nitrogen. While these high application rates correspond to large nitrogen removal in harvested materials, the intensity of the nitrogen throughput in these crops also raises the risk for large potential groundwater nitrogen loading.

Application rates have not increased since the 1990 period, but were much lower in the 1945, 1960, and 1975 period. However, harvested rates – obtained through the analysis of ACR records (see Section 11.7) – have seen significant increases, even between 1990 and 2005 (Table 11.21). This has led to improved nitrogen use efficiency on un-manured crops.

Table 11.20: Historic and current synthetic fertilizer use simulated with GNLM, for each crop group.

	Synthetic Fertilizer		[Gg N/yr]		
	1945	**1960**	**1975**	**1990**	**2005**
Alfalfa, Clover	2.968	6.231	6.474	3.311	3.809
Corn, Sorghum, Sudan	4.890	23.637	36.469	65.746	84.499
Cotton	8.965	28.206	49.069	88.986	58.574
Field Crops	5.115	13.856	17.090	40.726	29.522
Grain and Hay	32.315	50.656	58.729	56.857	70.104
Nuts	6.630	7.981	20.976	72.688	111.825
Olives	0.698	0.761	0.977	1.412	1.779
Rice	4.944	8.800	16.816	33.760	40.834
Subtropical	2.844	2.215	7.496	11.138	14.092
Tree Fruit	9.648	8.311	11.158	17.992	21.781
Vegetables and Berries	10.309	19.946	28.886	49.154	54.947
Vineyards	10.234	7.840	11.129	9.719	11.966
TOTAL ON AGRICULTURAL LAND	**99.559**	**178.441**	**265.270**	**451.491**	**503.731**
	Synthetic Fertilizer		**[kg N/ha/yr]**		
	1945	**1960**	**1975**	**1990**	**2005**
Alfalfa, Clover	12	17	22	13	13
Corn, Sorghum, Sudan	81	117	153	376	381
Cotton	63	92	116	184	188
Field Crops	52	68	93	145	146
Grain and Hay	49	70	102	193	183
Nuts	148	124	139	227	227
Olives	97	82	92	88	88
Rice	51	73	96	146	146
Subtropical	149	125	140	144	145
Tree Fruit	127	112	121	117	118
Vegetables and Berries	86	126	158	203	205
Vineyards	66	56	62	39	39
TOTAL ON AGRICULTURAL LAND	**57**	**75**	**104**	**162**	**164**

Table 11.21: Historic and current harvested nitrogen simulated with GNLM, for each crop group.

	Harvest		[Gg N/yr]		
	1945	**1960**	**1975**	**1990**	**2005**
Alfalfa, Clover	5.085	10.415	10.940	9.452	14.635
Corn, Sorghum, Sudan	2.245	15.751	26.370	49.470	76.725
Cotton	5.890	20.272	28.877	38.480	27.923
Field Crops	3.721	13.138	16.018	28.139	22.566
Grain and Hay	17.039	30.039	43.758	32.204	52.483
Nuts	2.266	4.161	11.898	29.909	59.698
Olives	0.510	0.742	0.792	1.645	2.053
Rice	4.073	7.853	13.277	24.716	30.640
Subtropical	0.580	0.515	1.388	2.789	4.409
Tree Fruit	1.430	1.547	2.439	4.401	4.415
Vegetables and Berries	3.802	8.296	12.641	21.500	29.546
Vineyards	1.665	2.138	2.926	4.036	5.312
TOTAL ON AGRICULTURAL LAND	**48.305**	**114.867**	**171.324**	**246.740**	**330.405**
	Harvest		**[kg N/ha/yr]**		
	1945	**1960**	**1975**	**1990**	**2005**
Alfalfa, Clover	20	28	37	36	48
Corn, Sorghum, Sudan	37	78	111	283	346
Cotton	41	66	68	80	90
Field Crops	38	64	87	100	112
Grain and Hay	26	42	76	109	137
Nuts	51	64	79	93	121
Olives	71	80	74	103	102
Rice	42	65	76	107	110
Subtropical	30	29	26	36	45
Tree Fruit	19	21	26	29	24
Vegetables and Berries	32	52	69	89	110
Vineyards	11	15	16	16	17
TOTAL ON AGRICULTURAL LAND	**28**	**48**	**67**	**88**	**108**

Central Valley Nitrogen Use Efficiencies by Crop Group: Nitrogen use efficiencies are here computed by considering all nitrogen fluxes in cropland except the potential groundwater nitrogen loading: Applied nitrogen ("A") includes atmospheric deposition, land applied manure, exported manure amendments, WWTP/FP effluent, biosolids, and synthetic fertilizer. Nitrogen removed ("R") includes atmospheric losses from cropland, runoff, and harvested nitrogen. Subtracting 1 from the A/R ratio in Table 11.22 provides the cropland potential groundwater nitrogen loading (pGW cropland) as fraction of total N removed. For example, the A/R ration of 2.0 indicates that pGW cropland is (2.0 – 1) = 100% of the total N removed. Effective nitrogen use efficiencies would be obtained by taking the inverse of A/R.

Tree-fruit and subtropical (mostly citrus) crops have the highest A/R ratios, indicating relatively high rates of N losses to groundwater and the largest potential for improving nitrogen management practices. Cotton, grain and hay, and vineyards also have very high A/R ratios (larger than 2.0), indicating significant opportunities to improve nitrogen management. Corn, sorghum, and sudan, nuts, and vegetables (and berries) are all well above 1.5, also offering opportunities to increase nutrient management efficiencies. The high A/R for corn, sorghum, and sudan (assumed double-cropped with winter grain) is particularly concerning due to the large harvest rate, which means that the absolute amount of potential groundwater nitrogen loading may be particularly high in these dairy forage crops. Rice and some field crops show relatively low A/R indicating that there are perhaps more limited opportunities to further improve nitrogen efficiencies. Current nitrogen use efficiencies, expressed in form of this comprehensive large-scale A/R ratio, have changed little over time – some have increased, some have decreased, or both. Those that have recently made the most gains (lower A/R in 2005 than in 1990) include vegetables (in the Central Valley predominantly tomatoes), rice, nuts, and cotton.

Table 11.22: Simulated ratio of Central Valley applied to Central Valley removed nitrogen using all inputs for applied nitrogen and all nitrogen outputs in each crop group except groundwater leaching for removed nitrogen.

	Ratio of Applied to Removed Nitrogen				
	1945	**1960**	**1975**	**1990**	**2005**
Alfalfa, Clover	0.6	0.7	0.8	0.8	0.8
Corn, Sorghum, Sudan	1.5	1.2	1.7	1.7	1.7
Cotton	1.2	1.2	1.8	2.2	2.1
Field Crops	1.0	0.9	1.0	1.4	1.4
Grain and Hay	1.2	1.3	1.3	1.7	2.0
Nuts	1.9	1.5	1.4	1.9	1.6
Olives	1.1	0.9	1.1	0.9	1.0
Rice	0.9	0.9	1.1	1.2	1.1
Subtropical	2.6	2.5	2.9	2.6	2.6
Tree Fruit	2.9	2.6	2.5	2.5	2.9
Vegetables and Berries	1.7	1.7	1.7	1.8	1.6
Vineyards	2.3	1.9	2.1	1.8	2.0
TOTAL ON AGRICULTURAL LAND	**1.4**	**1.2**	**1.5**	**1.7**	**1.7**

Table 11.23:a-c Manure, effluent, and biosolids applications, by crop-group (not including pasture and non-agricultural lands) – total amount [Gg N/yr], rate [kg/ha/yr], and cropland area [ha] used for the application of these nitrogen applications. 1 Gg N = 1,100 tons of nitrogen. 1 kg N/ha = 0.9 lb/acre. 1 ha = 2.5 acres.

	Manure, Effluent, and Biosolids applied to facility cropland		[Gg N/yr]		
	1945	1960	1975	1990	2005
Alfalfa, Clover	0.529	0.724	0.795	1.267	1.137
Corn, Sorghum, Sudan	0.047	0.154	19.583	36.235	74.808
Cotton	0.742	1.227	19.414	28.694	17.647
Field Crops	0.063	0.152	1.867	4.997	6.792
Grain and Hay	0.453	0.722	12.992	9.858	62.860
Nuts	0.004	0.008	0.047	0.112	0.199
Olives	0.001	0.005	0.002	0.002	0.004
Rice	0.000	0.003	0.000	0.000	0.000
Subtropical	0.005	0.003	0.008	0.022	0.060
Tree Fruit	0.037	0.053	0.090	0.104	0.100
Vegetables and Berries	0.025	0.072	0.100	0.103	0.142
Vineyards	0.069	0.111	0.196	0.373	0.479
TOTAL ON AGRICULTURAL LAND	**1.974**	**3.233**	**55.097**	**81.767**	**164.228**

	Manure, Effluent, and Biosolids applied to facility cropland		[kg N/ha/yr]		
	1945	1960	1975	1990	2005
Alfalfa, Clover	40	61	98	181	164
Corn, Sorghum, Sudan	41	49	476	656	1206
Cotton	66	104	380	480	754
Field Crops	33	56	392	356	535
Grain and Hay	30	57	326	521	1133
Nuts	14	20	30	60	84
Olives	13	37	27	43	54
Rice	36	102	16		2
Subtropical	25	28	61	93	162
Tree Fruit	50	74	98	157	175
Vegetables and Berries	26	50	77	84	105
Vineyards	43	92	125	217	254
TOTAL ON AGRICULTURAL LAND	**43**	**70**	**366**	**509**	**982**

	Manure, Effluent, and Biosolids applied to facility cropland		[ha]		
	1945	**1960**	**1975**	**1990**	**2005**
Alfalfa, Clover	13239	11963	8082	7002	6916
Corn, Sorghum, Sudan	1125	3120	41160	55262	62010
Cotton	11221	11841	51153	59837	23417
Field Crops	1913	2736	4759	14029	12694
Grain and Hay	14886	12606	39893	18933	55505
Nuts	256	372	1603	1856	2364
Olives	108	150	90	42	66
Rice	1	27	9	0	3
Subtropical	199	107	138	233	368
Tree Fruit	729	713	925	663	571
Vegetables and Berries	979	1437	1305	1216	1356
Vineyards	1613	1206	1566	1716	1890
TOTAL ON AGRICULTURAL LAND	**46,268**	**46,277**	**150,683**	**160,788**	**167,159**

Nitrogen Application on Dairy, WWTP, and FP Cropland: Dairy manure (2005: 174 Gg N/yr, Table 11.14) and effluent from WWTPs, FPs, and biosolids operations (2005: 3.9 Gg N/yr, Table 11.6) are applied to only a limited number of agricultural crops. Some is applied to pasture. FP effluent reaches the broadest groups of cropland and non-agricultural landuses (see Table 11.17). GNLM-CV identifies a total of 164 Gg N/yr of manure and effluent that is applied to 167,000 ha of cropland and 10.7 Gg N/yr is applied to 11,400 ha of pasture. Since over 97% of that is manure, it is not surprising that the largest amount, 138 Gg N/yr, is applied on 118,000 ha of forage crops (corn, sorghum, sudan, grain and hay). The application rates on these crops exceed 1,000 kg N/ha/year - much higher than recommended fertilizer rates on these crops. Rates are also high on 23,400 ha of cotton and 13,000 ha of field crops. On pasture, land application rate are also high, at over 900 kg N/ha/yr.

Actual land area to which dairy manure is applied may be as much as 20,000 ha higher and application rates [kg/ha/yr] therefore as much as 15% smaller than simulated with GNLM and reported in Table 11.23. This error arises from the method used for identifying cropland receiving dairy manure in GNLM: Using the assessor parcel numbers identified by each dairy, GNLM only used land area within these parcels that belonged to crops identified as receiving manure (Table 11.17). When overlaid with CAML landuse, not all parcels identified as application area in the “RB5 APN Database v2015” (section 11.8.1) coincide with crops that receive manure. This results in simulated dairy manure application areas in GNLM that are smaller than in “RB5 APN Database v2015”. For 2005, the target application area is 174,000 ha for dairies (Table 11.14) and 34,000 ha for wastewater treatment plants and food processor effluent (Table 11.7). Some of the latter will go to pasture, alfalfa, and urban landuses (Table 11.17). In GNLM, the total simulated land application area is 179,000 ha (Table 11.19), of which 167,000 ha is cropland and 11,400 ha is pasture (Table 11.23).

Potential Groundwater Nitrogen Loading from Croplands: The mass balance implemented in GNLM yields a potential groundwater nitrogen loading from all cropland types. In 2005, the total potential groundwater nitrogen loading from cropland in the Central Valley is estimated to be 331 Gg N/yr, including 9 Gg N/r from alfalfa and clover. Here, we do not include an estimated 8.5 Gg potential N loading to groundwater from pasture, where harvest rates and hence groundwater N loading rates are highly uncertain.

The magnitude of potential groundwater nitrogen loading from cropland in 2005 equals two-thirds of the synthetic fertilizer applied. It is also about twice as much as the total amount of land applied manure and effluent. And it is about three-quarter's of the magnitude of harvested nitrogen (including alfalfa). The Central Valley potential groundwater nitrogen loading in the 2000s is nearly 10 times larger than in the 1940s. GNLM estimates that it rose by 35% from 1945 to 1960, by 150% from 1960 to 1975, by another 100% from 1975 to 1990 and by 30% from 1990 to 2005. The increase in potential groundwater nitrogen loading was initially driven by increase in synthetic fertilizer applications and expansion of irrigated cropland areas. But since the 1970s the increases have been driven largely by the expansion of the dairy sector in the Central Valley and the associated land application of manure.

By the 2000s, the highest rates of groundwater loading occur on forage crops other than pasture or alfalfa (corn, sorghum, sudan: 320 kg N/ha/yr; grain and hay: 195 kg N/ha/yr). As a result, these two crop groups contribute well over 40% of all potential groundwater nitrogen loading from cropland (pGW cropland) in the Central Valley. Cotton also has a relatively high pGW rate (148 kg N/ha/yr), but planted acreage of cotton has been significantly declining over the past two decades. Other large contributors to pGW cropland include nuts (48 Gg N/yr, 98 kg N/ha/yr), subtropical (12 Gg N/yr, 124 kg N/ha/yr), tree fruit (18 Gg N/yr, 100 kg N/ha/yr), and vegetables and berries (23 Gg N/yr, 84 kg N/ha/yr).

The results suggest that agricultural coalitions, cooperative extension personnel, and agricultural consultants implementing the management practice evaluation programs for irrigated lands and dairies would achieve the greatest improvement in addressing groundwater nitrogen loading, if research and extension efforts in the Central Valley focus on improving the overall A/R in corn and grain, nuts, citrus, tree-fruit, and vegetables (specifically tomatoes, asparagus, carrots, melons and squash, which account for 80% of pGW from vegetables and berry crops in the Central Valley in the 2005 period).

Table 11.24: Potential groundwater nitrogen loading from cropland areas: total loading and rate of loading.

	Potential Groundwater Nitrogen Loading from Cropland		[Gg N/yr]		
	1945	**1960**	**1975**	**1990**	**2005**
Alfalfa, Clover	7.675	10.923	8.694	7.876	9.078
Corn, Sorghum, Sudan	1.727	4.971	24.203	44.097	71.142
Cotton	1.820	5.173	32.784	70.357	46.050
Field Crops	1.114	0.224	2.488	13.845	12.844
Grain and Hay	7.328	12.902	20.327	28.895	72.749
Nuts	3.324	2.743	7.120	37.640	48.369
Olives	0.063	0.002	0.104	0.000	0.208
Rice	0.000	0.010	1.159	5.054	5.411
Subtropical	1.867	1.469	5.576	8.323	12.027
Tree Fruit	6.725	5.758	7.733	12.909	18.439
Vegetables and Berries	4.613	9.169	13.307	23.383	22.537
Vineyards	6.589	4.793	7.828	7.282	11.823
TOTAL ON AGRICULTURAL LAND	**42.847**	**58.137**	**131.322**	**259.661**	**330.678**
	Potential Groundwater Nitrogen Loading from Cropland		**[kg N/ha/yr]**		
	1945	**1960**	**1975**	**1990**	**2005**
Alfalfa, Clover	30	30	30	30	30
Corn, Sorghum, Sudan	29	26	102	252	320
Cotton	13	17	77	146	148
Field Crops	35	5	39	52	75
Grain and Hay	12	18	35	99	195
Nuts	74	42	47	118	98
Olives	9	51	10		26
Rice	1	2	7	22	19
Subtropical	98	83	104	108	124
Tree Fruit	88	77	84	84	100
Vegetables and Berries	38	58	73	96	84
Vineyards	43	34	44	29	39
TOTAL ON AGRICULTURAL LAND	**33**	**34**	**61**	**104**	**122**

Nitrogen Fluxes at the County and Groundwater Basin Scale. The following tables show both total N fluxes and N flux rates for the various nitrogen flux components, by county, region, and the Central Valley, and by groundwater basin (now managed under Groundwater Sustainability Agencies and possibly future nitrate and salinity management agencies). These tables are mostly displayed to be used as lookup tables by local agencies. Importantly, we note that "pNgw cropland" in these tables includes pasture with land application, while "pNgw fixed rate lands" here includes loading from alfalfa and clover.

Largest 2005 potential cropland groundwater nitrogen loadings (pNgw cropland) in the Sacramento Valley come from Yolo (6.2 Gg N/yr), Glenn (5.8 Gg N/yr), Sutter (5.0 Gg N/yr), Butte (4.8 Gg N/yr), Colusa (4.7 Gg N/yr), and Sacramento (4.4 Gg N/yr) Counties. Their combined pGW cropland of 31 Gg N/yr is similar to that of Stanislaus County alone (29.5 Gg N/yr) and is less than that in either Merced (39 Gg N/yr), Kern (42 Gg N/yr), Fresno (43 G N/yr), or Tulare (71 Gg N/yr). In the Sacramento Valley, non-cropland sources contribute more than 10% of N loading to groundwater, while non-cropland sources contribute less than 10% to groundwater N loading in the San Joaquin Valley and in the Tulare Lake Basin (Table 11.25a).

Rates of potential groundwater nitrogen loading, at the 50 m raster cell scale, are provided as Central Valley maps in the appendix. Summaries by region, county, and groundwater basin (DWR 2003 boundaries) are provided in the tables below. Potential cropland nitrogen loading rates are lowest in the Sacramento Valley, where they average 52 kg N/ha/yr and range from less than 40 kg N/ha/yr in Placer and Colusa County to over 70 kg N/ha/yr in Sacramento, Shasta, and Tehama Counties. Average potential groundwater nitrogen loading rates from cropland are highest in the dairy dominated counties of the San Joaquin Valley and Tulare Lake Basin: In Stanislaus, Merced, and Tulare County county-average rates exceed 200 kg N/ha/yr (Table 11.25b).

Groundwater basins are mostly smaller than counties, and similar patterns to the county pattern are observed with groundwater basins: Those with the largest average potential groundwater nitrogen loading rate from cropland include, in reverse order of loading rate, all those with high dairy density: Turlock (301 kg N/ha/yr), Kaweah (287 kg N/ha/yr), Tule (281 kg N/ha/yr), and Chowchilla (275 kg N/ha/yr). These four groundwater basins stand significantly apart from all other groundwater basins in their potential groundwater nitrogen loading rate.

The group of groundwater basins with the second highest average cropland groundwater nitrogen loading rate include seven basins with significantly lower basin-wide rates than the above four basins: Modesto, Merced, Delta-Mendota, Tulare Lake, Kern County, Kings, and Eastern San Joaquin basins with 212, 179, 12, 122, 117, 115, and 114 kg N/ha/yr (pNgw cropland areas). These groundwater basins, while home to a large dairy herd also produce large amounts of other intensively farmed crops. Groundwater basins with the lowest cropland loading rates (below 50 kg N/ha/yr) include basins with no dairies and mostly alfalfa, pasture, vineyard, or rice crops: basins located adjacent to the Delta and in the rice region of the Sacramento Valley, including North American, Sutter, Colusa, and East/West Butte Basins.

Table 11.25a: Simulated total historic and current nitrogen fluxes [Gg N/yr] related to fertilizer and manure use in the Central Valley, by county and region.

Gg N/yr	Nsynthetic					NlandApplied					NmanureSale					Nharvest					pNgw cropland					pNgw fixed rate lands					pNgw all				
	1945	1960	1975	1990	2005	1945	1960	1975	1990	2005	1945	1960	1975	1990	2005	1945	1960	1975	1990	2005	1945	1960	1975	1990	2005	1945	1960	1975	1990	2005	1945	1960	1975	1990	2005
Butte	4.2	5.9	9.4	16.4	17.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.2	4.3	6.6	9.3	10.8	1.1	0.8	1.5	5.3	4.8	0.2	0.3	0.2	0.2	0.4	1.3	1.2	1.9	5.6	5.3
Colusa	3.6	5.7	11.5	19.5	22.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.2	4.4	8.3	11.8	14.5	0.6	0.4	1.5	5.2	4.7	0.1	0.2	0.1	0.1	0.2	0.7	0.6	1.6	5.3	4.9
Glenn	3.0	5.6	6.6	15.4	18.1	0.0	0.0	0.6	1.2	2.3	0.0	0.0	0.0	0.0	0.1	1.7	3.9	4.8	9.8	12.3	0.5	0.8	1.4	4.8	5.8	0.0	0.3	0.3	0.3	0.3	0.6	1.2	1.7	5.1	6.2
Placer	0.5	0.7	1.3	1.9	2.3	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.2	0.4	1.0	1.3	1.7	0.2	0.2	0.2	0.5	0.5	0.0	0.0	0.1	0.1	0.3	0.2	0.3	0.4	0.7	0.9
Sacramento	4.1	5.9	9.1	12.2	14.6	0.0	0.0	0.7	1.1	2.2	0.0	0.0	0.0	0.0	0.1	2.0	3.7	6.2	8.0	11.0	1.4	1.6	2.6	4.4	4.5	0.5	1.0	1.1	1.6	1.7	2.1	2.8	4.0	6.4	6.7
Shasta	0.0	0.4	0.8	0.3	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.6	0.2	0.4	0.0	0.2	0.1	0.1	0.3	0.0	0.1	0.3	0.1	0.3	0.1	0.3	0.5	0.4	0.7
Solano	3.3	4.4	7.3	12.1	13.7	0.0	0.0	0.1	0.2	0.4	0.0	0.0	0.0	0.0	0.0	1.7	2.8	5.1	7.3	9.9	0.9	0.9	1.6	4.0	3.1	0.2	0.2	0.3	0.5	0.7	1.1	1.1	2.0	4.5	4.0
Sutter	4.7	7.7	14.5	17.7	18.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.2	5.2	9.3	9.9	11.6	1.5	1.4	3.4	5.9	5.0	0.1	0.3	0.3	0.3	0.4	1.7	1.8	3.7	6.2	5.5
Tehama	1.3	1.7	2.8	4.4	6.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	1.0	1.7	2.2	3.7	0.3	0.4	0.6	1.8	2.4	0.1	0.1	0.2	0.1	0.3	0.5	0.5	0.9	2.0	2.8
Yolo	6.1	15.3	15.2	24.7	27.3	0.0	0.0	0.1	0.2	0.4	0.0	0.0	0.0	0.0	0.0	3.4	10.1	10.6	14.2	18.7	1.3	2.7	3.0	8.1	6.2	0.4	0.5	0.7	0.6	0.8	1.8	3.3	3.7	8.8	7.0
Yuba	1.0	1.3	2.8	4.7	5.3	0.0	0.0	0.1	0.1	0.3	0.0	0.0	0.0	0.0	0.2	0.5	0.7	1.6	2.5	3.0	0.3	0.4	0.9	1.9	2.2	0.1	0.1	0.1	0.1	0.2	0.4	0.5	1.0	2.0	2.4
Sacramento Valley	**31.8**	**54.6**	**81.3**	**129.4**	**147.2**	**0.0**	**0.0**	**1.7**	**2.8**	**5.6**	**0.0**	**0.0**	**0.0**	**0.1**	**0.4**	**16.7**	**36.7**	**55.9**	**76.4**	**97.5**	**8.3**	**9.9**	**16.9**	**41.9**	**39.5**	**1.8**	**3.1**	**3.7**	**4.1**	**5.6**	**10.5**	**13.6**	**21.4**	**47.2**	**46.5**
Contra Costa	2.5	2.8	2.3	3.1	4.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	1.2	1.3	1.8	3.0	1.1	1.2	0.7	1.0	0.8	0.2	0.3	0.3	0.4	0.6	1.3	1.5	1.1	1.5	1.4
Madera	4.1	6.2	8.2	16.8	20.1	0.0	0.1	3.1	5.1	9.9	0.0	0.0	0.0	0.4	1.9	2.1	4.1	5.5	8.6	13.0	1.2	1.6	5.4	12.6	16.9	0.4	0.5	0.9	0.7	0.9	1.7	2.2	6.4	13.5	17.9
Merced	5.5	8.8	15.0	32.2	35.5	0.1	0.2	8.7	14.6	28.9	0.0	0.0	0.0	0.9	4.4	2.8	5.6	10.5	19.8	26.0	2.1	2.9	12.1	25.6	38.7	1.2	1.2	1.8	2.1	2.5	3.3	4.2	14.1	27.8	41.4
San Joaquin	11.9	16.8	23.6	35.8	38.2	0.1	0.1	3.5	5.6	10.9	0.0	0.0	0.0	0.4	2.0	5.0	9.0	15.1	21.1	26.4	5.1	6.4	10.3	17.9	20.5	0.9	1.3	1.5	1.9	2.1	6.1	7.9	12.2	20.3	23.2
Stanislaus	6.3	9.6	12.0	23.8	24.1	0.1	0.1	6.4	10.6	20.8	0.0	0.0	0.0	0.9	4.3	3.5	5.6	7.7	15.5	17.4	2.5	4.1	10.5	18.9	29.5	1.4	1.2	1.7	1.6	1.9	4.0	5.5	12.4	20.9	31.8
San Joaquin Valley	**30.3**	**44.2**	**61.1**	**111.7**	**122.1**	**0.3**	**0.4**	**21.8**	**36.0**	**70.5**	**0.0**	**0.0**	**0.0**	**2.5**	**12.6**	**14.2**	**25.6**	**40.2**	**66.8**	**85.8**	**12.1**	**16.2**	**39.1**	**76.0**	**106.3**	**4.0**	**4.5**	**6.3**	**6.7**	**8.0**	**16.5**	**21.3**	**46.1**	**84.0**	**115.7**
Fresno	16.6	33.5	44.2	78.2	81.2	0.1	0.2	3.4	5.5	10.7	0.0	0.0	0.0	1.0	5.1	6.4	20.7	25.6	37.3	47.5	7.0	9.1	18.5	41.2	42.5	1.9	3.5	3.6	4.2	4.9	9.0	12.8	22.4	45.8	47.9
Kern	5.6	18.3	32.1	56.6	66.1	0.9	1.6	6.8	11.4	20.4	0.0	0.0	0.0	0.9	4.5	3.6	13.3	20.1	27.9	39.8	1.7	4.2	15.0	34.4	42.3	1.2	2.0	2.5	2.9	2.9	3.0	6.5	17.8	37.8	45.8
Kings	5.0	11.1	21.6	32.4	42.2	0.5	0.7	5.7	9.2	17.4	0.0	0.0	0.0	1.0	4.8	3.0	8.2	14.9	17.6	29.1	1.3	2.0	9.5	20.8	28.7	0.5	0.9	1.5	1.5	2.0	1.8	2.9	11.1	22.4	30.7
Tulare	10.4	16.8	25.0	43.2	45.0	0.2	0.2	15.7	25.8	50.4	0.0	0.0	0.0	3.6	17.9	4.4	10.4	14.6	24.9	35.0	4.8	5.9	24.4	44.3	70.9	1.3	1.7	2.9	3.1	3.6	6.2	7.8	27.6	47.7	74.9
Tulare Lake Basin	**37.5**	**79.7**	**122.8**	**210.4**	**234.4**	**1.7**	**2.8**	**31.7**	**52.0**	**98.9**	**0.0**	**0.0**	**0.0**	**6.5**	**32.4**	**17.4**	**52.6**	**75.3**	**107.8**	**151.5**	**14.8**	**21.2**	**67.4**	**140.8**	**184.4**	**4.8**	**8.2**	**10.6**	**11.8**	**13.4**	**20.0**	**30.0**	**78.8**	**153.8**	**199.4**
Central Valley	**99.6**	**178.4**	**265.3**	**451.5**	**503.7**	**2.0**	**3.2**	**55.1**	**90.8**	**175.0**	**0.0**	**0.0**	**0.0**	**9.1**	**45.4**	**48.3**	**114.9**	**171.3**	**251.0**	**334.8**	**35.2**	**47.3**	**123.3**	**258.7**	**330.2**	**10.6**	**15.7**	**20.5**	**22.6**	**27.0**	**47.0**	**64.9**	**146.4**	**285.0**	**361.6**

Table 11.25b: Simulated historic and current nitrogen rates [kg N/ha/yr] related to fertilizer and manure use in the Central Valley, by county and region.

kg N/ha/yr	Nsynthetic					NlandApplied					NmanureSale					Nharvest					pNgw cropland					pNgw fixed rate lands					pNgw all				
	1945	1960	1975	1990	2005	1945	1960	1975	1990	2005	1945	1960	1975	1990	2005	1945	1960	1975	1990	2005	1945	1960	1975	1990	2005	1945	1960	1975	1990	2005	1945	1960	1975	1990	2005
Butte	64	75	106	172	170	12	20	27	42	55						34	54	75	94	101	28	21	19	57	48	25	20	22	21	21	10	9	13	38	35
Colusa	54	72	108	169	167											32	56	77	101	109	15	13	16	49	37	25	26	23	27	25	6	5	11	36	31
Glenn	54	70	100	169	175			423	577	1133				0	1	30	48	73	99	110	13	20	25	61	64	21	24	27	27	27	5	10	14	41	48
Placer	58	76	95	164	164	1	1	106	156	278						28	43	71	91	100	24	28	15	41	33	21	21	20	20	20	6	8	9	17	20
Sacramento	63	93	130	214	208	45	74	304	435	841				0	2	30	58	89	113	134	29	36	42	79	71	23	22	21	20	21	12	15	21	31	32
Shasta	92	101	96	162	156											38	41	68	31	43	33	53	28	85	70	19	21	23	20	20	1	4	6	5	9
Solano	57	76	117	188	183	29	48	338	485	924						29	49	82	102	120	24	20	35	72	53	26	25	25	26	24	11	11	18	40	32
Sutter	68	75	114	162	159	11	17	23	35	46						32	51	73	89	97	34	28	29	56	45	34	29	35	45	42	16	16	27	46	40
Tehama	59	71	106	172	165	0	0	22	1	1						29	43	66	63	71	20	21	28	88	74	26	24	25	28	24	2	3	4	10	13
Yolo	55	79	112	176	189	12	19	253	349	656				0	0	31	52	78	99	127	18	19	27	65	49	26	27	27	25	25	10	16	19	44	35
Yuba	60	84	112	153	153	9	13	226	346	621				1	4	29	48	66	72	76	36	47	36	62	64	26	24	23	25	23	10	12	21	41	46
Sacramento Valley	59	77	111	174	175	15	25	287	422	815				0	1	31	52	77	95	108	23	23	27	62	52	25	24	24	23	23	8	10	15	33	31
Contra Costa	89	105	134	217	229											31	44	78	111	149	43	47	44	80	48	21	21	20	21	21	32	33	26	36	31
Madera	49	70	85	133	136	176	288	621	1014	1582				3	13	26	46	57	66	86	18	23	63	98	130	28	28	36	36	33	11	14	37	72	95
Merced	49	70	103	175	164	28	46	433	610	1136				4	19	25	45	72	96	111	29	30	64	124	210	29	29	47	45	40	12	14	44	85	128
San Joaquin	65	84	113	167	171	52	86	478	644	1156				2	8	27	45	72	92	111	34	41	53	84	104	27	27	32	31	30	20	25	37	61	70
Stanislaus	49	74	104	190	177	58	94	641	661	1200				6	28	27	44	66	104	109	34	36	68	120	210	28	26	42	45	39	16	22	49	81	124
San Joaquin Valley	57	78	105	168	165	42	69	512	669	1206				4	16	27	45	69	91	107	31	35	61	106	159	28	27	37	37	34	16	20	41	73	101
Fresno	58	70	97	150	151	31	51	236	363	710				2	10	23	43	56	71	87	29	24	47	84	87	35	35	40	43	47	20	23	39	73	76
Kern	47	76	106	155	166	64	119	305	444	823				3	12	31	55	66	76	100	20	24	58	103	117	28	28	32	29	29	10	18	40	75	88
Kings	48	65	95	161	172	29	40	173	289	545				5	21	29	48	66	87	118	15	14	48	117	137	28	29	42	40	37	13	15	45	97	113
Tulare	66	75	97	147	146	62	73	484	588	1206				12	59	28	46	57	84	113	40	31	86	154	263	29	30	52	49	46	19	22	73	125	197
Tulare Lake Basin	57	71	99	152	158	44	72	309	445	871				5	22	26	47	60	77	101	28	24	59	109	139	31	31	40	39	40	17	20	48	88	110
Central Valley	57	75	104	162	164	43	70	366	512	978				4	17	28	48	67	86	105	27	26	51	96	120	28	28	35	34	33	13	17	35	66	81

Table 11.26: Simulated historic and current nitrogen flux rates related to fertilizer and manure use in the Central Valley, by CDWR groundwater basin.

kg N/ha/yr	Ndeposition					Nirrigation					Nsynthetic					NlandApplied					NmanureSale					Nharvest_actual					NatmLosses					pNgw cropland					pNgw fixed rate lands					pNgw all				
	1945	1960	1975	1990	2005	1945	1960	1975	1990	2005	1945	1960	1975	1990	2005	1945	1960	1975	1990	2005	1945	1960	1975	1990	2005	1945	1960	1975	1990	2005	1945	1960	1975	1990	2005	1945	1960	1975	1990	2005	1945	1960	1975	1990	2005	1945	1960	1975	1990	2005
KERN COUNTY	6	8	10	10	8		2	3	5	7	47	76	106	155	166	64	119	305	444	823				3	12	31	55	66	76	100	2	5	12	21	36	20	24	58	103	117	28	28	32	29	29	10	18	40	75	88
PLEASANT VALLEY	4	5	7	7	6		1	2	4	5	65	88	112	185	198			24	37	48				3	15	32	48	74	98	114	1	3	3	10	16	21	34	27	67	68	22	23	20	20	20	8	21	16	51	54
TULE	10	13	16	17	14		3	7	10	14	60	71	93	144	140	111	94	591	669	1389				12	59	27	45	56	85	117	4	6	43	79	169	34	27	88	155	281	29	29	54	51	45	16	20	74	127	203
TULARE LAKE	6	8	10	11	9		0	1	1	2	47	63	96	158	169	29	40	141	232	423				5	21	30	48	67	85	114	4	6	22	34	69	14	13	41	108	122	29	29	40	38	35	13	15	40	90	101
KAWEAH	10	14	17	18	15		3	7	10	14	65	74	97	158	165	36	58	343	480	974				11	53	30	49	62	95	133	4	7	52	94	192	39	30	93	176	287	29	30	52	49	48	17	21	79	136	211
WESTSIDE	6	7	9	10	8		1	2	3	5	60	77	117	193	189	18	30	45	73	119				2	11	30	52	68	89	109	2	7	9	20	27	19	17	38	87	75	28	29	27	26	27	14	17	35	83	71
KINGS	8	10	13	14	11		3	7	10	14	62	64	83	112	114	34	56	296	446	858				4	17	19	36	45	54	67	5	7	19	32	58	36	30	59	88	115	37	37	45	48	55	25	26	46	74	94
LOS BANOS CREEK VALLEY	3	4	5	6	5																										0	0	1	1	0										20					20
CHOWCHILLA	10	13	17	18	15		2	5	7	10	43	68	83	152	151			537	825	1359				3	14	27	49	66	91	117	3	6	55	89	170	15	22	88	157	275	29	29	41	42	39	11	17	70	123	184
MADERA	8	10	13	14	11		2	5	7	10	51	68	85	120	124	176	288	548	1007	1431				3	13	24	42	51	55	71	3	4	8	16	30	20	25	48	73	86	27	27	33	31	29	11	12	23	51	63
MERCED	9	12	16	16	13		2	5	7	10	58	77	113	186	176	23	40	452	602	1115				4	19	25	47	76	96	114	2	4	18	34	66	37	30	45	98	179	29	29	46	45	39	12	13	35	73	110
TURLOCK	11	14	18	19	16		3	7	10	14	51	78	108	206	182	312	501	631	812	1462				5	24	26	46	74	121	121	4	6	49	83	161	34	38	101	182	301	28	27	58	63	53	19	23	77	133	210
DELTA-MENDOTA	7	9	11	12	10		3	7	10	14	44	67	96	160	160	6	10	316	431	865				4	17	27	46	63	83	101	3	5	14	25	44	20	26	53	104	129	30	30	35	34	33	13	18	36	74	89
MODESTO	10	14	18	18	15		4	7	11	14	55	85	112	217	188	90	136	665	572	1085				6	28	26	42	64	104	106	4	5	22	39	78	34	38	60	112	212	26	23	37	39	33	18	23	46	72	112
ARROYO DEL HAMBRE VALLEY	8	11	13	14	11																										1	1	1	1	1				0		20	20	20	20	20	20	20	20	20	20
YGNACIO VALLEY	5	6	8	8	7						62	84		127												17	42		23		1	1	1	1	1	32	27		84		20	20	20	20	20	11	16	19	19	20
PITTSBURG PLAIN	4	6	7	7	6						52	80	124		39											21	42	63		17	2	5	2	1	1	16	21	41		9	20	20	20	20	20	16	20	20	19	20
CLAYTON VALLEY	5	6	8	8	7						54	112	125	206	203											21	42	65	72	91	1	3	1	1	1	19	51	41	106	83	20	20	20	20	20	13	23	19	20	21
TRACY	7	9	12	13	10		1	1	2	2	66	88	115	163	182	6	10	589	591	1233				2	8	28	44	70	90	121	6	8	12	17	27	36	48	52	74	70	29	29	31	30	29	27	35	36	53	51
EASTERN SAN JOAQUIN	9	12	16	16	13		1	2	4	5	70	88	117	182	181	57	93	473	641	1160				2	10	29	48	77	98	114	4	6	18	30	49	36	36	48	84	114	24	25	32	31	29	17	21	35	60	71
SUISUN-FAIRFIELD VALLEY	4	6	7	8	6						83	77	114	165	165											20	32	66	73	93	1	1	2	2	3	61	34	33	65	44	19	19	20	20	20	7	5	11	17	17
COSUMNES	7	10	12	13	10		1	2	4	5	58	70	100	127	133	36	59	374	546	911				1	5	21	36	66	63	85	2	3	10	14	26	30	35	51	88	94	27	25	30	24	29	8	9	19	25	37
SOLANO	5	7	9	9	7		2	5	7	9	58	86	124	202	200	29	48	338	485	924				0	1	31	58	87	114	134	4	7	9	16	19	24	23	38	73	53	28	28	27	28	27	10	18	40	75	88

kg N/ha/yr	Ndeposition					Nirrigation					Nsynthetic					NlandApplied					NmanureSale					Nharvest_actual					NatmLosses					pNgw cropland					pNgw fixed rate lands					pNgw all				
	1945	1960	1975	1990	2005	1945	1960	1975	1990	2005	1945	1960	1975	1990	2005	1945	1960	1975	1990	2005	1945	1960	1975	1990	2005	1945	1960	1975	1990	2005	1945	1960	1975	1990	2005	1945	1960	1975	1990	2005	1945	1960	1975	1990	2005	1945	1960	1975	1990	2005
SOUTH AMERICAN	6	9	11	11	9		1	2	3	5	62	87	133	194	181	87	143	284	389	774				0	2	27	51	88	93	114	2	3	8	13	22	33	38	52	81	79	22	22	22	21	21	12	15	21	29	33
YOLO	4	6	7	8	6		2	5	7	9	53	78	111	181	195	12	19	230	349	656				0	0	28	49	73	103	134	4	9	10	18	22	15	20	36	69	55	25	25	25	24	24	12	19	24	49	39
CAPAY VALLEY	2	3	4	4	3		1	2	3	5	64	76	103	199	175									0	0	30	50	64	93	94	3	5	5	7	10	17	8	22	85	69	27	28	29	28	26	7	6	10	29	31
NORTH AMERICAN	6	9	11	11	9		1	2	3	5	62	74	106	163	157	1	1	106	156	278				0	2	33	54	78	101	103	3	4	8	10	12	27	26	19	40	33	21	20	20	20	20	10	12	15	24	23
SOUTH YUBA	6	8	10	11	9		1	2	3	5	58	81	115	159	159	11	17	326	495	908				1	4	28	45	69	68	75	2	3	7	11	16	33	45	40	73	74	28	27	26	32	27	11	14	23	43	48
SUTTER	5	7	9	9	7		1	2	3	5	70	77	117	162	163	11	17	23	35	46				0	1	31	52	72	86	98	4	6	12	14	15	34	28	33	59	47	38	38	37	49	44	18	18	31	53	45
EAST BUTTE	5	7	9	9	7		1	2	3	5	62	72	101	153	154									1	4	34	51	70	92	97	3	4	6	10	11	34	23	19	42	37	26	22	24	22	21	10	9	13	30	29
WEST BUTTE	4	6	7	8	6		1	2	3	5	62	76	106	182	182									0	1	33	55	77	103	115	4	5	8	14	16	20	18	17	60	47	27	23	25	24	23	11	9	13	45	39
COLUSA	3	5	6	6	5		1	2	3	5	55	74	108	169	174			391	598	1110				0	1	32	52	78	100	113	3	5	8	14	18	15	18	19	55	47	25	25	26	27	26	7	10	13	39	36
CORNING	3	4	5	5	4		1	2	3	5	65	66	95	154	166			911	501	1245				0	1	34	44	63	64	83	1	2	3	5	10	14	14	32	96	88	24	24	28	32	29	3	5	10	22	31
VINA	4	5	6	7	5		1	2	3	5	72	80	119	210	204									0	1	31	51	78	87	94	2	3	5	9	9	26	22	27	100	84	21	19	20	20	20	7	8	13	44	42
LOS MOLINOS	3	4	5	6	5		1	2	3	5	61	69	100	153	171											27	43	55	49	55	1	1	2	3	3	21	23	42	86	88	28	27	28	27	24	5	5	8	21	25
DYE CREEK	3	4	5	6	5		1	2	3	5	55	76	117	168	173											23	26	48	30	34	1	1	1	2	3	41	47	53	98	94	27	30	30	22	20	4	4	9	23	31
ANTELOPE	3	4	5	6	5		1	2	3	5	58	79	121	197	168	0	0	1	1	1						24	37	68	70	59	2	3	5	10	9	39	35	36	97	88	27	24	22	22	22	11	11	18	53	47
RED BLUFF	3	4	4	5	4		1	2	3	5	60	76	113	187	167	0	0	1	1	1						28	40	73	70	75	1	1	1	2	2	31	38	30	83	71	25	25	24	25	23	3	2	3	7	10
BEND	3	4	5	6	5		1	2	3	5		109	128	183	199												41	89	38	41	0	1	1	1	1		67	20	76	75		20	20	20	20	0	2	2	5	6
BOWMAN	3	4	5	5	4		1	2	3	4	46	64	95	219	153											24	43	61	31	32	0	1	1	1	1	6	6	18	102	80	20	20	21	25	21	0	1	2	2	4
ROSEWOOD	2	3	4	4	3		1	2	3	4	43	62	95	163	147											23	40	62	40	63	0	0	1	1	1	4	7	18	78	57		30	40	38	31	0	0	1	1	2
SOUTH BATTLE CREEK	3	4	5	6	5		1	2	3	4	49	64	100	191	157											24	41	66	49	34	1	1	1	1	1	10	8	19	99	86	30	30	30	28	25	2	2	5	15	21
ANDERSON	3	4	5	5	4		1	2	3	4	97	98	91	142	143											38	41	65	25	37	0	1	2	1	2	38	54	30	89	75	20	21	23	20	20	1	5	7	6	11
MILLVILLE	3	4	5	6	5		1	2	3	4	107	103	103	238	180											28	38	72	40	40	0	1	1	1	1	57	53	28	101	85		30	30	23	21	0	2	2	1	3
ENTERPRISE	3	4	5	6	5		1	2	3	4	80	106	98	174	167											41	43	71	39	54	0	1	2	1	2	20	53	27	73	54	17	20	23	20	20	1	5	9	7	13
NORTH YUBA	5	7	9	10	8		1	2	3	5	67	83	106	151	145	10	16	21	32	42				1	4	30	50	66	77	76	2	3	6	10	12	37	39	27	55	54	24	23	23	24	23	7	8	16	32	35

Nitrogen Fixation: The difference between potential harvest rate and actual harvest rate is due to the specified synthetic fertilizer rate not being sufficient to meet typical crop harvest uptake after accounting for other losses of nitrogen. This mostly affects some of the olives, sugar beets, and oats acreage. This also affects the amount of harvested N reported for any leguminous crops (beans, pasture, clover, alfalfa), as GNLM does not account for atmospheric nitrogen fixation by plants. The simulated harvested N reflects less than 20% of typically harvested rates for pasture and alfalfa (Table 11.27). This has no bearing on the potential groundwater nitrogen loading estimation in GNLM, as the loading from alfalfa and clover is pre-specified (30 and 15 kg N/ha/yr, respectively). Importantly, the difference between potential and actual nitrogen harvest shown in Table 11.27 for beans, pasture, alfalfa, and clover is a direct estimate of the amount of leguminous nitrogen fixation. Nearly all nitrogen fixation is associated with alfalfa, 115 Gg N/yr (Table 11.27). In the analysis below, nitrogen fixation at the regional and Central Valley scale is estimated by taking the difference between potential and actual alfalfa harvest (Figures 11.11 and 11.12). The amount of nitrogen fixation is added to GNLM computed "actual harvest" nitrogen.

Manure Nitrogen Use in Lieu of Synthetic Fertilizer: The difference between potential synthetic fertilizer - the typically recommended amount of fertilizer used, "*Nfertilizer*" - and synthetic fertilizer applications actually applied ("*Nsynthetic*") is due to synthetic fertilizer being replaced by manure on dairy cropland to meet the recommended or typical application amount (see Section 11.8.1 "Distribution of Manure across the Landscape"). Assuming for 2005 that as much as half of the recommended synthetic fertilizer rates on cropland managed by dairies is met with manure application, GNLM estimates that manure N replaces approximately 21 Gg N/yr of synthetic fertilizer, mostly in the San Joaquin Valley and the Tulare Lake Basin (Table 11.28a).

Regional and Central Valley Summary of Nitrogen Fluxes: Tables 11.28 and 11.29 summarize the various total nitrogen fluxes and nitrogen flux rates for the Central Valley and, separately, for each of the three regions in the Central Valley - Sacramento Valley, (Northern) San Joaquin Valley, and the Tulare Lake Basin. Corresponding land areas are listed in Table 11.19. The tables summarize the information in Table 11.25 and add information for some nitrogen fluxes not listed in Table 11.25 (e.g., nitrogen application from irrigation water). We note that, as Table 11.25, the fluxes listed here are for the areas listed in Table 11.19, some of which are not limited to cropland: atmospheric nitrogen deposition includes all land areas in the Central Valley; and atmospheric losses include large nitrogen fluxes from dairy animal holding areas. In these tables, pasture areas are included in "pGW cropland" (in 2005: 8.5 Gg N/yr on 9400 ha of pasture with land application) while alfalfa and clover is included under "pNgw fixed rate lands" (9.1 Gg N/yr on 304,000 ha).

Table 11.27: Simulated reduction in harvested nitrogen (for legumes: equivalent to atmospheric N fixation). The percent reduction given is relative to the potential harvest. 1kha = 2,500 acres. 1 Gg N = 1,100 tons N.

1945	[kha]	[Gg N/yr]	[kg N/ha/yr]		1960	[kha]	[Gg N/yr]	[kg N/ha/yr]	
Olives	7	0.0	0	0%	Olives	9	0.0	0	0%
Sugar Beets	26	0.9	33	34%	Sugar Beets	56	1.0	17	15%
Beans (dry)	40	0.8	20	37%	Beans (dry)	65	0.8	12	19%
Barley	436	0.0	0	0%	Barley	525	0.0	0	0%
Oats	37	0.0	0	0%	Oats	34	0.0	0	0%
Pasture	0.4	0.0	128	95%	Pasture	1	0.1	124	92%
Alfalfa	255	69.6	273	93%	Alfalfa	356	110.2	309	92%
Clover	2	0.2	121	89%	Clover	16	1.9	114	84%
TOTAL	**803**	**71.5**			TOTAL	**1063**	**113.8**		
1975	**[kha]**	**[Gg N/yr]**	**[kg N/ha/yr]**		**1990**	**[kha]**	**[Gg N/yr]**	**[kg N/ha/yr]**	
Olives	11	0.0	0	0%	Olives	16	0.5	32	24%
Sugar Beets	72	2.1	29	19%	Sugar Beets	51	0.0	0	0%
Beans (dry)	50	0.8	17	20%	Beans (dry)	41	0.0	0	0%
Barley	257	0.0	0	0%	Barley	0	0.0	0	0%
Oats	21	0.0	0	0%	Oats	2	0.0	0	0%
Pasture	0	0.0	125	93%	Pasture	1	0.1	115	85%
Alfalfa	287	91.4	319	89%	Alfalfa	261	90.9	349	91%
Clover	6	0.6	104	77%	Clover	4	0.4	111	82%
TOTAL	**704**	**94.9**			TOTAL	**377**	**92.0**		
2005	**[kha]**	**[Gg N/yr]**	**[kg N/ha/yr]**						
Olives	20	0.3	15	13%					
Sugar Beets	22	0.4	19	10%					
Beans (dry)	34	0.0	0	0%					
Barley	3	0.0	0	0%					
Oats	9	0.1	6	7%					
Pasture	4	0.5	116	86%					
Alfalfa	302	114.5	380	89%					
Clover	2	0.2	109	81%					
TOTAL	**395**	**116.0**							

Table 11.28a-d: Simulated historic, current, and future total nitrogen fluxes in Central Valley and its three regions. For associated land area, see Table 11.19.

Central Valley	1945	1960	1975	1990	2005	2020	2035	2050
	[Gg N/yr]	[Gg N/yr]	[Gg N/yr]	[Gg N/yr]	[Gg N/yr]	[Gg N/yr]	[Gg N/yr]	[Gg N/yr]
Atm. Deposition	34	45	57	60	49	37	25	13
Irrigation	0	5	10	18	26	32	38	45
Pot. Synth. Fertilizer	100	179	274	471	525	525	525	525
Synth. Fertilizer	100	178	265	451	504	504	503	503
Land Applied	2	3	55	91	175	196	224	239
Manure Sale	0	0	0	9	45	51	58	61
Pot. Harvest	120	229	266	339	446	446	446	446
Harvest	48	115	171	251	335	335	336	337
Atm. Losses	14	24	71	122	209	227	251	263
pGW cropland	35	47	123	259	330	352	381	396
pGW fixed rate lands	11	16	21	23	27	28	29	30
pGW All	47	65	146	285	362	385	416	433

Sacramento Valley	1945	1960	1975	1990	2005	2020	2035	2050
	[Gg N/yr]	[Gg N/yr]	[Gg N/yr]	[Gg N/yr]	[Gg N/yr]	[Gg N/yr]	[Gg N/yr]	[Gg N/yr]
Atm. Deposition	8	11	13	14	11	9	6	3
Irrigation	0	1	2	3	5	6	7	8
Pot. Synth. Fertilizer	32	55	82	130	148	148	148	148
Synth. Fertilizer	32	55	81	129	147	147	147	147
Land Applied	0	0	2	3	6	6	7	8
Manure Sale	0	0	0	0	0	0	0	1
Pot. Harvest	27	55	73	91	117	117	117	117
Harvest	17	37	56	76	97	97	97	97
Atm. Losses	4	7	11	17	20	21	21	22
pGW cropland	8	10	17	42	39	40	40	41
pGW fixed rate lands	2	3	4	4	6	6	6	6
pGW All	10	14	21	47	47	47	48	49

San Joaquin Valley	1945	1960	1975	1990	2005	2020	2035	2050
	[Gg N/yr]	[Gg N/yr]	[Gg N/yr]	[Gg N/yr]	[Gg N/yr]	[Gg N/yr]	[Gg N/yr]	[Gg N/yr]
Atm. Deposition	11	15	19	20	17	13	9	4
Irrigation	0	1	3	5	7	9	11	13
Pot. Synth. Fertilizer	30	44	64	119	128	128	128	128
Synth. Fertilizer	30	44	61	112	122	122	122	122
Land Applied	0	0	22	36	71	79	90	95
Manure Sale	0	0	0	3	13	14	16	17
Pot. Harvest	44	59	67	95	120	120	120	120
Harvest	14	26	40	67	86	86	86	86
Atm. Losses	4	6	23	41	72	79	88	92
pGW cropland	12	16	39	76	106	114	125	130
pGW fixed rate lands	4	4	6	7	8	8	8	8
pGW All	16	21	46	84	116	124	135	141

Tulare Lake Basin	1945	1960	1975	1990	2005	2020	2035	2050
	[Gg N/yr]	[Gg N/yr]	[Gg N/yr]	[Gg N/yr]	[Gg N/yr]	[Gg N/yr]	[Gg N/yr]	[Gg N/yr]
Atm. Deposition	15	20	25	26	21	16	11	6
Irrigation	0	3	6	9	13	17	20	23
Pot. Synth. Fertilizer	38	81	128	222	249	249	249	249
Synth. Fertilizer	37	80	123	210	234	234	234	234
Land Applied	2	3	32	52	99	111	127	136
Manure Sale	0	0	0	7	32	36	41	44
Pot. Harvest	49	115	126	153	209	209	209	209
Harvest	17	53	75	108	151	152	153	153
Atm. Losses	6	11	37	64	116	127	141	149
pGW cropland	15	21	67	141	184	198	215	225
pGW fixed rate lands	5	8	11	12	13	14	15	15
pGW All	20	30	79	154	199	214	233	243

Table 11.29a-d: Simulated historic, current, and future total nitrogen flux rates in Central Valley and its three regions. For associated land area, see Table 11.19.

Central Valley	1945	1960	1975	1990	2005	2020	2035	2050
	[kg N/ha/yr]	[kg N/ha/yr]	[kg N/ha/yr]	[kg N/ha/yr]	[kg N/ha/yr]	[kg N/ha/yr]	[kg N/ha/yr]	[kg N/ha/yr]
Atm. Deposition	6	9	11	11	9	7	5	3
Irrigation	-	2	4	6	8	10	12	14
Pot. Synth. Fertilizer	58	75	107	169	171	171	171	171
Synth. Fertilizer	57	75	104	162	164	164	164	164
Land Applied	43	70	366	512	978	1098	1253	1339
Manure Sale	-	-	-	4	17	19	22	23
Pot. Harvest	69	95	104	116	139	139	139	139
Harvest	28	48	67	86	105	105	105	105
Atm. Losses	3	5	15	26	47	51	56	59
pGW cropland	27	26	51	96	120	129	140	145
pGW fixed rate lands	28	28	35	34	33	34	35	36
pGW All	13	17	35	66	81	87	93	97

Sacramento Valley	1945	1960	1975	1990	2005	2020	2035	2050
	[kg N/ha/yr]	[kg N/ha/yr]	[kg N/ha/yr]	[kg N/ha/yr]	[kg N/ha/yr]	[kg N/ha/yr]	[kg N/ha/yr]	[kg N/ha/yr]
Atm. Deposition	4	6	7	8	6	5	3	2
Irrigation	-	1	3	4	5	7	8	9
Pot. Synth. Fertilizer	59	77	112	175	176	176	176	176
Synth. Fertilizer	59	77	111	174	175	175	175	175
Land Applied	15	25	287	422	815	913	1037	1105
Manure Sale	-	-	-	0	1	1	1	1
Pot. Harvest	50	78	100	114	130	130	130	130
Harvest	31	52	77	95	108	108	108	108
Atm. Losses	2	4	7	10	13	13	14	14
pGW cropland	23	23	27	62	52	52	53	53
pGW fixed rate lands	25	24	24	23	23	23	24	24
pGW All	8	10	15	33	31	31	32	33

San Joaquin Valley	1945	1960	1975	1990	2005	2020	2035	2050
	[kg N/ha/yr]	[kg N/ha/yr]	[kg N/ha/yr]	[kg N/ha/yr]	[kg N/ha/yr]	[kg N/ha/yr]	[kg N/ha/yr]	[kg N/ha/yr]
Atm. Deposition	9	12	15	15	13	10	7	3
Irrigation	-	2	4	7	9	12	14	16
Pot. Synth. Fertilizer	57	78	110	178	172	172	172	172
Synth. Fertilizer	57	78	105	168	165	164	164	164
Land Applied	42	69	512	669	1206	1351	1534	1633
Manure Sale	-	-	-	4	16	18	21	22
Pot. Harvest	81	103	115	130	150	150	150	150
Harvest	27	45	69	91	107	107	107	108
Atm. Losses	4	5	20	36	67	74	82	86
pGW cropland	31	35	61	106	159	177	194	203
pGW fixed rate lands	28	27	37	37	34	34	35	35
pGW All	16	20	41	73	101	109	118	123

Tulare Lake Basin	1945	1960	1975	1990	2005	2020	2035	2050
	[kg N/ha/yr]	[kg N/ha/yr]	[kg N/ha/yr]	[kg N/ha/yr]	[kg N/ha/yr]	[kg N/ha/yr]	[kg N/ha/yr]	[kg N/ha/yr]
Atm. Deposition	7	9	11	12	10	7	5	3
Irrigation	-	2	4	7	9	11	13	15
Pot. Synth. Fertilizer	58	72	103	161	167	167	167	167
Synth. Fertilizer	57	71	99	152	158	157	157	157
Land Applied	44	72	309	445	871	980	1120	1202
Manure Sale	-	-	-	5	22	25	28	30
Pot. Harvest	74	103	101	110	139	139	139	139
Harvest	26	47	60	77	101	101	102	102
Atm. Losses	3	6	19	34	63	69	77	81
pGW cropland	28	24	59	109	139	150	163	170
pGW fixed rate lands	31	31	40	39	40	41	44	46
pGW All	17	20	48	88	110	118	129	135

For 2005, nitrogen fluxes to and from agricultural cropland only, including alfalfa (and clover), but not including the uncertain fluxes to and from pasture are summarized in Figure 11.11. The pie-chart shows nitrogen inputs to Central Valley agricultural lands on the right (positive values) and nitrogen outputs from agricultural lands on the left (negative values), for the 2005 period. The largest nitrogen fluxes associated with cropland include synthetic fertilizer (504 Gg N/yr), harvested nitrogen (450 Gg N/yr, including 115 Gg N/yr from leguminous nitrogen fixation in alfalfa), potential nitrogen losses to groundwater from cropland (331 Gg N/yr), atmospheric nitrogen losses from cropland (78 Gg N/yr), and land application of manure on dairy cropland or exported to other crops (220 Gg N/yr).

Urban areas, including golf courses and WWTP/FP percolation basins leach approximately 13 Gg N/yr to groundwater, septic systems over 5 Gg N/yr, and dairy corrals and lagoons leach about 5 Gg N/yr (Table 11.30).

Table 11.30: Summary of potential groundwater nitrogen loading from Central Valley sources assessed in this report.

Mg N/yr	1945	1960	1975	1990	2005	2020	2035	2050
Cropland (incl Alfalfa)	42,847	58,137	131,322	259,661	330,680	351,527	378,527	392,966
Urban	2,131	3,492	5,118	7,166	9,543	9,543	9,543	9,543
Golf Courses	66	66	66	66	66	66	66	66
Lagoons	0	0	2787	2,787	2,787	2,787	2,787	2,787
Corrals	0	0	2243	2,243	2,243	2,243	2,243	2,243
WWTP Percolation Basins	680	1,113	1,480	2,273	2,988	3,609	4,503	5,311
FP Percolation Basins	62	102	136	208	274	331	413	487
Septic Systems	1,312	2,148	2,851	4,333	5,565			
tons N/yr	**1945**	**1960**	**1975**	**1990**	**2005**	**2020**	**2035**	**2050**
Cropland (incl Alfalfa)	47,217	64,067	144,717	286,147	364,409	387,383	417,137	433,049
Urban	2,348	3,848	5,640	7,897	10,517	10,517	10,517	10,517
Golf Courses	73	73	73	73	73	73	73	73
Lagoons	0	0	3,071	3,071	3,071	3,071	3,071	3,071
Corrals	0	0	2,472	2,472	2,472	2,472	2,472	2,472
WWTP Percolation Basins	749	1,227	1,630	2,504	3,293	3,978	4,962	5,852
FP Percolation Basins	69	113	150	230	302	365	455	537
Septic Systems	1,446	2,367	3,142	4,775	6,132	7,220	8,668	9,885

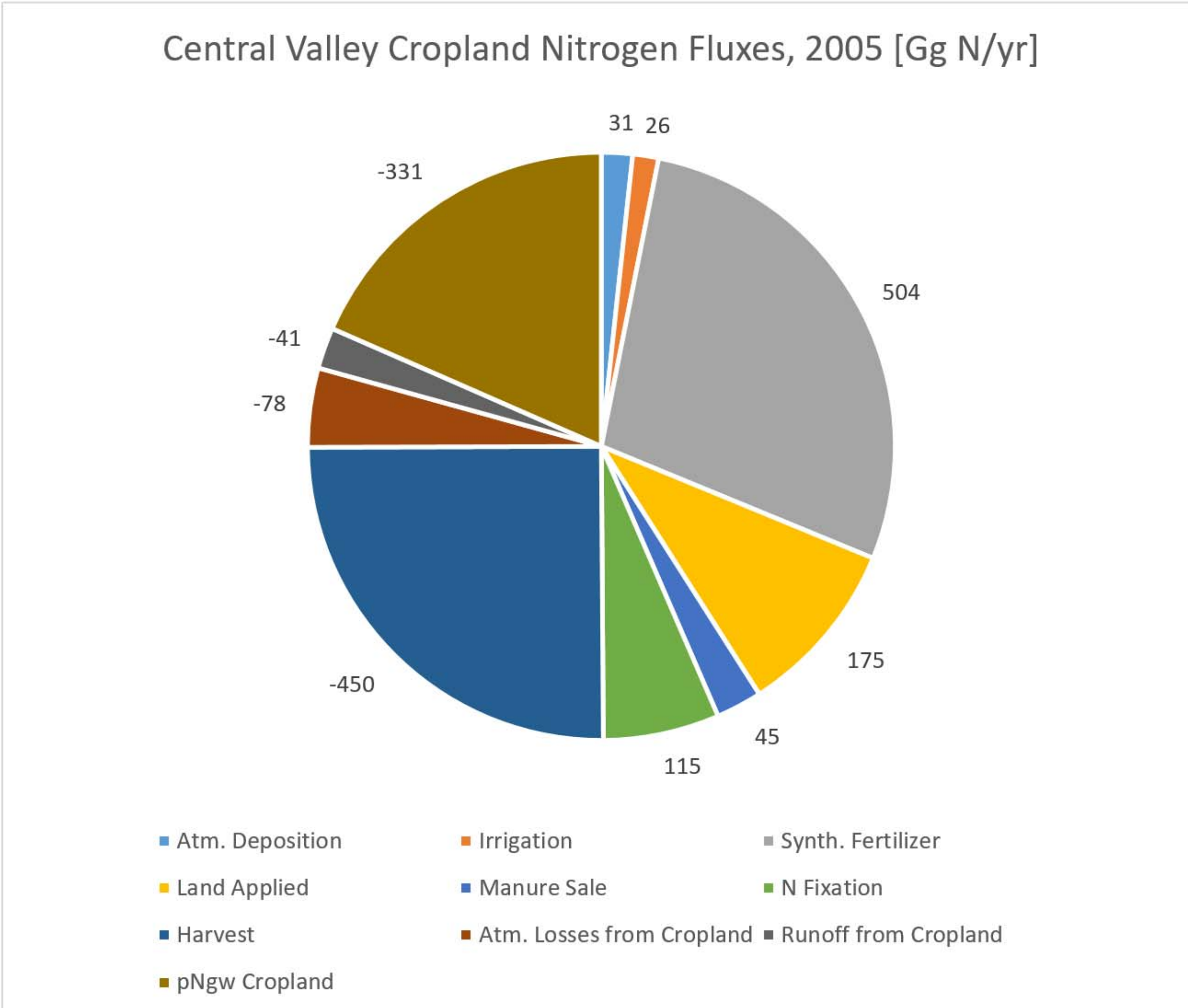

Figure 11.11: Sum of all GNLM simulated nitrogen fluxes in Central Valley Cropland [Gg N/yr]. 1 Gg N is 1,100 tons of nitrogen.

For the three regions within the Central Valley, 2005 nitrogen flux terms are summarized in Figure 11.12. Harvest, atmospheric losses, runoff, and potential groundwater nitrogen loading are listed as negative terms; atmospheric deposition, irrigation water nitrogen, manure applications, effluent application, biosolids application, and synthetic fertilizerare listed as positive terms. Like Figure 11.11, this figure shows only cropland fluxes for atmospheric deposition and atmospheric losses of nitrogen, includes alfalfa, but does not include pasture.

The Tulare Lake Basin accounts for the largest nitrogen fluxes but it also reflects nearly half of the total irrigated cropland area – 1.5 million ha of 3.2 million ha in the Central Valley. Nitrogen flux rates in the Tulare Lake Basin largely mirror those in the San Joaquin Valley (Table above), with large amounts and rates of manure land applications.

The Sacramento Valley, in contrast, has only small amounts of dairy cropland with manure land applications and little manure export. Lacking manure nitrogen sources to augment synthetic fertilizer, the Sacramento Valley in turn has somewhat higher rates of synthetic nitrogen application (175 kg N/ha/yr instead of 165 and 158 kg N/ha/yr in the San Joaquin Valley and Tulare Lake Basin, respectively).

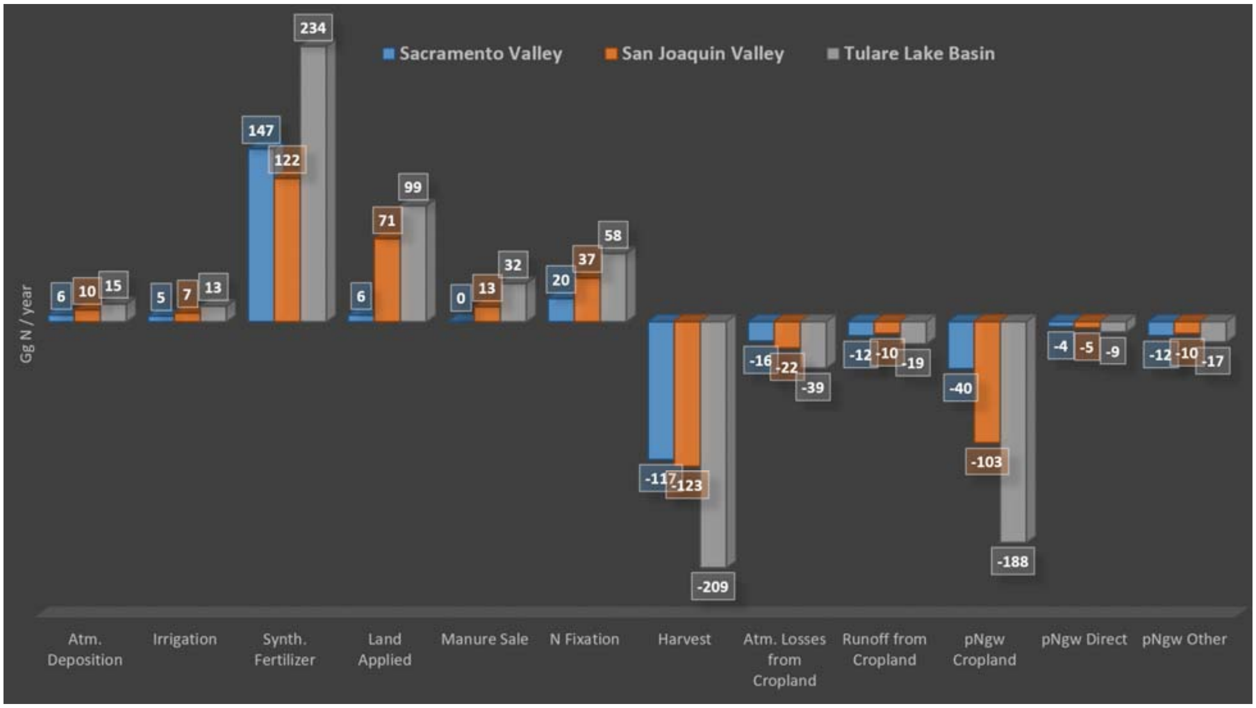

Figure 11.12: Comparison of GNLM simulated major nitrogen fluxes [Gg N/yr] in the Sacramento Valley, (Northern) San Joaquin Valley, and Tulare Lake Basin for the 2005 period. 1 Gg N = 1,100 tons of nitrogen.

To reduce groundwater nitrogen loading from cropland across the Central Valley and thus improve the quality of recharge water from the agricultural landscape, there are two basic system-changing options, dictated by the magnitude of fluxes shown in the pie-chart:

- Increase the amount of harvest without also increasing the amount of synthetic or organic fertilizer
- Reduce the nitrogen input to the agricultural landscape. However, of all fluxes into the agricultural landscape, only synthetic fertilizer use can be reduced significantly without significantly changing Central Valley landuse with cities and animal farming generating large amounts of nitrogen that is currently recycled in the local agricultural landscape.

This effort is currently being addressed by agricultural coalitions and Regional Water Boards in cooperation with research, extension, and industry experts. Chapter 12 outlines key practices now available to improve nitrogen use efficiencies in crops.

For the Central Valley, and particularly for the San Joaquin Valley and Tulare Lake Basin, a central challenge to improving groundwater quality is to develop nutrient management practices that make more efficient and effective use of animal derived nutrients to allow growers to increasingly rely on organic (manure) rather than synthetic fertilizer. Without major efforts in the development of new processes to transform manure into a market fertilizer product, it may be impossible to achieve much improved nitrogen use efficiencies:

- The cost of shipping manure, especially liquid manure, to reach a much larger cropland area is currently not economic;
- Manure, with its significant organic nitrogen content, being difficult to employ at high nitrogen use efficiencies (low A/R ratios) as the major or nearly exclusive nitrogen source in the intensive cropping systems common in the Central Valley
- Higher nitrogen use efficiency is typically linked to efficient irrigation, but applying manure in pressurized micro-irrigation systems requires significant processing (filtration).

Addressing these challenges will be critical to improving, in the long-term, overall groundwater nitrate conditions in the Central Valley.

Task 12: Develop a list of prominent alternative management practices in high loading crops.

A list of 49 practices, clustered into 10 management measures was developed via literature review and vetted via expert opinion (Table 12.1). We have received peer review comments through UC ANR on a manuscript that revises the original work published in Dzurella et.al (2013), and are working on making the final manuscript widely accessible to growers.

Measures aim to maximize irrigation and nitrogen use efficiency. All measures and practices fall into one of four categories:

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

While a number of these practices are already in high use, their prescription is highly site-specific. Due to the generally long travel time of nitrate molecules to aquifers, current measurements of well water nitrate levels are most representative of past management regimes. The effect any one practice has on leaching is variable and depends on climate, soil characteristics, crop characteristics, crop rotation strategies, irrigation strategies, and other factors. For all of these reasons, it is impossible to assess the level of impact the improved management regimes employed by today's producers will have on future groundwater quality, and impossible to assess to what degree increased adoption of mitigative practices will have on this quality. However, it is certain the impact will be positive and that current average management, while an improvement over past practices, can still be considerably improved in terms of groundwater protection. Tandem implementation of improved management practices, chosen in relation to each unique farm situation, is the best approach to reducing nitrate leaching from agricultural fields.

These recommended practices are almost all associated with significant barriers to their adoption, and some practices are simply not appropriate at all depending on the crop grown and other factors. High implementation costs, either capital or operational, can be prohibitive, exceptionally so in some cases. For example, the capital investment required to install drip irrigation on processing tomato fields is partially compensated for by way of yield increases. Installing drip for lower value crops (e.g. many forage crops) precludes use, or inapplicable, for example on fields receiving liquid manure, which cannot be applied through drip or sprinkler irrigation systems. Some practices, such as pre-plant irrigation reduction, can risk yields, in this case by risking germination success. Educational barriers and need for training is a commonly cited barrier that has significant opportunities to be overcome. Increased research and outreach education, as provided by extension specialists, FREP work, and others, has the potential to significantly increase adoption of practices that are appropriate and economically feasible for specific farm situations.

Table 12.1. Agricultural management measures that can increase nitrogen use efficiency and decrease nitrate leaching to groundwater, including the number of described practices used to achieve each measure (Dzurella et al. 2012).

Basic Component	Management Measure	Number of Recommended Practices Described
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	4
	MM 5. Improve micro-irrigation 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: 49

Task 13. Apply nitrate loading rates to NPS groundwater assessment tool to predict statistical distribution of nitrate in production wells

13.1 Work Description

Initially, we developed the GIS framework and compiled spatial land use data, collecting and digitizing data for performance of the nitrogen mass balance (historic and current), and worked on the groundwater loading model. Data collection was extensive, including land N applications (from atmospheric, fertilizer, animal, and human sources) and field nitrogen removal (harvest removal, atmospheric losses, surface runoff).

This was followed by extensive analysis of cropping data, that is, the annual fluxes into and out of the rootzone of individual fields (Harter et al., 2013). This is arguably the largest component of the overall nitrogen flux, as Harter *et al.* (2012) found that nearly 95% of groundwater nitrate in the Tulare Lake Basin and Salinas Valley was directly attributable to croplands, with approximately one half of this nitrogen coming from synthetic fertilizer and another third attributable to land-applied manure used as a fertilizer source or soil amendment. Crop area and production data have been used to determine the median period harvest removal rates of nitrogen by county, by sub-basin, and for the entire Central Valley, as well as by crop. Fertilization rates, based on our surveys and published literature (Viers et al. 2012, Rosenstock et al. 2013), for each period were then used to estimate total synthetic N applications based on reported crop area.

An extensive review of dairy nitrogen sources to groundwater was performed. Dairy related landuses are categorized into three groups: dairy corrals, dairy lagoons, and cropland receiving dairy manure. Groundwater monitoring data and literature reports were used to estimate ranges of nitrate loading to groundwater from dairy corrals and lagoons. A mass balance approach is applied for dairy cropland nitrate loading. For the analysis, we obtained estimated and reported data on manure production, manure exports, and manure and fertilizer applications to dairy forage crops.

Non-agricultural sources of nitrogen – some of the land applied to agricultural lands – also include waste effluent and biosolids from wastewater treatment plants and from food processors, leachate from septic systems, urban wastewater systems, and urban lawns and golf courses.

Based on our work in Kourakos et al. (2012), we continued to develop a groundwater nitrate transport modeling tool that allows computation of long-term transport of nitrate to individual domestic/municipal/irrigation wells, based on the spatially distributed, field-by-field, annual nitrogen loading to groundwater. Using this software, we have developed flow and transport models for the Central Valley. We will apply the nitrogen loading rates obtained from the mass balance assessment and from the literature review with this nitrate transport modeling tool to the Central Valley. The model results will provide long-term (1940 – 2100) statistical predictions of groundwater nitrate in domestic wells, irrigation wells, and municipal wells in several large project areas in the Central Valley. This will allow us to track nitrate travel paths and travel times from recharge zones to the groundwater capture in domestic wells, irrigation wells, and municipal wells. In the final project step, data developed will be published in a web-accessible GIS database.

13.2 Results and Discussion

The simulation of groundwater contamination from non-point sources has been an active arena of research for several decades. Approaches to evaluate the impact from non-point source pollution fall into three categories: index methods, statistical methods, and physically based methods. For example, the internationally widely applied DRASTIC tool (Aller et al., 1987) or the California nitrogen hazard index (Viers et al., 2012), are index-based tools that aggregate information such as soil type, landuse, topography, irrigation/precipitation, recharge, etc. using expert-assigned indexing levels. Index methods provide a composite vulnerability assessment map. Similarly, statistical methods such as multivariate statistics (Kaown et al., 2007), regression analysis (Nolan et al., 2006), artificial neural networks (Khalil et al., 2005) are employed to extract relationships between control variables (potential contaminant sources, climate-soil-aquifer conditions) and water quality data (nitrate, pesticides) in wells or springs to provide a tool to assess potential groundwater quality impacts. For example, the California Department of Pesticide Regulations uses a multivariate statistical approach to delineate groundwater protection zones vulnerable to pesticide contamination (Troiano et al., 1994, 1997).

Physically based methods – often referred to as "groundwater computer models" – explicitly capture the flow and transport dynamics that govern the contamination processes. These methods are based on the solution of partial differential equations of groundwater flow and contaminant transport. Physical or process-based approaches provide scientifically more rigorous insights into flow and transport dynamics than indexing or statistical methods. They allow for a wide range of analyses and assessments, including sensitivity, scenario, and stochastic analyses. A major drawback of physically based models is that their implementation is computationally demanding. NPS pollution often takes place in large agricultural basins that extend across thousands to tens of thousands of square miles, while individual sources such as crop fields, dairy lagoons/corrals, septic systems, etc. vary in extent from less than a few acres to few hundreds of acres. Groundwater and pollutant discharge to streams or to the large number of irrigation wells in semiarid and arid basins forces highly localized flow and transport systems. Therefore, the simulation of very large agricultural basins with sufficiently detailed discretization to account for the proper transport dynamics between the large assembly of relatively small but heterogeneous sources and the affected array of spatially distributed groundwater discharge locations (wells, springs, stream sections) would potentially require computer models with tens to hundreds of millions of pixel cells (currently, typical groundwater transport models employ up to one million pixel cells). The large contrast between the extent of groundwater basins and the size and number of contributing sources and affected receptors makes the simulation of NPS pollution a challenging problem, despite current software and hardware developments.

To simulate groundwater pollution from agricultural sources in Central Valley aquifer we developed the Non-Point Source Assessment Tool (NPSAT Kourakos and Harter 2014a) which is based on our previous theoretical work (Kourakos et al., 2012). NPSAT employs the streamline transport approach on a highly resolved steady-state groundwater flow field to derive an ensemble of unit response functions (URF) for each discharge point of interest (e.g., wells, streams etc.). The URFs are stored in a GIS database and can be used for predictions by convolution with actual spatiotemporally distributed pollutant loading functions to rapidly calculate breakthrough curves (BTCs). The approach has two distinct advantages. First, based on the premise of steady-state flow (see Kourakos et al., 2012 for full justification of the assumptions), the transport problem can be separated from the flow problem and second, using the URF concept, the transport problem becomes independent of the loading history.

The NPSAT consists of two phases, the construction phase and the implementation phase. During the construction phase the groundwater flow is simulated with sufficiently detailed discretization around wells, streams or other sources or receptors of interest. Due to the highly non-uniform distribution of boundary stresses, we apply the finite element method (FEM), which allows for locally variable size discretization. The groundwater flow field provides the basis for the streamline transport simulation. Note that this method was specifically developed for diffuse pollution problems where all or most recharge sources are associated with an identifiable and relevant level of pollutant concentration, and where a large number of discrete receptors or Compliance Discharge Surfaces (CDS) exist (e.g., wells, springs, stream sections).

> Streamlines consist of a set of positional vectors $X = \{\mathbf{x}_0, \mathbf{x}_1, \dots, \mathbf{x}_{n,}\}$ that hold the coordinates of the streamline and a set of velocity norms $V = \{v_0, v_1, \dots, v_n\}$, which contain the velocities at the points of the positional vectors. Note that we are using backward particle tracking that associates each streamline with a contamination source thus identifying contributing land uses within the source area of a CDS.

To identify the pathways of contaminants that are associated with each particular CDS, a large number of particles are released in the immediate vicinity of the CDS. The particles are tracked backwards until they exit the aquifer at the point of recharge, thus defining streamlines. For each streamline, the computer model solves a one-dimensional transport problem (see textboxes).

For each streamline we solve the one dimensional transport problem:

$$R\frac{\partial c}{\partial t} = \frac{\partial}{\partial x}\left(D\frac{\partial c}{\partial x} - vc\right) - \lambda Rc$$

subject to:

$$c(x)_{t=0} = 0\ \forall x \in [0, L]$$

$$c(\mathbf{x}_n)_{t>0} = 1$$

$$\left(\frac{\partial c}{\partial t}\right)_{x=\mathbf{x}_o} = 0$$

where $c(x,t)$ is the solute concentration at point x and time t, v is the pore velocity, D is dispersion coefficient, λ is first order degradation (or decay) constant and R is the retardation factor. Dispersion $D = \tilde{\alpha}_L v$ is a function of the effective macrodispersivity, $\tilde{\alpha}_L$. The latter, $\tilde{\alpha}_L = f(L)$, is typically scaled relative to the length of the streamline L (Gelhar et al., 1992; Green et al., 2010).

In the implementation phase, actual BTCs for each CDS are computed as a response to actual pollutant loading functions. The typical form of a loading function is a time series of spatially variable loading rates, varying, e.g., by field, possibly grouped into land use or crop type categories. Therefore the first step during the implementation phase is to associate the points $\boldsymbol{x}_n$ with the associated field or land use types that have a known loading function. Next, the loading functions are convolved with the URFs to derive the streamline BTCs. The convolution operator is a fast operator that involves only analytical calculations and the execution time is practically negligible.

The NPSAT requires a highly detailed resolution around the receptors to avoid the weak sink problem (Starn et al., 2012) during backward particle tracking. In addition, the scale of the discretization at the aquifer surface needs to be on the same order as the scale of the individual contributing recharge and pollution sources. Therefore, the simulation of large agricultural groundwater basins leads to a very large system of linear equations.

In the formulation of the transport problem we do not require any knowledge of loading. Instead, a continuous unit loading is applied at the source side $\mathbf{x}_n$. Solving the transport problem we calculate the unit response function (URF) at the CDS side $\mathbf{x}_0$ by shifting the solution of the 1D transport problem by the basic time unit defining the temporal discretization of the NPS loading function (e.g., one year for annually varying loading) and subtracting it, for a given time, from the original solution.

The URFs are subsequently archived into a Geodatabase and can be used during the implementation phase. In addition to URFs, archives are also established for the coordinates of point $\mathbf{x}_{n,}$ and the velocity v_0.

To deal with large scale simulations we modified the approach of Kourakos and Harter (2014a) to allow parallel implementation (Kourakos and Harter 2014b). Generally, the construction phase of NPSAT is time consuming and involves several sequential steps. However the memory requirements are relatively small even for large problems and more importantly the individual processes are embarrassingly parallel, i.e. little or no effort is required to separate the problem into separate tasks and almost no communication between tasks is needed.

The first step in numerical simulation is the discretization of the domain. Because of the complexity of parallel mesh generation and the lack of readily available libraries, in our framework we choose to construct a 2-dimensional mesh using standard methods which can be executed on a single processor. For parallel processing, the 2D mesh is subsequently split into subdomains and the mesh is extruded in the Z direction on each process individually. To allow independent assembly on each processor without the need to exchange information besides the locally owned elements, each subdomain owns a number of ghost elements, which are elements locally owned by another processor. The next step is the matrix assembly where the conductance terms and source/receptor vectors are assembled. The distributed system is solved by the algebraic multigrid method (AMG). Initially the grids and the restriction and interpolation operators on each level are constructed. The system is then solved iteratively using an appropriate solver and preconditioner. In our framework we propose conjugate gradient based solvers combined with algebraic multigrid methods as preconditioners (Kourakos and Harter 2014b). In cases where the partial differential equations are non-linear (e.g., unconfined flow), an additional loop is needed which iterates through all steps of the flow problem until

Let $f_L(t)$ be a loading function, which is associated with the URF $g_i^j(t)$ where the indices i and j correspond to the ID of the streamline and the ID of the CDS, respectively. The discrete form of convolution operator is expressed as: $G_i^j(t) = f_L * g_i^j = \sum_{\zeta=0}^{t} f_L(t-\zeta) g_i^j(\zeta)$ where $G_i^j(t)$ is the actual BTC in response to the loading function $f_L(t)$ for the streamline i, ζ is a free variable that increases in the summation at time step intervals and t is the total simulation time.

Finally, the actual BTC for the j CDS $\bar{G}^j(t)$ is the weighted average of the individual streamline BTCs $G_i^j(t)$ e.g. $\bar{G}^j(t) = \sum_{i=1}^{Ns} v_0^i \cdot G_i^j(t) / \sum_{i=1}^{Ns} v_0^i$, where the weights are taken equal to the amount of flow that each streamline contributes to the CDS.

the nonlinear problem converges. In unconfined groundwater flow simulations, for each non-linear iteration, the elevation of the top layer of the grid becomes equal with the hydraulic head of the previous iteration. This results in a change of the entire conductance matrix and source/receptors vector. Therefore the system is reassembled and solved iteratively until the change in the head between two consecutive iterations is smaller than a specified threshold.

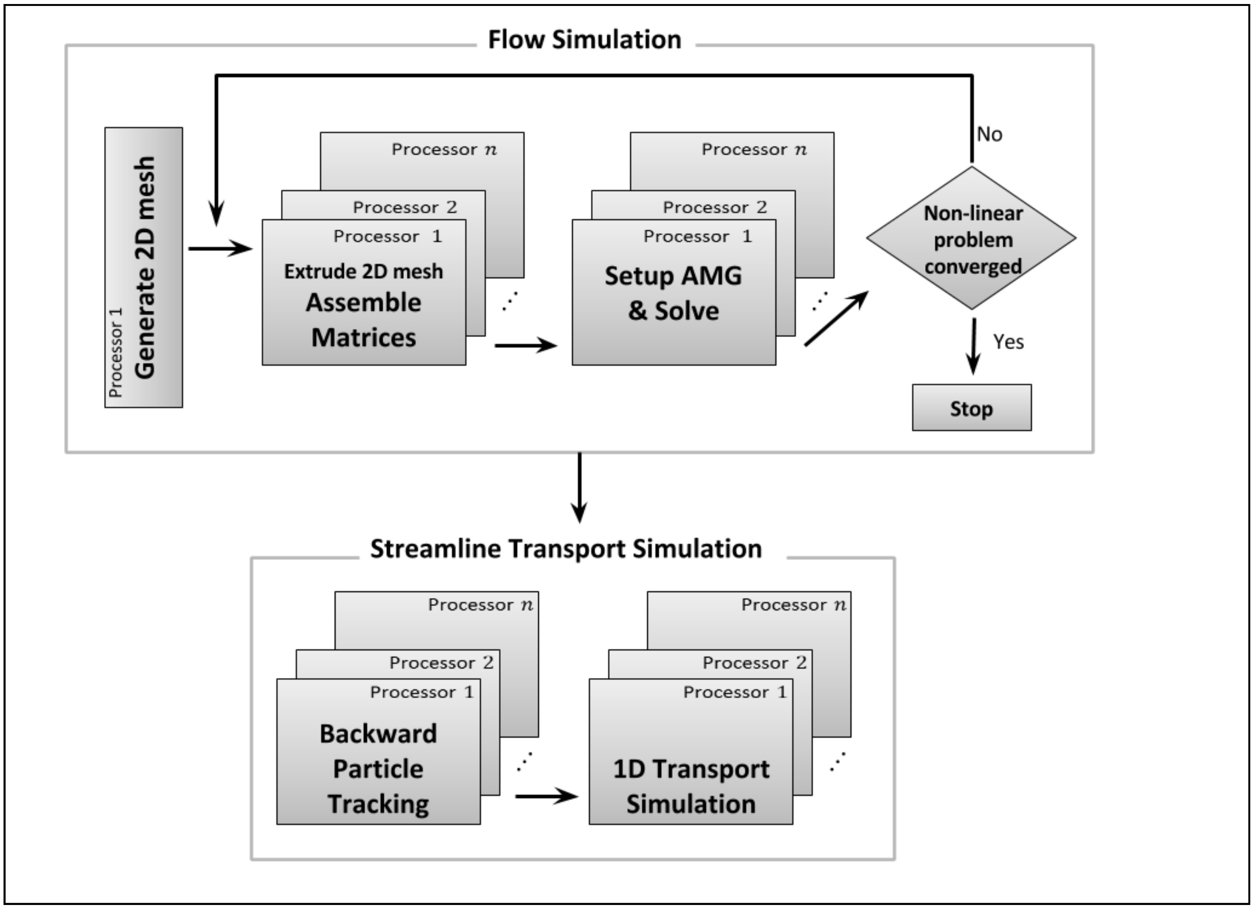

Figure 13.1: Schematic flow-chart of the computational tasks coded into the nonpoint source assessment simulation toolbox. The first step is a flow simulation to define the velocity distribution within the aquifer at very high resolution. The second step is a transport simulation in the three-dimensional aquifer system, which is achieved by computing nitrate or other pollutant transport along individual streamlines. The steps shown above generate so-called transfer functions that can be used within a GIS framework to generate simulated long-term contaminant histories in thousands of individual wells based on the pollutant loading history to the water table. The tool can be applied to evaluate future water quality changes due to improved management practices in selected crops, regions, or other land uses.

The computed head distribution is subsequently used for particle tracking. The streamline tracking simulation is a so-called embarrassingly parallel process. However, it is possible that a single streamline may span multiple subdomains and, hence, multiple processors. In cases where the available memory is able to support the entire 3D mesh it is advantageous to join the subdomains as streamline tracking becomes easy to implement. When the problem is too large to be stored on a single processor, additional algorithmic effort is needed to transfer particles between processors. The solution of the 1D transport problem along each streamline is an independent process even on very large problems and therefore can easily be parallelized. The implementation phase, which involves convolution of loading functions with the URF computed at the transport simulation, can be parallelized seamlessly although even the serial execution time is typically very small despite a very large number of CDS.

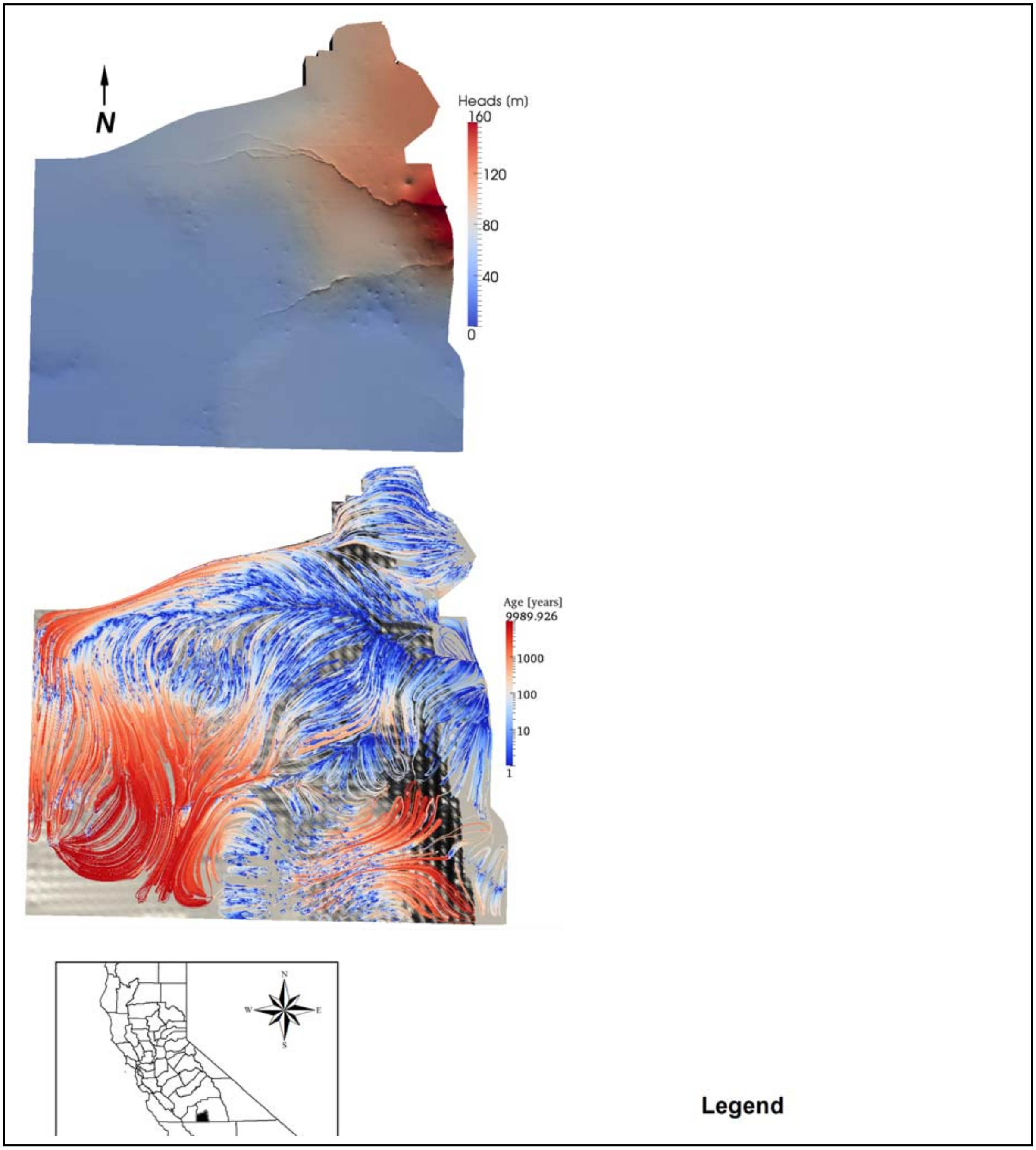

Figure 13.2: One application of the simulation algorithm was compelted for the Tule River basin in southern Tulare County, which features a wide range of crops, but also dairies (lower map). The flow model generates the simulated water table surface at high resolution (upper left), showing streams as recharge "walls" and large pumping wells as dotted depressions in the water table surface. Streamlines and travel time (water age, shown as the color of the streamline) are computed to all pumping wells and provide the basis for estimating pollutant transport.

Task 14: Publish all relevant data on web-accessible GIS database

Geo-referenced relevant data on nitrogen applications, nitrogen loading in soils, land use, soil textures and hydrologic groups, rainfall and temperatures, the various elements of the nitrogen budget listed in Task 11 including the groundwater nitrate loading potential, irrigation scheduling and nitrogen management practices, and groundwater quality impacts are organized into a GIS database framework. The data are made available as part of our outreach activities on the web (http://groundwaternitrate.ucdavis.edu/Data_And_Databases/).

Synthesis Discussion and Conclusions

The Central Valley is home to three-quarter of California's irrigated agriculture and a key U.S. producer of many specialty crops. The Central Valley is also responsible for nearly one-fifth of U.S. dairy production. In this work, we have developed comprehensive historic and current landuse maps for the Central Valley including nearly sixty different agricultural landuse categories (crops), from the 1940s to the 2000s as a basis for analyzing nitrogen fluxes through the Central Valley's agricultural and urban landscape. We have established a thorough analysis of fertilizer sales and fertilizer use in the Central Valley of California, established a comprehensive basis for estimating average or typical crop harvest rates, and considered other nitrogen sources that may impact groundwater quality.

A critical basis for estimating the total nitrogen fluxes from fertilizer and other sources in the Central Valley is the land area associated with crops. In this work, we have used two sources of land area for the 1990 and 2005 period: County Agricultural Commissioner Reports (ACR) (county aggregated data) and CAML maps based on landuse surveys by the California Department of Water Resources (CDWR). We found significant differences between these two information sources in the land area reported.

ACR reports for the 2005 period estimate the Central Valley production area to average 2.73 Mha. Overall measured crop production area is larger in CAML landuse map, 3.08 Mha. Differences are partially due to CDWR county surveys being performed only once in 7 to 10 years. They do not reflect annual variations. Even larger differences were found in the areas associated with individual crops and crop-groups due to the different survey mechanisms used by ACR and by CDWR. Largest cropping areas are associated with grain and hay (0.47/0.38 Mha), nuts (0.39/0.49 Mha), and alfalfa (0.32/0.30 Mha). These are followed by vegetables and berries, cotton, and corn-sorghum-sudan crops (about 0.26 Mha each in the ACR data; and 0.27, 0.31, 0.22 Mha, respectively, in the CAML map).

Since the cropping areas differ between the ACR and CAML, and with differing methods to account for the effect of manure application on synthetic fertilizer use, nitrogen application amounts and nitrogen harvest amounts for each crop and each county differ between ACR derived estimates and those obtained from GNLM, which is based on the CAML map. Total harvested N is estimated to be 256 Gg N/yr in the ACR-area based analysis, nearly 20% lower than the 316 Gg N/yr in the GNLM-based analysis (not including alfalfa or pasture). Total synthetic fertilizer use is estimated to be 432 Gg N/yr in the ACR-area based analysis, 14% lower than the 504 Gg N/yr estimated with GNLM.

Neither estimate of synthetic fertilizer use appears unrealistic: actual synthetic fertilizer sales independently reported by CDFA for Central Valley Counties are 533 Gg N/yr (average for 2002 – 2012, with outliers removed) and 740 Gg N/yr statewide. Some of the statewide synthetic fertilizer is used in urban areas and horticulture (53 Gg N/yr) and chemical production use (71 Gg N/yr), according to the California Nitrogen Assessment (Tomich et al., 2016). This suggests that statewide synthetic fertilizer use on cropland, based on fertilizer sales, is about 616 Gg N/yr. Since the Central Valley occupies about 75% of statewide cropland, this would suggest fertilizer use in the Central Valley of about 460 Gg N/yr. Both, ACR and CAML based estimates for synthetic fertilizer use are within 10% of this reported sales number indicating an overall good agreement of estimated fertilizer use and state-wide reported average fertilizer sales.

The highest estimated rates of synthetic fertilizer applications are in corn-sorghum-sudan, which is assumed to be typically double-cropped with winter grain (380 kg N/ha/yr),followed by nuts (227 kg N/ha/yr), vegetables and berries (201 kg N/ha/yr), cotton (188 kg N/ha/yr), and grain and hay (183 kg N/ha/yr). Lowest rates are associated with alfalfa (less than 20 kg N/ha/yr) and vineyards (39 kg N/ha/yr).

For 2005, GNLM estimates the potential groundwater nitrogen loading from Central Valley cropland to be 331 Gg N/yr (including alfalfa, but not highly uncertain fluxes from pasture). The magnitude of this flux is equal to two-thirds of the synthetic fertilizer applied. It is about twice as much as the total amount of land applied manure and effluent; and it is of similar magnitude to harvested nitrogen (not including alfalfa). The Central Valley potential groundwater nitrogen loading in the 2000s is nearly 10 times larger than in the 1940s. The increase in potential groundwater nitrogen loading was initially driven by increase in synthetic fertilizer applications and expansion of irrigated cropland areas. But since the 1970s the increases have been driven largely by the expansion of the dairy sector in the Central Valley and the associated land application of manure.

The highest potential loading rates are associated with the crops most intensively fertilized and particularly with those crops receiving dairy manure: corn-sorghum-sudan (320kg N/ha/yr), grain and hay (195 kg N/ha/yr), and cotton (148 kg N/ha/yr). These are followed by subtropical (124 kg N/ha/yr), deciduous tree fruit (100 kg N/ha/yr), nuts (98 kg N/ha/yr), and vegetables and berries (84 kg N/ha/yr). On the other hand, lowest rates are associated with rice (19 kg N/ha/yr), alfalfa (30 kg N/ha/yr), and vineyards (39 kg N/ha/yr). The current implementation of GNLM does not account for about 1 Gg N per year of nitrogen credit generated by alfalfa fields that are turned over to other crops (http://blogs.cdfa.ca.gov/FREP/?p=167).

We compared these mass-balance derived loading rates (see also Rosenstock et al., 2013) with estimates of loading that we obtained using Bayesian statistical methods that compare domestic well nitrate concentrations in over 2,100 Central Valley wells with surrounding landuses (Ransom et al., 2017b). The study found that loading rates may vary widely, but loading rates compared favorably to our mass balance derived estimates for manured crops, for vegetables and berries, citrus & subtropicals, field crops, and grapes. Groundwater nitrate derived loading rates for nuts (13 – 47 kg N/ha/yr), cotton (5 – 28 kg N/ha/yr), tree fruit (5 – 27 kg N/ha/yr), and rice (1 – 13 kg N/ha/yr) were much lower than those estimated by the mass balance approach. For rice, the difference may be explained by the large amount of denitrification typical in saturated soils underlying rice fields. A potential explanation for the difference found for cotton is that much of the cotton is cultivated in land area overlying the Corcoran Clay and where domestic wells typically tap into the confined aquifer system with older water, partially protected by denitrification in the Corcoran Clay confining layer. Differences obtained for nuts and tree fruit may be due partially to denitrification, but may also be due to groundwater age in domestic wells (10 – 50 years): Nuts and tree fruit acreage in 2005 is between twice and three times of the area when compared to 1975.

A separate statistical analysis (Ransom, 2017a) that compared over 140 individual explanatory factors against groundwater nitrate data from over 3,000 Central Valley wells measured in the 2000s showed that the nitrogen loading rate estimates from GNLM for 1975 was the most significant predictor of groundwater nitrate concentrations after accounting for factors explaining the denitrification potential. Loading rates for 1990 and 2005 were less significant predictor variables. This may confirm the decadal delay between loading and nitrate occurrence in domestic and public drinking water supply wells, which has also been shown by groundwater transport models and with groundwater age dating research.

Synthetic fertilizer contributes nearly 60% of all nitrogen fluxes to cropland. The second largest contributor is dairy manure (nearly 20%). The remaining inputs of nitrogen to cropland come from atmospheric deposition, irrigation water nitrate, wastewater treatment plant and food processor effluent applications.

To reduce potential groundwater nitrogen loading from cropland across the Central Valley and thus improve the quality of recharge water from the agricultural landscape, there are only few options, dictated by the magnitude of fluxes shown in Figure 11.11:

- Increase the amount of harvest without also increasing the amount of synthetic fertilizer or manure applications.
- Reduce the nitrogen input to the agricultural landscape. However, of all fluxes into the agricultural landscape, only synthetic fertilizer use can be reduced significantly without also significantly changing Central Valley landuse where cities and in particular dairies generate large amounts of nitrogen that is currently recycled in the agricultural landscape.

A central challenge to improving groundwater quality in the Central Valley is to develop nutrient management practices that make more efficient and effective use of animal derived nutrients to allow growers to increasingly rely on manure-derived fertilizer. This will require the development of new processes to transform manure into a marketable fertilizer product that performs much like synthetic fertilizer.

In the meantime, a wide range of agricultural practices have been documented, as part of this work (Chapter Task 12), as part of CDFA FREP's work, and elsewhere, that significantly improve crop nitrogen use efficiency at a region-wide scale over today's practices. Some improvements can be achieved by incorporating the value of irrigation water nitrogen into nutrient management (http://blogs.cdfa.ca.gov/FREP/?p=189). The results from this work suggest that agricultural coalitions, cooperative extension personnel, and agricultural consultants implementing the management practice evaluation programs for irrigated lands and dairies may achieve the greatest improvement in addressing groundwater nitrogen loading, if research and extension efforts in the Central Valley focus on improving the overall A/R in corn and grain, nuts, citrus, tree-fruit, and vegetables (specifically tomatoes, asparagus, carrots, melons and squash, which account for 80% of pGW from vegetables and berry crops in the Central Valley in the 2005 period).

Extending knowledge about efficient water and nutrient management practices to growers is a key goal of the agricultural coalitions in the Central Valley engaged in the implementation of the Irrigated Lands Regulatory Program and the Dairy Order. Agricultural management improvements are urgently needed to not further degrade groundwater recharge quality, even if improvements of groundwater quality in supply wells will only be felt at decadal time-scales, due to the slow-moving nature of groundwater. Identifying vulnerable areas and helping producers understand potential impacts to groundwater is part of the outreach to improve practices for groundwater protection purposes. The nitrogen application and harvest rates developed here are also being employed in the development of a quantitative Nitrogen Hazard Index currently under development (http://blogs.cdfa.ca.gov/FREP/?p=184).

The Groundwater Nitrogen Loading Model (GNLM) can be used in future "what-if" scenario analysis while also being improved as additional information on specific nitrogen flux components becomes available. Further cross-validation of the GNLM results will be possible once data on nitrogen application and harvest are more widely available from nitrogen management plans collected and summarized by the agricultural coalitions in the Central Valley.

In addition to developing an in-depth nitrogen flux model that allows us to estimate spatially distributed nitrogen fluxes, including potential fluxes to groundwater from all key sources in the Central Valley, we have developed a nonpoint-source groundwater transport modeling framework to track leached nitrate through the aquifer system to irrigation and drinking water wells. The transport model confirms the statistical results obtained from measured nitrate data: individual wells are influenced by multiple sources of nitrogen, often delayed by one to few decades or – in the case of deeper production wells – even a century or more due to the travel time of groundwater. The software developed provides the foundation for also developing a user-friendly scenario tool that can be used to estimate the dynamics and extend of future groundwater quality improvements from select improvements in specific location nitrogen discharges or from improvements in specific crop nutrient management practices. We are continuing to test the approach of the nitrate groundwater transport model and to develop applications in the Central Valley.

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Project Impacts

Specific ways in which the work, findings, or products of the project have had an impact during this reporting period:

- Project results were shared with consultants that used data in their work with agricultural coalitions on the implementation of the Central Valley Regional Water Board's Irrigated Lands Regulatory Program
- Project results informed discussions with agricultural stakeholders, but also with policy and decision-makers, technical advisory committees to the Central Valley Irrigated Lands Agricultural Program and to the Central Valley Salinity Coalition. These stakeholder-led coalitions are developing the framework for regulatory programs that will have major influence on future agricultural management practices and reporting in the Central Valley.
- The mass balance approach (identifying nitrogen applied and nitrogen removed) has been identified as the key tool for assessing grower contributions with respect to Waste Discharge Requirements used in the State. The mass balance approach used here is the underlying principle now employed in the annual reporting from growers to their coalitions (Central Valley) or to the Regional Water Board (Central Coast).

How data obtained from the project can be used, what further steps will be needed to make it applicable for growers, how the management practice will be demonstrated to growers, how the research will be applied to impact growers, and how this will impact the grower community:

- Digital landuse maps generated for this project for the 1945, 1960, 1975, 1990, and 2005 periods can be employed in numerous applications related to landuse planning; to environmental, natural resources, urban, and agricultural planning, including planning efforts by the Irrigated Lands Agricultural Coalitions in the Central Valley, by local Salinity Management Agencies to be created under CV-SALTS, and local Groundwater Sustainability Agencies now beginning to develop and implement Groundwater Sustainability Plans.
- Digital data obtained from county Agricultural Commissioner Reports can be used for a wide range of statistical analysis involving agricultural crop production and crop acreage, particularly historical data previously unavailable in digital format.
- Assessment of historic and current typical nitrogen fertilization rates and nitrogen harvest rates for nearly 60 crops can be used in numerous research applications and in consulting project work related to nitrogen use on agricultural lands. These numbers may also be useful in planning and assessing farm nutrient management and guide growers in understanding their potential impacts to groundwater quality. Importantly, this dataset provides a well-researched baseline against which to measure future assessments of nitrogen use and harvest in California and to identify long-term trends in nitrogen fluxes to and from agricultural lands, as part of future nitrogen assessments.

- The nitrogen flux analyses at the county scale (based on agricultural commissioner report data) and at the 50 m raster scale provide important information on the spatial and temporal distribution of past and current potential groundwater nitrogen loading. The data identify regions with the potentially most significant groundwater nitrogen loading. This information further validates other data on current nitrogen fluxes collected by the Irrigated Lands Regulatory Program and CV SALTS. Because we include a historical perspective, the dataset may prove useful in a wide range of analyses that use spatio-temporally distributed nitrogen fluxes as input.
- The Groundwater Nitrogen Loading Model provides a platform that is well suited to perform "what-if" scenario analyses to evaluate how user-defined changes in nitrogen management and harvest impact local, groundwater basin, county, or regional nitrogen fluxes in the future. This type of analysis can be done for a specific crop and at user-identified locations or with user-defined statistical distributions future changes.
- The nonpoint source groundwater modeling toolbox provides a software package that is useful for basin analysis of the fate of groundwater nitrate. Coupled to "what-if" scenarios of the Groundwater Nitrogen Loading Model, future changes in groundwater nitrate in domestic or public supply wells can be performed at the basin or sub-basin scale.
- The compendium of nitrogen fertilizer practices useful for improving nitrogen use efficiency is potentially an important learning tool for agricultural coalitions, extension personnel, agricultural consultants, and growers engaged in implementing the Irrigated Lands Regulatory Program in the Central Valley.

Cost-benefit analysis of adoption of the new technology and a discussion of barriers to adoption:

An economic analysis associated with adopting agricultural practices that can lead to a reduction in potential groundwater nitrogen loading was performed by J. Medellin: Medellin, J., T.S. Rosenstock, R.E. Howitt, T. Harter, K.K. Jessoe, K. Dzurella, G.S. Pettygrove, J.R. Lund, 2013. Agro-economic analysis of nitrate crop source reductions. J. Water Resources Planning and Mgmt. 139(5):501-511, doi:10.1061/(ASCE)WR.1943-5452.0000268.

We also evaluated several scenarios to change landuse around disadvantaged communities in the Tulare Lake Basin to agricultural crops with low nitrogen impact but high potential for clean recharge to improve both water quality and water supply: Mayzelle, M. M., J. H. Viers, J. Medellin-Azuara, and T. Harter, 2015. Economic feasibility of irrigated agricultural land use buffers to reduce groundwater nitrate in rural drinking water sources. Water 7(1):12-37, doi: 10.3390/w7010012 (open access).

Project's contribution toward advancing the environmentally safe and agronomically sound use of fertilizing materials:

This work provides a comprehensive baseline analysis of nitrogen fertilizer use relative to other nitrogen fluxes in the Central Valley and of nitrogen fertilizer contributions to potential groundwater nitrogen loading. It provides an assessment of long-term groundwater quality trends related to fertilizer use. Importantly this project, together with the SBX2 1 project, compiled an extensive survey of agricultural water and nutrient management practices that improve nitrogen use efficiency and that are applicable to the wide variety of crops in the Central Valley and neighboring regions.

Outreach Activities Summary

Project-related presentations by the Principal Investigator (Dr. Thomas Harter), 2012-2014

Event presentation title, role, attendees, organizer, event title, location, date, number of attendees:

Nitrate Sources and Impacts to Drinking Water in California, Invited Speaker, State Water Resources Control Board: Briefing (Tom Howard - Chief Exec. Officer), Robert Egel (Legislative Director), State Water Resources Control Board, Briefing, Sacramento, CA, 1/03/2012, 5 Attendees.

Organized and co-chaired planning meeting for "Nitrate in Drinking Water" study release events in March-May 2012, Organizer, Media representatives from SWRCB, CDPH, CalEPA, UC Davis, UCD CA&ES, UCD Ag Sustainability Institute, UC ANR, UC Watershed Sciences Center, UC Davis Watershed Sciences Center, Public Relations Planning Meeting, Davis, CA, 1/26/2012, 20 Attendees.

Nitrate Sources and Impacts to Drinking Water in California, Invited Speaker, Extension faculty, University of California, Annual Meeting of the Division of Agriculture and Natural Resources, Davis, CA, 2/02/2012, 40 Attendees.

Organized and co-chaired planning meeting for "Nitrate in Drinking Water" study release events in marc-May 2012, Organizer, Media representatives from SWRCB, CDPH, CalEPA, UC Davis, UCD CA&ES, UCD Ag Sustainability Institute, UC ANR, UC Watershed Sciences Center, UC Davis Watershed Sciences Center, Public Relations Planning Meeting, Davis, CA, 2/09/2012, 20 Attendees.

Nitrate Sources and Impacts to Drinking Water in California, Invited Speaker, Leadership staff of the governor's office, undersecretary of CDFA, Chief Executive Officer of SWRCB, Governor's Office, Briefing, Sacramento, CA, 2/09/2012, 10 Attendees.

Nitrate Sources and Impacts to Drinking Water in California, Invited Speaker, Undersecretary of CDFA, Chair of California Ag Board, Executive Director of California Ag Board, Director of UC Agricultural Sustainability Issue, California Secretary of Food and Agriculture, Briefing, Sacramento, CA, 2/14/2012, 6 Attendees.

Abandoned Wells and Improperly Destroyed Wells: How Many Wells Are We Talking About, Invited Speaker, College Dean, Groundwater Resources Association, Webcast Series "Abandoned Wells", Davis, CA, 2/15/2012, 2 Attendees.

Nitrate Sources and Impacts to Drinking Water in California, Invited Speaker, Secretary and undersecretary of CalEPA, UCD CA&ES Deans Office, Briefing, Sacramento, CA, 2/16/2012, 5 Attendees.

Organized and co-chaired planning meeting for "Nitrate in Drinking Water" study release events in March-May 2012, Organizer, Media representatives from SWRCB, CDPH, CalEPA, UC Davis, UCD CA&ES, UCD Ag Sustainability Institute, UC ANR, UC Watershed Sciences Center, UC Davis Watershed Sciences Center, Public Relations Planning Meeting, Davis, CA, 2/16/2012, 20 Attendees.

Organized and co-chaired planning meeting for "Nitrate in Drinking Water" study release events in March-May 2012, Organizer, Media representatives from SWRCB, CDPH, CalEPA, UC Davis, UCD CA&ES, UCD Ag Sustainability Institute, UC ANR, UC Watershed Sciences Center, UC Davis Watershed Sciences Center, Public Relations Planning Meeting, Davis, CA, 2/23/2012, 20 Attendees.

Nitrate Sources and Impacts to Drinking Water in California, Invited Speaker, Governor's office: Exec. Briefing (Dr. Ron Chapman), CDPH (Director); Karen Ross, CDFA (Secretary); Matt Rodriguez, CalEPA (Secretary); exec. staff of CalNRA; Leahy, director of DPR; Tom Howard, chief exec. officer of SWRCB, other California agency leader, CalEPA, Executive Briefing, Sacramento, CA, 2/16/2012, 30 Attendees.

Introduction to Groundwater Hydrology and the Interface Between Groundwater and Surface Water, Invited Speaker, Committee members, growers, local agency personnel, consultants, Extending Knowledge Page 62 of 77
landowners, stakeholder representatives, Napa County, Groundwater Management Advisory Committee, Napa, CA, 2/23/2012, 45 Attendees.

Nitrate Sources and Impacts to Drinking Water in California, Invited Speaker, Dr. Ron Chapman, CDPH (Director); Karen Ross, CDFA (Secretary); Matt Rodriguez, CalEPA (Secretary); executive staff of CalNRA; Leahy, director of DPR; Tom Howard, chief executive officer of SWRCB, other California agency leaders, Governor’s Office, Executive Briefing, Sacramento, CA, 02/23/2012, 30 Attendees.

Nitrate Sources and Impacts to Drinking Water in California, Presenter, Executive Leaders from the Dairy Industry, UC Davis: Executive, Briefing, Davis, CA, 2/27/2012, 5 Attendees.

Organized and co-chaired planning meeting for "Nitrate in Drinking Water" study release events in March-May 2012, Organizer, Media representatives from SWRCB, CDPH, CalEPA, UC Davis, UCD CA&ES, UCD Ag Sustainability Institute, UC ANR, UC Watershed Sciences Center, UC Davis Watershed Sciences Center, Public Relations Planning Meeting, Davis, CA, 3/01/2012, 20 Attendees.

Nitrate Sources and Impacts to Drinking Water in California, Invited Speaker, 50 commodities/100 attendees, Committee of Commodities, Briefing, Modesto, CA, 3/06/2012, 100 Attendees.

Nitrate Sources and Impacts to Drinking Water in California, Participant, Robert Gore, NO3G Team, Center for Watershed Sciences, Media Training, Davis, CA, 3/07/2012, 25 Attendees.

Nitrate Sources and Impacts to Drinking Water in California, Invited Speaker, Nancy McFadden, Executive Secretary to Gov. Jerry Brown, 4 staff members, Governor’s Office, Briefing, Sacramento, CA, 3/07/2012, 6 Attendees.

Nitrates and Groundwater: Is Regulating Agriculture the Answer?, Invited Speaker, Policy makers, policy consultants, lobbyists, federal/state/local agency employees, NGO representatives, California Water Policy Conference, Annual Meeting, Davis, CA, 3/09/2012, 80 Attendees.

Nitrate Sources and Impacts to Drinking Water in California, Presenter, Dr. Ron Chapman, Director of California Department of Public Health, Secretary of Public Health, Briefing, Sacramento, CA, 3/11/2012, 2 Attendees.

Nitrate Sources and Impacts to Drinking Water in California, Presenter, ANR farm advisors and county directors, UC ANR, ANR Webcast for County Directors and Farm Advisors, Davis, CA, 3/12/2012, 50 Attendees.

Addressing Nitrate in California's Drinking Water, Presenter, CA legislature: Legislative Briefing (25 capitol staffers, 2 Assembly Members (Yamada, Carter), 1 Senator), CA Legislature, Legislative Briefing, Davis, CA, 3/13/2012, 50 Attendees.

Addressing Nitrate in California's Drinking Water, Presenter, News Media, UC Davis, Press Conference, Sacramento, CA, 3/13/2012, 30 Attendees.

Addressing Nitrate in California's Drinking Water, Presenter, 100 stakeholder representatives, local/state/federal agency representatives, public, SWRCB/CalEPA, Public Release Workshop, Sacramento, CA, 3/13/2012, 100 Attendees.

Organized and co-chaired statewide event to present and discuss the release of our study on "Addressing Nitrate in California's Drinking Water", Organizer, 100 stakeholder representatives, local/state/federal agency representatives, public, SWRCB/CalEPA, Public Release Workshop, Sacramento, CA, 3/13/2012, 100 Attendees.

Organized and co-chaired planning meeting for "Nitrate in Drinking Water" study release events in March-May 2012, Organizer, Media representatives from SWRCB, CDPH, CalEPA, UC Davis, UCD CA&ES, UCD Ag Sustainability Institute, UC ANR, UC Watershed Sciences Center, UC Davis Watershed Sciences Center, Public Relations Planning Meeting, Davis, CA, 3/15/2012, 20 Attendees.

Addressing Nitrate in California's Drinking Water, Invited Speaker, Farmers, committee members, farm advisors, local groundwater stakeholders, state and federal agency personnel, U.S. EPA, San Joaquin Valley Environmental Justice Task Force, Ft. Jones, CA, U.S. EPA: San Joaquin Valley Environmenta3/19/2012, 25 Attendees.

Addressing Nitrate in California's Drinking Water, Invited Speaker, Farm advsiors, CE specialists, UC Davis and Cooperative Extension, Pomology Extension Continuing Conference, Davis, CA, 3/27/2012, 40 Attendees.

Addressing Nitrate in California's Drinking Water: Background and Potential Roles for PECC, Invited Speaker, Farm advisors, cooperative extension specialists, UC ANR, Pomology Extension Continuing Conference, Davis, CA, 3/27/2012, 45 Attendees.

Organized 1-day workshop to provide a forum for leaders in groundwater mgmt. and protection to network, and to identify crtical groundwater-related policy, research and management needs; and to identify the most importan education, outreach and extension, Organizer, State leadership in groundwater issues: agencies, stakeholders, academics, consultants, Groundwater Resources Association and University of California, Contemporary Groundwater Issues Council, Davis, CA, 3/28/2012, 40 Attendees.

Invited "Addressing Nitrate in Drinking Water: Key Findings", Keynote Speaker, State leadership in groundwater issues: agencies, stakeholders, academics, consultants, Groundwater Resources Association and University of California, Contemporary Groundwater Issues Council, Davis, CA, 3/28/2012, 40 Attendees.

Addressing Nitrate in California's Drinking Water, Invited Speaker, Governor's Office of Research and Planning, Groundwater Resources Association of California, Contemporary Groundwater Issues Council # Briefing, Davis, CA, 3/28/2012, 50 Attendees.

Addressing Nitrate in California's Drinking Water, Invited Speaker, EPA staff, CNA staff, U.S. EPA Region 9 Headquarters, Brownbag Lunch Briefing, San Francisco, CA, 4/02/2012, 40 Attendees.

Addressing Nitrate in California's Drinking Water: Overview, Sources, and Groundwater Quality, Invited Speaker, EPA staff, U.S. EPA Region 9, Brownbag Lunch Series, San Francisco, CA, 4/02/2012, 35 Attendees.

Nitrate in California's Drinking Water: Understanding Sources, Groundwater Pathways, and Drinking Water Impacts, Invited Speaker, Researchers/scientists, broadcast nationally to USGS offices, webinar/archived, live version had about 40 active connections (30 people present in room), U.S. Geological Survey Menlo Park, Seminar, Davis, CA, 4/05/2012, >100 Attendees.

"Addressing Nitrate in California's Drinking Water", CA&ES Dean's Office:Dairy Meeting (Stu Pettygrove-presenter; dairy industry representatives)., Davis, CA, 04/06/2012.

Addressing Nitrate in California's Drinking Water, Other, Stu Pettygrove (presenter), dairy industry representatives, CA&ES Dean' Office, Dairy Meeting, Davis, CA, 4/16/2012.

"Addressing Nitrate in California's Drinking Water", Other, CA&ES Dean's Office:Dean's Advisory Council (Jay Lund- presenter; executives from key stakeholder groups of the college)., CA&ES Dean' Office, Dean's Advisory Council, Davis, CA, 04/18/2012.

"Addressing Nitrate in California's Drinking Water", Invited Speaker, Groundwater managers at local and regional level, Center for the West, Stanford University, Stanford Uncommon Dialogue on Groundwater Management, Stanford, CA, 04/20/2012, 50 Attendees.

"Addressing Nitrate in California's Drinking Water", Other, Groundwater managers, stakeholders, Groundwater Resources Association, Sacramento, Legislative Symposium, Sacramento, CA, 04/23/2012.

"Addressing Nitrate in California's Drinking Water", Organizer, Media representatives from SWRCB, CDPH, CalEPA, UC Davis, UCD CA&ESm UCD Ag Sustainability Institue, UC ANR, UC Watershed Sciences Center, UC Davis Watershed Sciences Center, Public Relations Planning Meeting, Davis, CA, 04/26/2012, 20 Attendees.

"Nitrate in Groundwater of the Tulare Lake Basin and Salinas Valley", Other, Growers, consultants, community representatives, local stakeholder groups)., UC Davis and UC ANR, Public Workshop, Kearney Ag Center, Parlier, CA, 05/03/2012, 200 Attendees.

"Sources of Groundwater Nitrate", Presenter, Growers, consultants, community representatives, local stakeholder groups)., UC Davis and UC ANR, Public Workshop, Kearney Ag Center, Parlier, CA, 05/03/2012, 200 Attendees.

"Addressing Nitrate in California's Drinking Water", Invited Speaker, Consultants, agency personnel, California State University Fresno, Water Technology Conference, Parlier, CA, 05/03/2012, 150 Attendees.

"Reducing Nitrate Loading- Future Options", Other, Growers, consultants, community representatives, local stakeholder groups, UC Davis and UC ANR, Public Workshop, Kearney Ag Center, Parlier, CA, 05/03/2012, 200 Attendees.

"Remediation of Groundwater Nitrate", Other, Growers, consultants, community representatives, local stakeholder groups)., UC Davis and UC ANR: Public Workshop, Kearney Ag Center, Parlier, CA, 05/03/2012, 200 Attendees.

"Addressing Nitrate in California's Drinking Water", Presenter, Growers, consultants, community representatives, local stakeholder groups, UC Davis and UC ANR: Public Workshop, Kearney Ag Center, Parlier, CA, 05/03/2012, 200 Attendees.

"Addressing Nitrate in California's Drinking Water"- Workshop, Organizer, Growers, consultants, community representatives, local stakeholder groups, UC Davis and UC ANR, Public Workshop, Kearney Ag Center, Parlier, CA, 05/03/2012, 200 Attendees.

"A Semi-Stochastic Approach to Nonpoint Source Pollution in Large Groundwater Basins: Application to the Southern Central Valley, California", Other, Academics, students, consultants, agency personnel, National Ground Water Association, Ground Water Summit, Garden Grove, CA, 05/07/2012, 30 Attendees.

"Addressing Nitrate in California's Drinking Water", Other, Jeannie Darby, Vivian Jensen, Pamela Creedon, ad hoc task force members, Central Valley Regional Water Board, Rancho Cordova, Nitrate Treatment Discussion, Rancho Cordova, CA, 05/07/2012.

"The Central Valley Groundwater System: Emerging Issues and Challenges", Organizer, Academics, students, consultants, agency personnel, National Ground Water Association, Ground Water Summit, Garden Grove, CA, 05/07/2012, 60 Attendees.

"Nitrate Sources, Groundwater Quality, and Drinking Wate rin the Tulare Lake Basin", Presenter, Academics, students, consultants, agency personnel, National Ground Water Association, Ground Water Summit, Garden Grove, CA, 05/07/2012, 60 Attendees.

"Addressing Nitrate in California's Drinking Water", Invited Speaker, Water district representatives, attornerys, lobbyists, Association of California Water Agencies, Semi-Annual Meeting, Focus Panel on Groundwater Nitrate, Monterey, CA, 05/09/2012, 80 Attendees.

"Addressing Nitrate in California's Drinking Water", Other, Stu Pettygrove- presenter; specialty crop representatives-stone fruit, citrus, pears, leafy greens, onions, and garlic, etc.)., Specialty Crops Council, Tulare Ag Center, Tulare: Semi-annual meeting, Tulare, CA, 05/09/2012, 20 Attendees.

"Addressing Nitrate in California's Drinking Water", Invited Speaker, Water district representatives, attorneys, lobbyists, Association of California Water Agencies: San Joaquin Valley Agricultural Water Suncommittee Meeting, Monterey, CA, 05/10/2012, 70 Attendees.

"Addressing Nitrate in California's Drinking Water", Invited Speaker, State policy leaders, key statewide groundwater stakeholder representatives, Capitol assembly/senate staff, Stanford University, Reforming California's Groundwater Management, Exploring Regulatory Options, Sacramento, CA, 05/11/2012, 50 Attendees.

"Remediation of Groundwater Nitrate", Other, Growers, consultants, community representatives, local stakeholder groups, UC Davis: Public Workshop, UCCE Monterey County, Salinas, CA, 05/17/2012, 120 Attendees.

"Reducing Nitrate Loading- Future Options", Other, Growers, consultants, community representatives, local stakeholder groups, UC Davis: Public Workshop, UCCE Monterey County, Salinas, CA, 05/17/2012, 120 Attendees.

"Addressing Nitrate in California's Drinking Water: Overview", Presenter, Growers, consultants, community representatives, local stakeholder groups, UC Davis, Public Workshop, UCCE Monterey County, Salinas, CA, 05/17/2012, 120 Attendees.

"Sources of Groundwater Nitrate", Presenter, Growers, consultants, community representatives, local stakeholder groups, UC Davis, Public Workshop, UCCE Monterey County, Salinas, CA, 05/17/2012, 120 Attendees.

"Nitrate in Groundwater of the Tulare Lake Basin and Salinas Valley", Other, Growers, consultants, community representatives, local stakeholder groups, UC Davis, Public Workshop, UCCE Monterey County, Salinas, CA, 05/17/2012, 120 Attendees.

"Addressing Nitrate in California's Drinking Water:Overview"- workshop, Organizer, Growers, consultants, community representatives, local stakeholder groups, UC Davis, Public Workshop, UCCE Monterey County, Salinas, CA, 05/17/2012, 120 Attendees.

"Addressing Nitrate in California's Drinking Water", Presenter, Thomas Harter, Stu Pettygrove, growers, ag consultants, Grower-Shipper Association, Growers meeting, GSA, 512 Pajaro St.,Salinas, CA, 05/18/2012, 30 Attendees.

Stochastic Analysis of Non-Point Source Loading of Fecal Bacteria in Shallow Heterogeneous Aquifers, Other, Academics, students, agency personnel, U.S. Department of Agriculture, Land Grant and Seagrant National Water Conference, Portand, OR, 5/23/2012, 40 Attendees.

Addressing Nitrate in California's Drinking Water with a Focus on Tulare Lake Basin and Salinas Valley Groundwater, Other, Consultants, representatives of agricultural groups, state agency leaders, SWRCB Board, representatives of NGOs, public, U.S. Department of Agriculture: Land Grant and Seagrant National Water Conference , Portand, OR, 5/23/2012, 40 Attendees.

"Addressing Nitrate in California's Drinking Water", Invited Speaker, Consultants, representatives of agricultural groups, state agency leaders, SWRCB Board, representatives of NGOs, public, SWRCB, Public Workshop, Sacramento, CA, 5/23/2012, 140 Attendees.
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"Addressing Nitrate in California's Drinking Water", Invited Speaker, Faculty, extension folks, ag advisors, farmers, UC Davis: Russell Ranch Field Day, Davis, CA, 5/31/2012, 60 Attendees.

"Addressing Nitrate in California's Drinking Water", Invited Speaker, Local and county agency personnel, Yolo County Water Resources Association: Monthly Meeting, Woodland, CA, 6/7/2012, 20 Attendees.

Addressing Nitrate in California's Drinking Water, Invited Speaker, Farm advisors, crop consultants, agricultural commodity representatives, CDFA, Sacramento, CDFA # UCANR Workshop, Sacramento, CA, 6/11/12, 70 Attendees.

Co-Chair of the Programming Committee, host, co-organizer, session chair. Responsible for organizing nearly half of the 20day program, including inviting the entire executive keynote speaker panel, Organizer, Federal, state, and local agency personnel, environmental NGOs personnel, farmers, consultants, academics, Groundwater Resources Association, “Salt and Nitrate in Groundwater: Finding Solutions for a Widespread Problem”, 26th Symposium, Groundwater Contaminant Series, Fresno, CA, 6/13-14/2012, 175 Attendees.

Key findings from groundwater nitrates study and implications for San Joaquin Valley Grape Growers, Invited Speaker, San Joaquin Valley Winegrowers Assn & UC Cooperative Extension, grape growers, San Joaquin Valley Winegrowers Assn. & UC Cooperative Extension, Fresno County Opportunity Corporation, Fresno, CA, Fresno Viticulture Research Roadshow , 3110 W. Nielsen, Fresno, CA, 6/14/2012, 40 Attendees.

Addressing Nitrate in California's Drinking Water, Participant, Statewide stakeholder representatives, state agency leaders, Governor’s Office, Drinking Water Task Force, Sacramento, CA, 6/14/2012, 40 Attendees.

Addressing Nitrate in California's Drinking Water, Other, Growers and producers, farm advisors, crop consultants, Tulare County, CDFA # UCANR Workshop, Tulare, CA, 6/18/2012, 50 Attendees.

G. Kourakos, T. Harter et al.: "Simulation of Non Point Source Pollution based on the Substructuring Domain Decomposition Method", Other, Academics, students, Gordon Research Conferences, Flow and Transport in Porous Media, Les Diablerets, Switzerland, 6/26/2012, 30 Attendees.

Addressing Nitrate in California's Drinking Water, Participant, Statewide stakeholder representatives, state agency leaders, Governor's Office, Drinking Water Task Force, Sacramento, CA, 6/28/2012, 40 Attendees.

Addressing Nitrate in California's Drinking Water, Invited Speaker, Citizens, Unitarian Universalist Church of Davis, Green Sanctuary Committee, Davis, CA, 7/15/2012, 90 Attendees.

Addressing Nitrate in California's Drinking Water, Participant, Statewide stakeholder representatives, state agency leaders, Governor's Office, Drinking Water Task Force, Sacramento, CA, 7/20/2012, 40 Attendees.

Proposal for Monitoring Nonpoint Sources of Groundwater in the ILRP, Keynote Speaker, Agency personnel, consultants, Central Valley Regional Water Board, Rancho Cordova, CA, 7/31/2012, 15 Attendees.

Historic Perspective on Monitoring and Enforcement of nonpoint Source Discharges to Groundwater, Invited Speaker, Public, agricultural stakeholder representatives, environmental NGO representatives, consultants, regulatory agency personnel, RB Board Members, Central Valley Regional Water Board, Rancho Cordova, CA, 8/2/2012, 80 Attendees.

Addressing Nitrate in California's Drinking Water, Participant, Statewide stakeholder representatives, state agency leaders, Governor's Office, Drinking Water Task Force, Sacramento, CA, 8/21/2012, 40 Attendees.

Addressing Nitrate in California's Drinking Water, Invited Speaker, water districts, groundwater contractors, consultants, California Groundwater Council, Los Angeles, CA, 9/11/2012, 30 Attendees.

Perspectives on Developing an Irrigated Lands Regulatory Program to Protect Groundwater, Invited Speaker, Representatives from agriculture, water districts, consultants, local agencies, Sacramento Valley Watershed Coalition, Woodland, CA, 9/19/2012, 40 Attendees.

Perspectives on Regulating Nitrate Pollution in Groundwater, Invited Speaker, Students, growers, consultants, ag industry leaders, public, CSU Monterey Bay and Grower-Shipper Association, Dividing the Waters Annual Conference, Monterey CA, 10/25/2012, 200

Attendees.

Perspectives on Drinking Water and Agricultural Regulations, Keynote Speaker, Ag industry leaders, UC leadership circle, UC President's Office, Presidents' Advisory Committee on Agriculture, Oakland, CA, 11/1/2012, 35 Attendees.

Groundwater Quality and Dairy Management-Basics and Regulations, Invited Speaker, Young dairy operators, Western United Dairymen, Dairy Leadership Class of 2012, Modesto, CA, 11/13/2012, 15 Attendees.

Testimony: "Nitrate in Drinking Water-Overview of the SBX21 Study and key Conclusions", Invited Speaker, California Assembly members, Executive agency members (SWRCB, CDPH), disadvantage communities' members, California State Assembly, Oversight Hearing, Sacramento, CA, 11/14/2012, 60 Attendees.

Special Session: Nonpoint Source Fluxes in the Vadose Zone and Groundwater, Organizer, Academic and agency researchers, students, AGU Fall Meeting, San Francisco, CA, 12/03/2012, 70 Attendees.

Streamline Simulation of Non Point Sources Pollution in Unconfined Aquifers Based on Iterative Moving Mesh and Domain Decomposition Methods (Poster by Kourakos and Harter), Participant, Academic and agency researchers, students, AGU Fall Meeting, San Francisco, CA, 12/03/2012.
Reducing Nitrate in California's Drinking Water: Perspectives on Business Opportunities, Invited Speaker, Consultants, agricultural business representatives, researchers, Dutch Embassy wIth UCD, Davis, CA, 12/10/2012, 90 Attendees.

Reducing Nitrate in Drinking Water: Perspectives on Agriculture, Keynote Speaker, Academic researchers, USDA W3188 Workgroup Meeting, Las Vegas, NV, 01/03/2013, 40 Attendees.

Nitrate in Drinking Water: Next Steps, Invited Speaker, CDPH Executive Leadership, CDPH and UCD, Davis, CA, 01/22/2013, 5 Attendees.

Nitrate in Drinking Water: Key Findings and Challenges to Developing Solutions, Invited Speaker, Attorneys, consultants, water district representatives, agricultural business representatives, environmental NGO personnel, California Water Law Conference, Davis, CA, 01/26/2013, 90 Attendees.

Groundwater Monitoring in the Irrigated Lands Regulatory Program, Invited Speaker, Growers, agricultural consultants, ag industry representatives, California Irrigation Institute, Annual Meeting, Sacramento, CA, 02/04/2013, 110 Attendees.

Water Quality Exceedances: Nitrate Report and Perspectives on the ILRP, Invited Speaker, Growers, agricultural consultants, local agency personnel, Yolo County Farm Bureau, "Spray Safe" Workshop, Woodland, CA, 02/07/2013, 300 Attendees.

Nitrate in Drinking Water-Where do we go From Here?, Invited Speaker, Students, CSUF, Fresno, CA, 02/19/2013, 20 Attendees.

The Next Frontier: Nonpoint Source Pollution of Groundwater", Invited Speaker, faculty, students, Indian Institute of Technology, Roorkee, India, 4/10/2013, 25 Attendees.

Workshop on Nitrate in Groundwater and Drinking Water, Organizer, Attorneys, California State Bar, Davis, CA, 04/24/2013, 80 Attendees.

Nitrate in Drinking Water for Attorneys: Overview and Historical Perspectives, Invited Speaker, Attorneys, California State Bar, Davis, CA, 04/24/2013, 80 Attendees.

Bayesian Deconvolution of Landuse-Specific Nitrate Loading to Groundwater using Domestic Well Data, Presenter, Students, researchers, faculty, Bayesian Statistics Shortcourse, EAWAG, Zuerich, Switzerland, 06/07/2013, 40 Attendees.

Nitrate in Drinking Water of California's Agricultural Regions: Comprehensive Assessment and Solutions, Keynote Speaker, researchers, students, Internatl Conf on Land Use and Water Quality, The Hague, NL, 06/11/2013, 150 Attendees.
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A Historic Perspective on Current Challenges to Regulate Groundwater from Nonpoint Sources in California, Presenter, researchers, students, Internatl Conf on Land Use and Water Quality, The Hague, NL, 06/12/2013, 80 Attendees.
Modeling Spatio-Temporally Distributed Groundwater Nitrate Loading in California's Agricultural-Urban Heartland, 1945- Current, Presenter, researchers, students, Internatl Conf on Land Use and Water Quality, The Hague, NL, 06/13/2013, 80 Attendees.

"Spatially Distributed Stochastic Modeling of Non-Point Source Pollutants in Groundwater", Presenter, researchers, students, Internatl Conf on Land Use and Water Quality, The Hague, NL, June 13, 2013, 80 Attendees.

Addressing Nitrate in California's Drinking Water, Invited Speaker, Citizens, Putah Creek Council, Winters, CA, July 19, 2012, 40 Attendees.

CDFA Nitrogen Tracking and Reporting Task Force, Participant, task force members, state administration leadership, California Department of Food and Agriculture, Sacramento, 07/29/2013, 35 Attendees.

"For Want of Food: Groundwater and Global Ag Production", Invited Speaker, growers, consultants, crop advisors, Intl. Agriculture World Expo, Tulare, CA, 2/13/2014, 45 Attendees.

Why Nitrate Matters: Agriculture and its Nexus to Nitrate in California Drinking Water, Invited Speaker, growers, vintners, enologists, crop consultants, farm advisors, UCCE Workshop "N Managment from Vine to Wine", Davis, CA, 4/18/2014, 100+ Attendees.

Institutional History of Regulating Nonpoint Sources for Water Quality Protection in California, Invited Speaker, local/regional/state/federal policy and deicsion-makers, agency personnel, agriculture leadership/representatives, Western US Irrigation Water Conference, Davis, CA, 4/24/2014, 100 Attendees.

Lessons Learned from California's Dairy Order and Irrigated Lands Regulatory Program, Invited Speaker, local/regional/state/federal policy and deicsion-makers, agency personnel, agriculture leadership/representatives, Western US Irrigation Water Conference, Davis, CA, 4/25/2014, 100 Attendees.

The History of the Central Valley Dairy Order for Water Quality Protection, Invited Speaker, consultants, agency personnel, state dairy leadership, dairymen, agricultural consultants, Washington State Department of Ecology, Olympia, WA, 5/1/2014, 30 Attendees.

Understanding and Managing Groundwater Impacts from Dairies in California, Invited Speaker, consultants, agency personnel, state dairy leadership, dairymen, agricultural consultants, Washington State Conservation Commission, Olympia, WA, 5/2/2014, 120 Attendees.
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SBX2 1 Uc Davis Study: Agriculture and Its Nexus to Nitrate in California Drinking Water, Invited Speaker, consultants, agency personnel, state dairy leadership, dairymen, agricultural consultants, State Water Resources Control Board, Sacramento, CA, 5/9/2014, 70 Attendees.

Interviewed for film; also provided consultation to film director, "Thirsty for Justice", Participant, environmental justice community, community leaders, state policy makers, NGO staff, UULM Film Screening, Sacramento, CA, 4/14/2014, 200+ Attendees.

Digitizing Dairy Annual Reports and Preliminary Results on N Cycling in Dairies, Organizer, regulatory agency personnel, dairy leadership representatives, Central Valley Regional Water Quality Control Board, Racho Cordova, CA, May 29, 2014, 10 Attendees.

N Cycling Gone Underground: Addressing Nitrate in Groundwater, Invited Speaker, students, research staff, faculty, Stanford University, Stanford,CA, 6/4/2014, 60 Attendees.

National Water Policy: Challenges to Developing Groundwater Protection Policies, Invited Speaker, Capitol Hill staffers, journalists, policy and decision makers in federal agencies, scientits, AGU Science Policy Conference, Washington, D.C, 6/16/2014, 80 Attendees.

Groundwater and Life, Invited Speaker, public, Putah Creek Watershed Council, Winters, CA, 6/19/2014, 60 Attendees.

Project-related Websites

http://groundwaternitrate.ucdavis.edu (2012 through June 2017): 68,000 page views, 34,000 sessions, 71% new visitors, 29% returning visitors).

Project-Related Media Interviews:

11/6/2012: Patricia Leigh Brown, New York Times, on drinking water systems issues in disadvantaged communities; http://www.nytimes.com/2012/11/14/us/tainted-water-in-california-farmworker-communities.html?hp&_r=0

11/9/2012: Fresno Bee: http://www.fresnobee.com/2012/11/08/3059561/dairy-waste-focus-of-court-ruling.html

11/14/2012: Webcast of the State Assembly hearing, http://calchannel.granicus.com/MediaPlayer.php?view_id=7&clip_id=803

4/20/2013: Interview with Jeremy Miller, High Country News, published in High Country News 45(11), p.12-17, June 24, 2013

6/17/2013: San Francisco Chronicle: "Will dairy industry resurgence fuel pollution?"

6/24/2014: Hari Sreenivasan, studio interview for PRI/America Abroad; http://www.pri.org/programs/america-abroad/global-water-scarcity-combating-drought

7/2014: Dairy CARES, video on clean water, https://youtu.be/gGgqXEHiRLo

11/3/2015: Alec Rosenberg, University of California Newsroom, on the SBX2 1 nitrate study, http://universityofcalifornia.edu/news/research-changing-us-food-policy

4/21/2016: Patricia Leigh Brown, New York Times, on groundwater nitrate contamination

8/17/2016: Working together to help agriculture manage nitrogen, Diane Nelson, UC Davis – Dairy Herd Management, http://www.dairyherd.com/news/industry/working-together-help-agriculture-manage-nitrogen

3/6/2017: Bree Zender, KCBX / NPR San Luis Obispo/Salinas, on the SBX2 1 nitrate study from 2012

6/2/2017: Robin Meadows, Water Deeply. Groundwater quality in the San Joaquin Valley

Factsheet

Nitrogen Fertilizer Loading to Groundwater in the Central Valley

FREP Project No. 11-0301 and No. 15-0454

Project Leaders: Harter, T., Zhang, M., Pettygrove, G.S., Department of Land, Air, and Water Resources; and Tomich T.P., Agricultural Sustainability Institute, University of California, Davis.

Project Period: 2012 - 2016

Location and Counties: Central Valley, California:

- Sacramento Valley: Butte, Colusa, Glenn, Placer, Sacramento, Shasta, Solano, Sutter, Tehama, Yolo, Yuba
- (Northern) San Joaquin Valley: Contra Costa, Madera, Merced, San Joaquin, Stanislaus
- Tulare Lake Basin: Fresno, Kern, Kings, Tulare

Highlights

- Agricultural lands are the largest contributor of nitrate to Central Valley groundwater. Urban and domestic contributions to potential groundwater nitrogen loading are less than 10%.
- Synthetic fertilizer contributes nearly 60%, dairy manure nearly 20% of nitrogen to croplands.
- New technologies are urgently needed to derive synthetic fertilizer-like materials from dairy manure to address the largest pollution risks.
- A wide range of agricultural practices are available to improve crop nitrogen use efficiency at a region-wide scale.
- Agricultural management improvements will only gradually affect groundwater quality in supply wells, at decadal time-scales.
- New modeling tools can assess future groundwater quality trends including those achievable from broader adoption of currently available or future best agricultural practices.

Introduction

Nitrogen in form of nitrate is the most common pollutant found in the Central Valley aquifer system of California. This project provides a long-term assessment of past and current potential nitrogen loading to groundwater on irrigated and natural lands across the entire Central Valley of California using a nitrogen mass balance approach; assesses the long-term implications for groundwater quality in the Central Valley (Sacramento Valley, San Joaquin Valley, and Tulare Lake Basin); evaluates potential best management practices to reduce groundwater nitrogen loading from irrigated lands; and provides a planning tool to better understand local and regional groundwater quality response to specific best management practices and policy/regulatory actions. The project complements other work to assess the vulnerability of Central Valley groundwater to nitrate contamination, sources of nitrate in groundwater, and how to reduce source loading.

Methods/Management

The primary tool for this Central Valley assessment are field-scale, crop-scale, crop-group scale, county-scale, groundwater-basin scale, and Central Valley-wide nitrogen mass balance computations that can be linked to groundwater transport models. We developed a GIS framework and a compilation of spatial land use data, collecting and digitizing data for performance of the nitrogen mass balance (historic and current). Data collection included a comprehensive assessment of historic and current nitrogen applications to cropland (from atmospheric, fertilizer, animal, and human sources) and field nitrogen removal (harvest removal, atmospheric losses, surface runoff). Agricultural Commissioner reported crop area and production data have been used to determine the mean period harvest removal rates of nitrogen. We used the tabularized county-by-county crop acreage information and a number of existing geospatial databases to generate digital maps of current and 1990 landuses; and then developed an algorithm that backcasts agricultural crop maps of the Central Valley to the mid-1970s, late 1950s/early 1960s and to the 1940s when fertilizer use in the Central Valley first started to be widespread. Published N fertilization rates (Viers et al. 2012, Rosenstock et al. 2013) were updated through an extensive interview process and used to estimate total synthetic N applications based on reported crop area. New concepts for handling various components of crop data emerged, and extensive quality control was performed on the data collected.

For comparison of synthetic fertilizer nitrogen loading to that from other sources, we tabularized nitrogen loading from wastewater treatment plants, food processors, and from septic systems. Dairy manure nitrogen amounts and fate were assessed through review of existing research results and by performing dairy nitrogen mass balances.

We also extended the computational performance of groundwater transport modeling software: The groundwater nitrate transport modeling tool developed here allows computation of long-term transport of nitrate to individual domestic/municipal/irrigation wells, based on the spatially distributed, field-by-field, annual nitrogen loading to groundwater. We have developed new solver capacities and the ability to run the software program on parallel computing machines, with initial runs of a highly detailed flow and transport model for several basins in the Central Valley.

Findings

This report updates and expands the 2012 SBX2 1 Report "Addressing Nitrate in Groundwater", which focused geographically on the Tulare Lake Basin and Salinas Valley. The data presented here confirm the major findings of the earlier report and of information since then submitted by agricultural coalitions and CV-SALTS to the Central Valley Regional Water Quality Control Board:

The largest nitrogen fluxes into the agricultural landscape include synthetic fertilizer (504 Gg N/yr), land application of manure on dairy cropland or exported to other crops and land application of wastewater effluent (220 Gg N/yr), and nitrogen fixation in alfalfa (115 Gg N/yr). The largest nitrogen fluxes out of the agricultural landscape include harvested nitrogen (450 Gg N/yr including alfalfa), potential nitrogen losses to groundwater from cropland (331 Gg N/yr), and atmospheric nitrogen losses (209 Gg N/yr, which includes 131 Gg N/yr of atmospheric N losses from dairy manure prior to land application).

The Tulare Lake Basin accounts for the largest nitrogen fluxes but it also reflects nearly half of the total irrigated cropland area – 1.5 million ha of 3.2 million ha in the Central Valley. Nitrogen flux rates in the Tulare Lake Basin largely mirror those in the San Joaquin Valley, with large amounts and rates of manure land applications.

The Sacramento Valley, in contrast, has only small amounts of dairy cropland with manure land applications and little manure export. Lacking manure nitrogen sources to augment synthetic fertilizer, the Sacramento Valley in turn has a slightly higher rate of synthetic nitrogen application (175 kg N/ha/yr instead of 165 and 158 kg N/ha/yr in the San Joaquin Valley and Tulare Lake Basin, respectively).

To reduce potential groundwater nitrogen loading from cropland across the Central Valley and thus improve the quality of recharge water from the agricultural landscape, there are only few options, dictated by the magnitude of nitrogen fluxes:

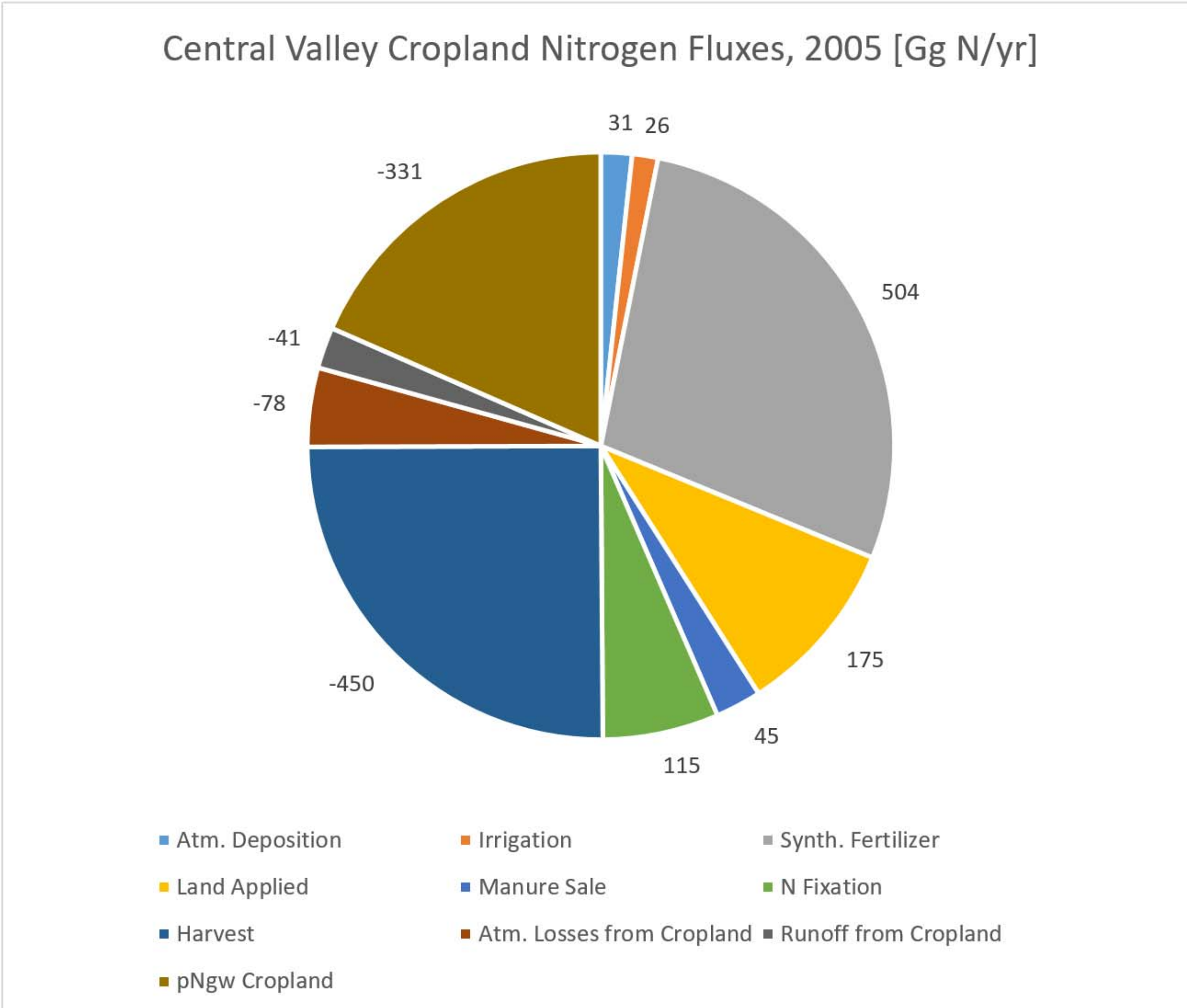
- Increase the amount of harvest without also increasing the amount of synthetic or organic fertilizer
- Reduce the nitrogen input to the agricultural landscape. However, of all fluxes into the agricultural landscape, only synthetic fertilizer use can be reduced significantly without significantly changing Central Valley landuse: Cities and particularly dairy farming are generating large amounts of nitrogen that is currently recycled in the agricultural landscape.

A central challenge to improving groundwater quality in the Central Valley is to develop nutrient management practices that make more efficient and effective use of animal derived nutrients to allow growers to increasingly rely on organic fertilizer. This will require the development of new processes to transform manure into a fertilizer product that can be marketed and that performs much like synthetic fertilizer.

In the meantime, a wide range of agricultural practices have been documented, as part of this work, as part of CDFA FREP's work, and elsewhere, that significantly improve crop nitrogen use efficiency at a region-wide scale from today's practices. Extending this knowledge to growers will be a key goal for the agricultural coalitions in the Central Valley that are engaged in the implementation of the Irrigated Lands Regulatory Program and the Dairy Order. Agricultural management improvements are urgently needed to not further degrade groundwater recharge quality, even if improvements of groundwater quality in supply wells will only be felt at decadal time-scales, due to the slow-moving nature of groundwater.

Fact Sheet Table 1: Summary of potential groundwater nitrogen loading from Central Valley sources assessed in this report.

Mg N/yr	1945	1960	1975	1990	2005	2020	2035	2050
Cropland (incl Alfalfa)	36,714	49,490	124,979	254,348	330,680	351,527	378,527	392,966
Urban	2,131	3,492	5,118	7,166	9,543	9,543	9,543	9,543
Golf Courses	66	66	66	66	66	66	66	66
Lagoons	0	0	2787	2,787	2,787	2,787	2,787	2,787
Corrals	0	0	2243	2,243	2,243	2,243	2,243	2,243
WWTP Percolation Basins	680	1,113	1,480	2,273	2,988	3,609	4,503	5,311
FP Percolation Basins	62	102	136	208	274	331	413	487
tons N/yr	**1945**	**1960**	**1975**	**1990**	**2005**	**2020**	**2035**	**2050**
Cropland (incl Alfalfa)	40,458	54,538	137,727	280,292	364,409	387,383	417,137	433,049
Urban	2,348	3,848	5,640	7,897	10,517	10,517	10,517	10,517
Golf Courses	73	73	73	73	73	73	73	73
Lagoons	0	0	3,071	3,071	3,071	3,071	3,071	3,071
Corrals	0	0	2,472	2,472	2,472	2,472	2,472	2,472
WWTP Percolation Basins	749	1,227	1,630	2,504	3,293	3,978	4,962	5,852
FP Percolation Basins	69	113	150	230	302	365	455	537



Factsheet Figure 1: Sum of all GNLM simulated nitrogen fluxes in Central Valley Cropland [Gg N/yr]. 1 Gg N is 1,100 tons of nitrogen.

Project Products: Websites, Databases, Publications

Websites

- http://groundwaternitrate.ucdavis.edu
- http://groundwater.ucdavis.edu
- http://ag-groundwater.org

Databases

- Digitized crop acreage and crop harvest amount, and estimated crop nitrogen content transcribed from County Agricultural Commissioner Reports for all Central Valley Counties for the following years: 1942 – 1947, 1958 – 1962, 1973 – 1977, 1988 – 1992, 2003 – 2007
- "UCD Dairy Annual Report Database v2012"
- "RB5 APN Database v2015"
- GIS shapefile of Central Valley dairy lagoons, 2009
- GIS shapefile of Central Valley dairy corrals, 2009
- Typical crop nitrogen applied and harvested
- SBX2 1 Report related databases for the Tulare Lake Basin and Salinas Valley: http://groundwaternitrate.ucdavis.edu/Data_And_Databases/

Publications

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Dzurella, K., R. H. Beede, M. Cahn, K. Day, C. Frate, T. Harter, M. LeStrange, S. Mueller, B. Sanden, R. Smith, S. Stoddard, S. Wright, and G.S. Pettygrove (submitted). Farming Practices for Improving Crop Nitrogen Use Efficiency in California's Irrigated Agriculture. *Submitted to UC ANR Publications*.

Tomich, T. et al, 2016. California Nitrogen Assessment. http://asi.ucdavis.edu/programs/sarep/research-initiatives/are/nutrient-mgmt/california-nitrogen-assessment

Harter, T., 2015. California's agricultural regions gear up to actively manage groundwater use and protection. California Agriculture 69(3):193-201, doi:10.3733/ca.E.v069n03p193 (open access).

Mayzelle, M. M., J. H. Viers, J. Medellin-Azuara, and T. Harter, 2015. Economic feasibility of irrigated agricultural land use buffers to reduce groundwater nitrate in rural drinking water sources. Water 7(1):12-37, doi: 10.3390/w7010012 (open access).

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Kourakos, G. and T. Harter, 2014. Vectorized simulation of groundwater flow and streamline transport. Environmental Modelling & Software 52:207-221, doi:10.1016/j.envsoft.2013.10.029.

Gold, A., D. Parker, R. Waskom, J. Dobrowolski, M. O'Neill, P. Groffman, and K. Addy with contributing authors:M. Barber, S. Batie, B. Benham, M. Bianchi, T. Blewett, C. Evenson, K. Farrell-Poe, C. Gardner, W. Graham, J. Harrison, T. Harter, J. Kushner, R. Lowrance, J. Lund, R. Mahler, M. McClaron, M. McFarland, D. Osmond, J. Pritchett, L. Prokopy, C. Rock, A. Shober, M. Silitonga, D. Swackhamer, J. Thurston, D. Todey, R. Turco, G. Vellidis, and L.Wright Morton, 2013. Advancing water resource management in agricultural, rural, and urbanizing watersheds: Enhancing university involvement, Journal of Soil and Water Conservation 68(4):337-348, doi:10.2489/jswc.68.4.337.

Medellin, J., T.S. Rosenstock, R.E. Howitt, T. Harter, K.K. Jessoe, K. Dzurella, G.S. Pettygrove, J.R. Lund, 2013. Agro-economic analysis of nitrate crop source reductions. J. Water Resources Planning and Mgmt. 139(5):501-511, doi:10.1061/(ASCE)WR.1943-5452.0000268.

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Appendix Tables

Appendix Table 1: County Agricultural Commissioner Reports analysis - Central Valley crop group N harvested, N applied (Nnorm, total N, synthetic N, manure N), area harvested, average harvest rate of the crop group, application rate, and nitrogen use efficiency (NUE, here defined as only Nharvest / Nsynthetic+Nmanure), 1945-2005.

Period	Crop Group	N harvest Gg	Total Nnorm applied Gg	Total N applied (synthetic + manure) Gg	Total Synthetic N applied Gg	Manure N applied Gg	Area harvested Ha	Harvest Rate (kg/ha)	Application Rate (Nnorm) kg/ha	NUE (including manure)
1945	Corn, Sorghum, Sudan	2	4	4	4	0	55,073	36	80	45%
1960	Corn, Sorghum, Sudan	16	24	24	24	0	206,395	77	117	65%
1975	Corn, Sorghum, Sudan	27	41	50	31	19	242,069	111	168	54%
1990	Corn, Sorghum, Sudan	25	35	53	23	30	149,465	170	236	48%
2005	Corn, Sorghum, Sudan	52	61	140	33	107	256,940	202	238	37%
1945	Cotton	6	9	9	9	0	145,305	41	65	64%
1960	Cotton	21	29	29	29	0	312,253	66	93	71%
1975	Cotton	29	52	62	36	26	426,868	68	122	47%
1990	Cotton	39	94	113	65	48	484,958	80	195	34%
2005	Cotton	23	51	85	27	59	259,669	90	195	27%
1945	Deciduous Tree Fruit	1.4	9.8	9.8	9.8	0	76,488	18	128	14%
1960	Deciduous Tree Fruit	1.7	9.1	9.1	9.1	0	81,234	21	112	18%
1975	Deciduous Tree Fruit	2.5	11.5	11.5	11.5	0	94,986	26	121	22%
1990	Deciduous Tree Fruit	3.3	13.4	13.4	13.4	0	109,919	30	122	24%
2005	Deciduous Tree Fruit	3.2	15.1	15.1	15.1	0	126,260	25	119	21%
1945	Field Crops	4.7	4.6	4.63	4.6	0	88,905	53	52	103%
1960	Field Crops	15.0	14.0	14.0	14.0	0	206,788	72	68	107%
1975	Field Crops	19.1	17.4	18.6	15.5	3.0	184,291	103	95	103%
1990	Field Crops	19.1	24.0	25.6	20.7	4.9	181,722	105	132	75%
2005	Field Crops	6.8	9.3	10.9	8.01	2.9	81,437	84	114	62%
1945	Grain and Hay	17	33	33	33	0	650,483	26	50	52%
1960	Grain and Hay	32	54	54	54	0	771,576	42	70	59%
1975	Grain and Hay	47	65	67	61	6	617,912	75	104	69%
1990	Grain and Hay	44	76	83	72	12	400,855	111	190	53%

Period	Crop Group	N harvest Gg	Total Nnorm applied Gg	Total N applied (synthetic + manure) Gg	Total Synthetic N applied Gg	Manure N applied Gg	Area harvested Ha	Harvest Rate (kg/ha)	Application Rate (Nnorm) kg/ha	NUE (including manure)
2005	Grain and Hay	60	98	131	89	42	466,463	129	209	46%
1945	Grapes	1.7	10.3	10.3	10.3	0	154,808	11	67	16%
1960	Grapes	2.1	7.8	7.8	7.8	0	140,335	15	56	27%
1975	Grapes	2.9	11.2	11.2	11.2	0	178,741	16	63	26%
1990	Grapes	3.4	8.3	8.3	8.3	0	210,990	16	39	41%
2005	Grapes	4.1	9.3	9.3	9.3	0	237,830	17	39	44%
1945	Nuts	1.8	5.0	5.0	5.0	0	33,870	52	149	35%
1960	Nuts	4.1	7.9	7.9	7.9	0	64,194	64	124	52%
1975	Nuts	11.9	21.1	21.1	21.1	0	151,016	79	140	57%
1990	Nuts	23.5	57.2	57.2	57.2	0	251,717	93	227	41%
2005	Nuts	46.9	88.4	88.4	88.4	0	390,478	120	226	53%
1945	Rice	4.0	4.9	4.9	4.9	0	96,164	42	51	82%
1960	Rice	7.8	8.7	8.7	8.7	0	119,101	65	73	89%
1975	Rice	13.3	16.8	16.8	16.8	0	174,511	76	96	79%
1990	Rice	18.4	25.1	25.1	25.1	0	171,852	107	146	73%
2005	Rice	25.2	33.6	33.6	33.6	0	229,803	110	146	75%
1945	Subtropical Tree Fruit	0.6	2.8	2.8	2.8	0	18,694	30	149	20%
1960	Subtropical Tree Fruit	0.5	2.1	2.1	2.1	0	17,159	29	125	23%
1975	Subtropical Tree Fruit	1.4	7.7	7.7	7.7	0	54,421	26	141	19%
1990	Subtropical Tree Fruit	2.2	9.1	9.1	9.1	0	63,116	35	145	24%
2005	Subtropical Tree Fruit	3.6	12.4	12.4	12.4	0	84,602	42	146	29%
1945	Vegetables and Berries	5.2	11.8	11.8	11.8	0	132,890	39	89	44%
1960	Vegetables and Berries	8.5	20.5	20.5	20.5	0	162,059	52	126	41%
1975	Vegetables and Berries	12.7	29.1	29.1	29.1	0	184,135	69	158	44%
1990	Vegetables and Berries	20.7	50.7	50.7	50.7	0	251,892	82	201	41%
2005	Vegetables and Berries	29.1	53.9	53.9	53.9	0	265,001	110	203	54%

Appendix Table 2: County Agricultural Commissioner Reports analysis - 1945-2005 county total area, N harvested and N applied (Nnorm, Nsynthetic, Nmanure, Total N). Nnorm represents the typical (Nnorm) application rates applied to the harvested area, synthetic N is based on reducing Nnorm by the portion of on-dairy manure N that can be used to meet some of certain field and grain crops.

County	Region	Period	Total Area (Ha)	N Harvested (Gg)	Nnorm Applied (Gg)	Nsynthetic fertilizer Applied (Gg)	Manure N (Gg)	Total N applied (synthetic + manure Gg)
Butte	SCV	1945	62,049	2.4	4.2	4.2	0	4.2
Butte	SCV	1960	73,183	4.4	5.9	5.9	0	5.9
Butte	SCV	1975	86,141	6.7	9.4	9.4	0	9.4
Butte	SCV	1990	73,567	7.2	12.6	12.6	0	12.6
Butte	SCV	2005	76,909	8.0	13.3	13.3	0	13.3
Colusa	SCV	1945	64,158	2.1	3.6	3.6	0	3.6
Colusa	SCV	1960	75,068	3.7	5.7	5.7	0	5.7
Colusa	SCV	1975	105,422	7.7	11.5	11.5	0	11.5
Colusa	SCV	1990	94,074	9.1	15.7	15.7	0	15.7
Colusa	SCV	2005	102,638	11.0	17.0	17.0	0	17.0
Glenn	SCV	1945	54,662	1.1	2.9	2.9	0.2	3.1
Glenn	SCV	1960	68,612	3.2	5.4	5.4	0.4	5.8
Glenn	SCV	1975	58,606	4.1	6.6	5.8	0.8	6.6
Glenn	SCV	1990	65,961	6.5	11.0	9.9	1.3	11.3
Glenn	SCV	2005	75,313	8.2	12.9	11.8	3.0	14.8
Placer	SCV	1945	18,358	0.3	1.6	1.6	0.01	1.6
Placer	SCV	1960	14,414	0.5	1.3	1.3	0.01	1.3
Placer	SCV	1975	14,802	0.7	1.5	1.5	0.02	1.5
Placer	SCV	1990	9,503	0.8	1.6	1.5	0.04	1.6
Placer	SCV	2005	7,741	0.7	1.1	1.1	0.1	1.2
Sacramento	SCV	1945	65,761	1.8	4.5	4.5	0.1	4.6
Sacramento	SCV	1960	55,928	4.0	5.9	5.9	0.3	6.2
Sacramento	SCV	1975	67,951	6.6	9.6	9.0	0.6	9.6
Sacramento	SCV	1990	46,762	5.0	8.6	7.6	1.0	8.6
Sacramento	SCV	2005	43,081	4.0	6.7	4.8	2.2	7.0
Shasta	SCV	1945	2,912	0.1	0.2	0.2	0	0.2
Shasta	SCV	1960	8,698	0.4	0.9	0.9	0	0.9

County	Region	Period	Total Area (Ha)	N Harvested (Gg)	Nnorm Applied (Gg)	Nsynthetic fertilizer Applied (Gg)	Manure N (Gg)	Total N applied (synthetic + manure Gg)
Shasta	SCV	1975	7,791	0.4	1.1	1.1	0	1.1
Shasta	SCV	1990	8,658	0.6	1.6	1.6	0	1.6
Shasta	SCV	2005	10,219	0.8	1.9	1.9	0	1.9
Solano	SCV	1945	0	0.0	0.0	0.0	0.02	0.0
Solano	SCV	1960	57,555	3.0	4.6	4.6	0.05	4.7
Solano	SCV	1975	59,095	5.2	7.4	7.3	0.10	7.4
Solano	SCV	1990	70,231	7.3	11.7	11.5	0.18	11.7
Solano	SCV	2005	40,165	3.4	7.0	6.5	0.41	7.0
Sutter	SCV	1945	66,676	2.4	4.7	4.7	0.00	4.7
Sutter	SCV	1960	94,179	5.2	7.5	7.5	0.01	7.5
Sutter	SCV	1975	123,210	8.8	14.5	14.4	0.02	14.5
Sutter	SCV	1990	87,660	7.3	13.8	13.7	0.03	13.8
Sutter	SCV	2005	92,011	8.2	14.3	14.2	0.07	14.3
Tehama	SCV	1945	0	0.0	0.0	0.0	0	0.0
Tehama	SCV	1960	20,773	0.7	1.6	1.6	0	1.6
Tehama	SCV	1975	23,768	1.3	2.7	2.7	0	2.7
Tehama	SCV	1990	19,631	1.4	3.4	3.4	0	3.4
Tehama	SCV	2005	20,119	1.7	3.6	3.6	0	3.6
Yolo	SCV	1945	99,140	3.8	6.0	6.0	0.02	6.0
Yolo	SCV	1960	196,127	10.8	16.7	16.7	0.05	16.7
Yolo	SCV	1975	119,061	9.3	14.9	14.8	0.09	14.9
Yolo	SCV	1990	94,288	9.5	16.3	16.1	0.16	16.3
Yolo	SCV	2005	90,025	7.9	14.1	13.8	0.36	14.1
Yuba	SCV	1945	16,989	0.5	1.1	1.1	0.02	1.1
Yuba	SCV	1960	14,408	0.7	1.3	1.3	0.05	1.3
Yuba	SCV	1975	24,591	1.7	2.8	2.7	0.10	2.8
Yuba	SCV	1990	24,287	2.2	3.8	3.7	0.18	3.9
Yuba	SCV	2005	26,500	2.2	4.1	4.0	0.41	4.5
Contra Costa	NSJV	1945	0	0	0	0.0	0	0.0
Contra Costa	NSJV	1960	30,615	1.2	3.2	3.2	0	3.2
Contra Costa	NSJV	1975	17,953	1.2	2.5	2.5	0	2.5

County	Region	Period	Total Area (Ha)	N Harvested (Gg)	Nnorm Applied (Gg)	Nsynthetic fertilizer Applied (Gg)	Manure N (Gg)	Total N applied (synthetic + manure Gg)
Contra Costa	NSJV	1990	10,443	0.7	2.0	2.0	0	2.0
Contra Costa	NSJV	2005	7,568	0.8	1.5	1.5	0	1.5
Madera	NSJV	1945	73,027	1.8	4.2	4.2	0	4.2
Madera	NSJV	1960	78,197	3.1	6.5	6.5	0	6.5
Madera	NSJV	1975	75,785	4.6	8.1	8.1	0	8.1
Madera	NSJV	1990	99,989	6.7	14.7	14.7	0	14.7
Madera	NSJV	2005	103,599	9.6	15.7	15.7	0	15.7
Merced	NSJV	1945	78,066	2.2	5.1	5.1	2.2	7.3
Merced	NSJV	1960	87,375	4.2	8.0	8.0	4.5	12.5
Merced	NSJV	1975	122,251	9.5	16.0	12.1	9.2	21.3
Merced	NSJV	1990	149,487	14.7	29.1	22.9	16.2	39.1
Merced	NSJV	2005	176,402	22.2	36.5	28.6	36.3	64.9
San Joaquin	NSJV	1945	163,120	5.0	11.6	11.6	0.8	12.4
San Joaquin	NSJV	1960	170,716	9.3	16.2	16.2	1.7	17.9
San Joaquin	NSJV	1975	186,196	16.1	23.8	20.3	3.5	23.8
San Joaquin	NSJV	1990	167,076	16.6	29.8	24.8	6.1	30.8
San Joaquin	NSJV	2005	231,309	25.0	40.5	34.6	13.7	48.2
Stanislaus	NSJV	1945	92,522	3.3	6.0	6.0	1.6	7.6
Stanislaus	NSJV	1960	104,573	4.7	9.3	9.3	3.4	12.7
Stanislaus	NSJV	1975	104,859	8.0	12.8	11.4	6.9	18.2
Stanislaus	NSJV	1990	124,311	12.4	22.5	20.4	12.0	32.5
Stanislaus	NSJV	2005	140,753	18.8	28.9	25.2	27.0	52.2
Fresno	TLB	1945	249,437	5.4	16.2	16.2	1.0	17.2
Fresno	TLB	1960	408,776	19.2	32.4	32.4	2.0	34.4
Fresno	TLB	1975	414,697	23.7	44.5	40.5	4.0	44.5
Fresno	TLB	1990	419,658	31.6	68.0	61.9	7.1	69.0
Fresno	TLB	2005	418,931	38.2	70.1	59.4	15.9	75.2
Kern	TLB	1945	139,436	6.1	9.6	9.6	1.3	10.9
Kern	TLB	1960	208,641	14.6	19.1	19.1	2.7	21.8
Kern	TLB	1975	277,201	22.1	34.0	28.4	5.6	34.0
Kern	TLB	1990	303,593	25.6	54.7	45.7	9.8	55.5

County	Region	Period	Total Area (Ha)	N Harvested (Gg)	Nnorm Applied (Gg)	Nsynthetic fertilizer Applied (Gg)	Manure N (Gg)	Total N applied (synthetic + manure Gg)
Kern	TLB	2005	303,218	34.6	57.9	50.5	21.9	72.5
Kings	TLB	1945	91,325	2.9	5.1	5.1	1.3	6.4
Kings	TLB	1960	144,709	7.7	11.0	11.0	2.7	13.7
Kings	TLB	1975	202,076	15.6	22.9	17.3	5.6	22.9
Kings	TLB	1990	175,278	15.3	33.0	24.0	9.8	33.8
Kings	TLB	2005	171,112	19.4	36.0	25.1	22.0	47.0
Tulare	TLB	1945	122,108	3.7	10.0	10.0	4.1	14.0
Tulare	TLB	1960	178,569	8.4	15.9	15.9	8.4	24.3
Tulare	TLB	1975	228,724	13.9	26.7	21.1	17.1	38.2
Tulare	TLB	1990	244,129	20.0	40.7	31.0	29.9	60.9
Tulare	TLB	2005	272,356	31.1	49.1	37.9	67.2	105.1
	SCV	2005	584,721	56	96	92	7	99
	NSJV	2005	659,631	76	123	106	77	182
	TLB	2005	1,165,616	123	213	173	127	300
Total	**CV**	2005	2,409,969	256	432	371	210	581

Appendix Table 2: County Agricultural Commissioner Reports analysis - typical crop N application rates (Nnorm) and mean Central Valley harvest rates (kg/ha) for periods 1945-2005. These rates were also used in GNLM.

Crop Name	DWR/ CAML Crop Code	Application Rate (Nnorm) kg/ha					Mean Harvest Rate (CV) kg/ha				
		1945	1960	1975	1990	2005	1945	1960	1975	1990	2005
Citrus and Subtropical (Also Miscellaneous subtropical and jojoba)	300	163.0	137.0	153.4	156.9	156.9	10.0	14.4	14.5	15.9	15.1
Grapefruit	301	183.3	154.0	172.5	128.5	128.5	9.3	16.7	30.8	46.6	30.6
Lemons	302	197.5	166.0	185.9	138.3	138.3	33.6	30.4	29.8	31.7	64.6
Oranges	303	146.4	123.0	137.8	146.0	146.0	31.7	29.4	26.3	37.0	45.5
Avocados	305	148.8	125.0	140.0	124.9	124.9	15.2	10.9	14.6	25.0	19.8
Olives	306	97.6	82.0	91.8	88.5†	88.5†	71.2	79.7	74.2	135.3†	117.3†
Kiwis	308	116.9	98.3	110.1	112.6	112.6	10.0†	10.0†	10.3	22.3	25.6
Deciduous Fruits and Nuts	400	151.5	127.3	142.6	145.9	145.9	8.4	11.7	12.6	12.0	15.3
Mixed deciduous (Apples)	401	97.6	82.0	91.8	66.7	66.7	3.0	7.9	11.9	20.0	18.4
Apricots	402	102.3	86.0	96.3	106.1	106.1	17.7	24.7	27.3	37.5	37.9
Cherries	403	77.4	65.0	72.8	76.4	76.4	12.5	9.7	14.3	15.6	10.4
Peaches and Nectarines	405	153.5	129.0	144.5	116.3	116.3	22.6	25.2	30.1	35.4	32.5
Pears	406	141.6	119.0	133.3	157.9	157.9	7.3	16.4	14.8	21.3	24.0
Plums	407	130.9	110.0	123.2	115.9	115.9	7.1	9.0	19.2	21.0	21.1
Prunes	408	113.1	95.0	106.4	145.9	145.9	33.7	29.5	35.1	36.9	25.1
Figs	409	97.6	82.0	91.8	86.2	86.2	4.9†	3.4†	2.5†	3.2†	4.0†
Almonds	412	151.1	127.0	142.2	246.0	246.0	61.2	98.0	93.3	109.1	142.1
Walnuts	413	142.8	120.0	134.4	196.0	196.0	32.8	27.8	55.9	62.3	76.1
Pistachios	414	184.4	155.0	173.6	177.5	177.5	8.0†	8.2	34.4	66.2	87.3
Field Crops (includes Flax, Hops, Castor Beans, Miscellaneous Field, and Millet)	600	73.4	105.7	138.9	182.9	182.9	20.7	43.1	63.1	103.6	129.7
Cotton	601	64.5	92.9	122.1	194.6	194.6	41.2	65.9	68.0	79.6	89.7
Safflower	602	48.0	69.1	90.7	114.8	114.8	19.2	55.4	60.2	69.2	63.3

Crop Name	DWR/ CAML Crop Code	Application Rate (Nnorm) kg/ha 1945	1960	1975	1990	2005	Mean Harvest Rate (CV) kg/ha 1945	1960	1975	1990	2005
Sugar Beets	605	65.1	93.8	123.2	174.7	174.7	97.1	110.8	154.0	153.5	201.6
Corn (Field and Sweet)	606	100.6	144.9	190.4	239.0‡ (437)	239.0‡ (437)	48.1	84.2	126.8	175.1‡ (283.8)	209.0‡ (349.5)
Grain sorghum	607	62.9	90.6	119.0	156.8	156.8	30.5	73.4	79.7	93.4	95.2
Sudan	608	98.9	142.4	187.1	246.0‡ (560.1)	246.0‡ (560.1)	34.4	13.6	39.3	42.8‡ (305.2)	85.9‡ (392.5)
Beans (dry)	610	30.2	43.5	57.1	101.5	101.5	54.9	62.3	82.8	90.4	95.0
Sunflowers	612	36.0	51.8	68.0	89.6	89.6	26.9†	49.2†	59.2†	49.2†	22.7†
Grain and Hay (includes miscellaneous)	700	79.5	114.4	150.3	198.0	198.0	40.8	41.1	101.6	108.7	140.5
Barley	701	42.9†	61.8†	81.1†	63.3†	63.3†	23.2†	42.0†	52.2†	63.9†	65.0†
Wheat	702	61.6	88.7	116.5	231.0	231.0	28.7	47.3	96.2	126.7	117.1
Oats	703	29.3†	42.2†	55.5†	69.4†	69.4†	18.8†	27.0†	40.8†	63.5†	89.5†
Pasture	1600	0.0	0.0	0.0	0.0	0.0	135.0	135.0	135.0	135.0	135.0
Alfalfa	1601	11.8	17.1	22.4	12.7	12.7	292.8	337.8	356.0	384.8	427.9
Clover	1602	10.9	15.5	22.0	12.0	12.5	135.0	135.0	135.0	135.0	135.0
Mixed pasture	1603	0.0	0.0	0.0	0.0	0.0	135.0	135.0	135.0	135.0	135.0
Rice (includes rice & wild rice subclasses)	1800	50.9	73.3	96.3	146.0	146.0	41.9	65.4	76.0	106.9	109.6
Truck,Nursery, Berry Crops (includes cole mix, mixed, and misc. truck crops)	2000	81.4	123.9	159.3	215.6	215.6	25.1	41.2	25.6	29.9	91.5
Asparagus	2002	81.3	123.7	159.0	157.9	157.9	11.6	13.9	14.4	14.4	16.2
Beans (green)	2003	44.1	67.1	86.2	137.8	137.8	19.0	22.8	26.2	27.5	22.5
Carrots	2006	91.0	138.5	178.1	242.2†	242.2†	23.1†	57.3†	70.7†	111.6†	111.6†
Celery	2007	109.3	166.3	213.9	290‡ (463.2)	290‡ (492.2)	21.7	52.9	100.0	100.0‡ (160.0)	100.0‡ (170.0)
Lettuce	2008	91.0	138.5	178.1	216.0‡ (345.0)	216.0‡ (366.5)	5.5	41.8	52.7	67.6‡ (108.2)	70.4‡ (119.7)

Crop Name	DWR/ CAML Crop Code	Application Rate (Nnorm) kg/ha 1945	1960	1975	1990	2005	Mean Harvest Rate (CV) kg/ha 1945	1960	1975	1990	2005
Melons, squash, cucumbers	2009	97.9	115.6	139.0	165.2	165.2	18.8	23.3	30.7	27.8	42.9
Onions and garlic	2010	94.9	136.7	179.6	236.5	236.5	43.4	90.3	100.5	136.8	159.3
Peas	2011	30.3	46.2	59.4	101.5	101.5	5.3	11.2	10.5	10.6	11.0
Potatoes	2012	111.9	161.1	211.7	202.0	202.0	91.1	117.1	153.2	149.7	153.0
Sweet Potatoes	2013	67.4	97.1	127.5	168.0	168.0	20.9	25.3	55.7	57.7	93.5
Spinach	2014	100.2	152.4	196.0	157.0‡ (250.9)	157.0‡ (266.6)	46.2	72.1	106.2	104.0‡ (166.4)	120.0‡ (204.0)
Tomatoes (processing)	2015	81.3	123.7	159.0	203.6	203.6	38.3	60.4	82.1	110.3	130.8
Bush berries	2019	138.0	116.0	129.9	231.2	231.2	5.0	11.7	11.1	11.4	6.2
Strawberries	2020	189.2	159.0	178.1	215.7	215.7	8.1	18.2	27.9	33.2	21.6
Peppers	2021	92.7	141.1	181.4	316.8	316.8	15.1	31.8	34.0	40.5	69.9
Broccoli	2022	104.2	158.5	203.8	213.0‡ (340.9)	213.0‡ (362.2)	13.0	31.1	37.4	78.2‡ (125.2)	90.6‡ (154.0)
Cabbage	2023	73.7	112.1	144.2	195.0‡ (312.3)	195.0‡ (331.8)	35.8	65.3	58.1	63.7‡ (101.8)	63.7‡ (108.2)
Cauliflower	2024	100.7	153.3	197.1	267.0‡ (426.9)	267.0‡ (453.6)	36.7	41.2	41.7	40.9‡ (65.4)	41.4‡ (70.4)
Brussels Sprouts	2025	51.0	78.0	100.0	138.0‡ (220.8)	138.0‡ (234.6)	55.9	74.6	80.8	124.0‡ (198.3)	124.0‡ (210.7)
Vineyards (includes table grapes, wine grapes, and raisins)	2200	66.5	55.9	62.6	39.1	39.1	10.8	15.2	16.4	16.2	17.3

† These values may be questionable.

‡ These values reflect a single crop. For GNLM only and only for periods 1990 and 2005 it was assumed that fields identified by this crop were double-cropped or triple-cropped: corn (606) was assumed double-cropped with grain (700); Sudan was assumed triple-cropped with corn (606) and grain (700); Select vegetables were assumed to be double cropped at an average rate of 160% (1990) and 170% (2005) (see Viers et al., 2012). Values in parentheses provide the total annual fertilizer application and harvest rates for double-/triple-cropping used in GNLM.

Appendix Table 4: Wastewater treatment plant facilities included in analyses: N concentration (mg N/L), and actual flow (MGD) to irrigation and/or percolation, hectares of disposal area, annual N load (kg N/yr), and N loading rate (kg N/ha/yr). Of 90% of total design flow within each region, listed here and included in analyses are those facilities with known actual flow, and excluding facilities that discharge to surface waters.

			Irrigation				*Percolation*			
County	**Facility Name**	**mg N/L**	**MGD**	**Ha**	**kg N/yr**	**kgN/ha/yr**	**MGD**	**Ha**	**kg N/yr**	**kgN/ha/yr**
Placer	CITY OF LINCOLN WWT & WRF	0.7	0.24	85	242	2.8	0.00	-	-	-
Sacramento	GALT WWTP & RECLAMATION FACILITY	14.4	1.10	138	21,840	159	-	-	-	-
Solano	DIXON WWTF	12.1	-	-	-	-	1.18	65	19,661	304
Sutter	YUBA CITY WWTF	18.4	-	-	-	-	5.38	56	136,551	2,450
Tehama	RED BLUFF WW RECLAMATION PLANT	12.7	0.02	283	312	1.1	-	-	-	-
Yuba	LINDA CNTY WATER DISTRICT WWTP	23.4	-	-	-	-	1.14	36	36,842	1,029
Yuba	MARYSVILLE WWTP	12.7	0.75	283	13,154	46	0.75	31	13,154	422
Madera	MADERA WWTF	1.4	-	-	-	-	5.39	130	10,277	79
Merced	LOS BANOS WWTF	0.5	2.93	166	2,024	12	-	-	-	-
San Joaquin	ESCALON TREATMENT PLANT	19.8	-	-	-	-	0.75	36	20,507	573
San Joaquin	MANTECA WW QUALITY CONTROL FACILITY	9.2	2.88	101	36,649	362	0.65	2.5	8,303	3,363
San Joaquin	RIPON INDUSTRIAL AND DOMESTIC TP	16.6	-	-	-	-	1.40	40	32,071	802
San Joaquin	TRACY WWTP	12.0	-	-	-	-	7.50	24	124,350	5,121
San Joaquin	WHITE SLOUGH WATER POLLUTION CONTROL FACILITY	22.7	4.64	320	145,208	454	-	-	-	-
Stanislaus	MODESTO CITY WATER QUALITY CONTROL FACILITY	12.7	7.12	138	124,871	902	-	-	-	-
Stanislaus	OAKDALE WWTF	15.7	-	-	-	-	1.62	15	35,141	2,360
Stanislaus	PATTERSON WWTF	17.9	-	-	-	-	1.39	32	34,355	1,061
Fresno	CLOVIS WWTF	6.3	2.30	181	20,020	111	-	-	-	-
Fresno	FRESNO REGIONAL WWTF	23.2	9.78	1,485	313,496	211	55.42	708	1,776,475	2,508
Fresno	KERMAN WWTF	37.0	-	-	-	-	1.20	5.9	61,346	10,451
Fresno	MALAGA CWD WWTF	9.0	-	-	-	-	0.85	15	10,570	725
Fresno	MENDOTA WWTF	21.5	-	-	-	-	1.20	61	35,631	587
Fresno	PARLIER WWTF	10.6	-	-	-	-	1.10	28	16,141	570
Fresno	REEDLEY WWTF	7.4	-	-	-	-	2.40	14	24,373	1,771
Fresno	SANGER INDUSTRIAL WWTF	16.3	0.25	76	5,630	74	-	-	-	-
Fresno	SANGER WWTF	28.0	-	-	-	-	1.67	65	64,653	999
Fresno	SELMA-KINGSBURG-FOWLER CSD WWTF	13.0	-	-	-	-	2.90	42	52,089	1,226
Kern	ARVIN WWTF	23.6	1.10	2,428	35,868	15	-	-	-	-

County	Facility Name	mg N/L	Irrigation				Percolation			
			MGD	Ha	kg N/yr	kgN/ha/yr	MGD	Ha	kg N/yr	kgN/ha/yr
Kern	BAKERSFIELD WWTP #2	5.7	13.70	2,216	107,895	49	-	-	-	-
Kern	BAKERSFIELD WWTP #3	6.1	9.76	1,274	82,259	65	5.20	45	43,827	977
Kern	DELANO WWTF	31.2	4.28	463	184,503	398	-	-	-	-
Kern	KERN SANITATION AUTHORITY WWTF	9.9	3.90	445	53,292	120	-	-	-	-
Kern	LAMONT WWTF	16.2	2.00	465	44,877	96	-	-	-	-
Kern	MCFARLAND WWTF	20.9	0.55	30	15,898	524	0.55	20	15,898	786
Kern	NORTH OF RIVER WWTF	28.0	5.50	704	212,777	302	-	-	-	-
Kern	TAFT WWTF	35.0	1.20	75	58,030	775	-	-	-	-
Kern	WASCO WWTF	26.0	0.90	158	32,331	205	0.90	65	32,331	499
Kings	CORCORAN WWTF	18.1	-	-	-	-	1.24	137	30,919	226
Kings	HANFORD WWTF	10.7	2.45	1,619	36,221	22	2.45	58	36,221	622
Kings	LEMOORE NAS WWTF (NAVAL SERVICES)	4.9	0.95	124	6,432	52	0.95	45	6,432	143
Kings	LEMOORE WWTF	12.8	2.00	5,396	35,288	6.5	-	-	-	-
Tulare	CUTLER-OROSI WWTF	15.5	0.60	43	12,850	300	0.60	6.5	12,850	1,983
Tulare	DINUBA WWTF	16.9	-	-	-	-	2.25	40	52,383	1,294
Tulare	EXETER WWTF	5.2	-	-	-	-	0.90	16	6,441	398
Tulare	FARMERSVILLE WWTF	20.0	-	-	-	-	0.92	14	25,423	1,785
Tulare	LINDSAY WWTF	16.0	0.65	85	14,369	169	0.65	45	14,369	320
Tulare	PORTERVILLE WWTF	15.0	3.70	251	76,683	306	1.60	45	33,160	740
Tulare	TULARE WWTF	10.0	10.80	809	149,220	184	1.20	121	16,580	137
Tulare	VISALIA WWTF	19.5	7.11	911	190,936	210	5.15	97	138,264	1,424
Tulare	WOODLAKE WWTF	16.0	0.46	14	10,169	718	0.46	3.9	10,169	2,614

Appendix Table 5: Food processing facilities included in analysis: N concentration (mg N/L), and actual flow (MGD) to irrigation and/or percolation, hectares of disposal area, annual N load (kg N/yr), and N loading rate (kg N/ha/yr). Approximately 60% of known facilities are listed here and included in analyses (those for which actual flow was known), excluding those facilities that are not required to report N, or with N reporting waivers.

				IRRIGATION				*PERCOLATION*			
County	**Facility**	**Type**	**mg N/L**	**MGD**	**ha**	**Kg N/yr**	**kgN/ha/yr**	**MGD**	**ha**	**kg N/yr**	**kgN/ha/yr**
Butte	PACIFIC COAST PRODUCERS OROVILLE PROCESSING FACILITY	Tomato	20	0.29	149	8,154	55	-	-	-	-
Glenn	SIERRA NEVADA CHEESE PROCESSING PLANT	Dairy	468	-	-	-	-	0.02	2.6	14,226	5,408
Sacramento	SACRAMENTO RENDERING FACILITY	Meat	28	0.30	30	11,625	383	-	-	-	-
Solano	CAMPBELL SOUP SUPPLY DIXON FACILITY	Tomato	13	1.04	246	18,700	76	-	-	-	-
Solano	SUPERIOR PACKING CO., TRANSHUMANCE INC.	Meat	66	0.25	57	22,678	400	-	-	-	-
Solano	DIXON SPROUT FACILITY, SALAD COSMO CO.	Vegetables	2.5	0.004	19	14	0.7	-	-	-	-
Sutter	SACRAMENTO PACKING PRUNE DRYER, BAINS, JASWANT	Fruit+Nut	132	-	-	-	-	0.02	7.2	7,322	1,022
Yolo	PACIFIC COAST PRODUCERS WOODLAND CITY	Tomato	22	0.55	304	16,714	55	-	-	-	-
Yolo	SUNSWEET DRYERS WINTERS FACILITY	Fruit+Nut	0.3	0.003	19	1.5	0.1	-	-	-	-
Yuba	SUNSWEET DRYERS MARYSVILLE	Fruit+Nut	19	0.01	57	202	3.6	-	-	-	-
Madera	E & J GALLO WINERY MADERA FACILITY	Wine	4.3	0.01	36	30	0.8	-	-	-	-
Madera	GOLDEN VALLEY GRAPE JUICE & WINE FACILITY	Wine	17	0.03	6	678	120	-	-	-	-
Madera	LAMANUZZI & PANTALEO MADERA PLANT	Wine	2.9	0.003	4	13	3.2	-	-	-	-

County	Facility	Type	mg N/L	IRRIGATION MGD	IRRIGATION ha	IRRIGATION Kg N/yr	IRRIGATION kgN/ha/yr	PERCOLATION MGD	PERCOLATION ha	PERCOLATION kg N/yr	PERCOLATION kgN/ha/yr
Madera	MISSION BELL WINERY, CONSTELLATION WINES US, INC	WIne	204	0.60	40	168,852	4172	-	-	-	-
Madera	THE WINE GROUP ALMADEN-MADERA	Wine	16	0.06	40	1,352	33	-	-	-	-
Madera	VICTOR PACKING RAISIN PROCESSING PLANT	Fruit+Nut	2.6	0.04	75	128	1.7	-	-	-	-
Madera	ZORIA FARMS FRUIT PROCESSING PLANT	Fruit+Nut	15	0.04	20	762	38	-	-	-	-
Merced	ATWATER CANNERY, SUN GARDEN GANGI CANNING CO	Tomato	25	1.00	1,633	34,597	21	-	-	-	-
Merced	ATWATER FROZEN FOOD PLANT, DOLE PACKAGE	Fruit+Nut	72	0.34	117	34,031	290	-	-	-	-
Merced	DEHYDRATED FLAVORS PLANT, SENSIENT TECHNOLOGIES CORP	Vegetables	14	0.66	142	12,612	89	-	-	-	-
Merced	E & J GALLO WINERY LIVINGSTON WINERY	Wine	111	0.85	57	130,706	2307	-	-	-	-
Merced	FOSTER POULTRY FARMS WWTF	Meat	40	-	-	-	-	2.40	90.2	131,314	1,455
Merced	HILMAR CHEESE PROCESSING PLANT	Dairy	102	1.55	57	218,571	3858	-	-	-	-
Merced	INGOMAR PACKING TOMATO PROCESSING PLANT	Tomato	10	2.50	1,052	35,799	34	-	-	-	-
Merced	LIBERTY PACKING TOMATO PROCESSING PLANT	Tomato	12	0.64	178	10,691	60	-	-	-	-
Merced	MORNING STAR TOMATO PROCESSING PLANT	Tomato	13	0.25	486	4,516	9.3	-	-	-	-
Merced	YOSEMITE VALLEY BEEF PACKING PLANT	Meat	87	0.01	3	988	287	-	-	-	-

County	Facility	Type	mg N/L	IRRIGATION MGD	IRRIGATION ha	IRRIGATION Kg N/yr	IRRIGATION kgN/ha/yr	PERCOLATION MGD	PERCOLATION ha	PERCOLATION kg N/yr	PERCOLATION kgN/ha/yr
San Joaquin	BEAR CREEK WINERY, GOLDSTONE LAND CO	Wine	33	0.04	38	1,895	49	-	-	-	-
San Joaquin	CHEROKEE FREIGHT LINES FACILITY	Wine	19	0.02	32	538	17	-	-	-	-
San Joaquin	CHINCHIOLO STEMILT FRUIT PROCESSING FACILITY	Fruit+Nut	2.9	0.02	8	86	11	-	-	-	-
San Joaquin	FRANZIA WINERY, THE WINE GROUP	Wine	74	0.32	134	32,882	246	-	-	-	-
San Joaquin	MUSCO FAMILY OLIVE WWTP AND LAND DISPOSAL FACILITY	Fruit+Nut	3.5	0.49	92	2,368	26	-	-	-	-
San Joaquin	OAK RIDGE WINERY	Wine	16	-	-	-	-	0.04	9.3	843	91
San Joaquin	RIVERCREST VINEYARDS, INC., RJM ENTERPRISES	Wine	54	-	-	-	-	0.01	0.8	684	845
San Joaquin	SCHENONE SPECIALTY FOODS FACILITY	Other	36	0.001	57	38	0.7	-	-	-	-
San Joaquin	WOODBRIDGE WINERY, RME INC	Wine	36	-	-	-	-	0.23	7.2	11,691	1,632
San Joaquin	BARREL TEN QUARTER CIRCLE, ESCALON CELLARS	Wine	131	0.07	44	13,232	303	-	-	-	-
San Joaquin	CALIFORNIA NATURAL PRODUCTS FOOD PROCESSING WW	Other	7.4	0.21	22	2,121	95	-	-	-	-
San Joaquin	DRY WINE MANUFACTURE, DELICATO VINEYARDS	Wine	4.2	0.13	9	746	80	-	-	-	-
San Joaquin	CA CONCENTRATE COMPANY GRAPE PROCESSING FACILITY	Fruit+Nut	35	0.01	5	605	115	-	-	-	-
San Joaquin	JESSIE'S GROVE WINERY, SPENKER RANCH INC	Wine	11	0.001	28	14	0.5	-	-	-	-
San Joaquin	LONG RANCH SWINE FACILITY	Meat	41	0.003	65	169	2.6	-	-	-	-
San Joaquin	ALPINE MEATS PACKING PLANT	Meat	22	0.02	6	600	106	-	-	-	-

County	Facility	Type	mg N/L	IRRIGATION MGD	ha	Kg N/yr	kgN/ha/yr	PERCOLATION MGD	ha	kg N/yr	kgN/ha/yr
San Joaquin	SUTTER HOME WINERY WESTSIDE FACILITY	Wine	28	0.08	74	3,180	43	-	-	-	-
San Joaquin	TURNER ROAD VINTNERS, CANANDAIGUA WINE COMAPANY	Wine	1.3	0.11	6	204	34	-	-	-	-
San Joaquin	WILDROSE VINEYARDS, R. LAWSON ENTERPRISES	Wine	1.5	0.01	6	17	3.1	-	-	-	-
Stanislaus	BRONCO WINERY, BRONCO WINE CO.	Wine	39	0.40	52	21,645	418	-	-	-	-
Stanislaus	CEBRO FROZEN FOODS, CERUTTI BROS. INC.	Vegetables	6.5	0.99	210	8,862	42	-	-	-	-
Stanislaus	CONAGRA GROCERY PRODUCTS OAKDALE FACILITY	Tomato	26	0.81	182	29,129	160	-	-	-	-
Stanislaus	DARLING INTERNATIONAL INC	Meat	0.4	0.17	57	105	1.9	-	-	-	-
Stanislaus	CAG 45 INC. GILROY FACILITY	Vegetables	25	0.70	17	24,359	1468	-	-	-	-
Stanislaus	HUGHSON NUT COMPANY	Fruit+Nut	27	0.80	17	29,455	1733	-	-	-	-
Stanislaus	PATTERSON VEGETABLE PROCESSING WASTE	Vegetables	1.1	0.80	273	1,162	4.3	-	-	-	-
Stanislaus	VSP PRODUCTS, INC. AND ROBERT BENECH	Tomato	4.8	0.04	2	240	99	-	-	-	-
Fresno	BAKER COMMODITIES KERMAN DIVISION	Meat	900	0.05	202	66,590	329	-	-	-	-
Fresno	BALLANTINE PRODUCE REEDLEY PACKING FACILITY	Fruit+Nut	7.6	0.01	16	81	5.1	0.01	7.7	81	11
Fresno	BIANCHI VINEYARDS, MODERN DEVELOPMENT CO	Wine	23	-	-	-	-	0.001	1.2	32	27
Fresno	BOGHOSIAN RAISIN PACKING PLANT	Fruit+Nut	4.3	0.02	26	128	4.9	-	-	-	-

				IRRIGATION				PERCOLATION			
County	**Facility**	**Type**	**mg N/L**	**MGD**	**ha**	**Kg N/yr**	**kgN/ha/yr**	**MGD**	**ha**	**kg N/yr**	**kgN/ha/yr**
Fresno	BOOTH RANCHES CITRUS PACKING FACILITY	Fruit+Nut	12	-	-	-	-	0.002	1.5	32	22
Fresno	CHOOLJIAN BROS RAISIN DEHYDRATOR & PACKING PLANT	Fruit+Nut	11	0.02	4	321	88	-	-	-	-
Fresno	CONAGRA GROCERY PRODUCTS HELM TOMATO PROCESSING PLANT	Tomato	38	0.48	970	24,842	26	-	-	-	-
Fresno	DEL MONTE PLANT 25 (LAND APP)	Fruit+Nut	33	0.10	32	4,378	139	-	-	-	-
Fresno	DEL REY PACKING CO.	Fruit+Nut	45	0.01	12	566	48	-	-	-	-
Fresno	E & J GALLO WINERY FRESNO WINERY	Wine	303	0.15	142	63,348	447	-	-	-	-
Fresno	E & J GALLO WINERY FRESNO WINERY	Wine	62	0.10	24	8,308	342	-	-	-	-
Fresno	FAMILY TREE REEDLEY PACKING HOUSE	Fruit+Nut	42	0.01	3	610	216	-	-	-	-
Fresno	FIG GARDEN PACKING FACILITY	Fruit+Nut	42	0.01	24	499	21	-	-	-	-
Fresno	FOWLER PACKING CO. CEDAR AVENUE FACILITY	Fruit+Nut	42	-	-	-	-	0.02	7.7	1,343	176
Fresno	GOLDEN STATE VITNERS FRESNO WINERY	Wine	38	0.30	255	15,751	62	-	-	-	-
Fresno	LAMANUZZI & PANTALEO FRESNO PLANT NO 2	Fruit+Nut	42	-	-	-	-	0.004	1.4	210	148
Fresno	LAMANUZZI & PANTALEO PLANT NO 1		42	-	-	-	-	0.004	2.0	210	104
Fresno	LION RAISINS SELMA PLANT	Fruit+Nut	29	0.09	23	3,590	156	-	-	-	-
Fresno	LOS GATOS TOMATO PRODUCTS HURON PLANT	Meat	78	0.68	890	73,623	83	-	-	-	-
Fresno	MCCALL WINERY, SAN JOAQUIN VALLEY EXPRESS	Wine	20	-	-	-	-	0.07	6.7	1,874	280

County	Facility	Type	mg N/L	IRRIGATION MGD	ha	Kg N/yr	kgN/ha/yr	PERCOLATION MGD	ha	kg N/yr	kgN/ha/yr
Fresno	NATIONAL RAISIN PLANT, SUNSHINE RAISIN CORP	Fruit+Nut	42	0.05	99	2,861	29	-	-	-	-
Fresno	NONINI WINERY	Wine	36	-	-	-	-	0.00	0.1	4	36
Fresno	NORDMAN OF CALIFORNIA REEDLEY DISTILLERY	Wine	303	0.02	12	7,888	650	-	-	-	-
Fresno	O'NEILL VINTNERS REEDLEY WINERY	Wine	36	-	-	-	-	0.50	14.9	25,141	1,688
Fresno	PARAMONT FARMS EL DORADO FACILITY	Fruit+Nut	42	0.03	32	1,552	48	-	-	-	-
Fresno	POM WONDERFUL FRUIT PROCESSING PLANT	Fruit+Nut	42	0.21	146	11,954	82	-	-	-	-
Fresno	SALWASSER SOUTH PLANT	Fruit+Nut	42	0.003	4	162	43	0.003	2.4	162	68
Fresno	SIX JEWELS DEHYDRATOR, JUE, JEFF & VELVET	Fruit+Nut	6.6	0.004	5	38	7.8	-	-	-	-
Fresno	SUN-MAID GROWERS KINGSBURG PLANT	Fruit+Nut	24	0.17	18	5,458	300	-	-	-	-
Fresno	SUN-MAID GROWERS ORANGE COVE PLANT	Fruit+Nut	286	0.01	8	4,065	502	0.02	7.7	8,288	1,083
Fresno	SURABIAN PACKING CO, INC	Fruit+Nut	85	-	-	-	-	0.00	7.7	231	30
Fresno	THE WINE GROUP FRANZIA WINERY-SANGER	Wine	65	0.15	61	13,643	225	-	-	-	-
Fresno	VIE-DEL PLANT #2, KINGSBURG	Wine	4.6	0.01	14	91	6.4	-	-	-	-
Fresno	VITA-PAKT FRUIT PROCESSING & DEHYDRATING PLANT	Fruit+Nut	48	0.001	26	70	2.7	-	-	-	-
Kern	ARVIN PACKING SHED, KERN RIDGE GROWERS	Vegetables	19	0.12	32	3,143	97	-	-	-	-
Kern	BOLTHOUSE BUTTONWILLOW PLANT	Vegetables	15	3.01	286	62,285	218	-	-	-	-

County	Facility	Type	mg N/L	*IRRIGATION* MGD	ha	Kg N/yr	kgN/ha/yr	*PERCOLATION* MGD	ha	kg N/yr	kgN/ha/yr
Kern	DELANO WINERY, DELANO GROWERS GRAPE PRODUCTS	Wine	18	-	-	-	-	0.25	8.1	6,368	787
Kern	EDISON WINERY, GIUMARRA VINEYARDS CORP	Wine	5.1	0.01	66	101	1.5	0.01	7.7	101	13
Kern	FRITO-LAY CHIPS & PRETZELS MFG PLANT	Other	50	1.18	78	81,378	1047	-	-	-	-
Kern	GRIMMWAY FRESH PROCESSING	Vegetables	22	3.61	412	108,686	264	-	-	-	-
Kern	GRIMMWAY FROZEN FOODS	Vegetables	33	1.07	196	49,210	251	-	-	-	-
Kern	GRIMMWAY MOUNTAIN VIEW FACILITY	Vegetables	1.6	0.03	29	61	2.1	0.03	13.8	61	4
Kern	HECK CELLARS	WIne	53	-	-	-	-	0.06	23.9	4,104	172
Kern	J G BOSWELL TOMATO COMPANY, KERN FACILITY	Tomato	21	1.87	250	54,374	217	-	-	-	-
Kern	MCFARLAND WINERY, GOLDEN STATE VINTNERS	Wine	111	-	-	-	-	0.04	16.2	6,676	412
Kern	MONARCH NUT COMPANY	Fruit+Nut	121	-	-	-	-	0.07	7.7	11,438	1,495
Kern	PARAMOUNT FARMS KING FACILITY	Fruit+Nut	190	0.05	53	12,706	242	-	-	-	-
Kern	PARAMOUNT FARMS LOST HILLS FACILITY	Vegetables	40	0.48	503	26,684	53	0.48	7.7	26,684	3,488
Kern	SUN PACIFIC BAKERSFIELD PACKINGHOUSE	Fruit+Nut	0.7	0.04	469	32	0.1	0.04	7.7	32	4
Kern	SUN WORLD COMMODITY CENTER FACILITY	Fruit+Nut	42	0.001	16	61	3.9	-	-	-	-
Kings	BAKER COMMODITIES HANFORD FACILITY	Meat	140	0.02	50	4,449	89	-	-	-	-
Kings	CALIFORNIA PISTACHIO ORCHARDS PLANT	Fruit+Nut	107	0.002	15	269	18	-	-	-	-

County	Facility	Type	mg N/L	IRRIGATION MGD	IRRIGATION ha	IRRIGATION Kg N/yr	IRRIGATION kgN/ha/yr	PERCOLATION MGD	PERCOLATION ha	PERCOLATION kg N/yr	PERCOLATION kgN/ha/yr
Kings	CORCORAN TOMATO PROCESSING FACILITY, JG BOSWELL CO.	Tomato	28	1.40	162	54,162	335	-	-	-	-
Kings	DEL MONTE FOODS PLANT #24	Tomato	42	1.07	389	61,815	159	-	-	-	-
Kings	KEENAN FARMS PISTACHIO PLANT	Fruit+Nut	2.1	-	-	-	-	0.11	7.7	321	42
Kings	NICHOLS PISTACHIO	Fruit+Nut	1.7	0.11	328	251	0.8	-	-	-	-
Kings	OTP LEMOORE PLANT, SSC FARMS II	Tomato	62	0.54	364	45,926	126	-	-	-	-
Tulare	CACCIATORE FINE WINES & OLIVE	WIne	19	-	-	-	-	0.01	22.3	130	6
Tulare	DINUBA PACKING PLANT, GILLETTE CITRUS CO	Fruit+Nut	8.0	-	-	-	-	0.003	0.1	36	302
Tulare	EUCLID PACKING CITRUS PACKINGHOUSE	Fruit+Nut	7.9	0.00	16	44	2.7	-	-	-	-
Tulare	GOLDEN STATE CITRUS PACKING SHED	Fruit+Nut	42	-	-	-	-	0.002	0.1	127	979
Tulare	GSV CUTLER WINERY, GOLDEN STATE VINTNERS	Wine	8.5	-	-	-	-	0.01	20.8	130	6
Tulare	LOBUE BROS/EARLIBEST	Fruit+Nut	8.5	0.01	66	124	1.9	0.01	7.7	124	16
Tulare	MOZZARELLA FRESCA TIPTON CHEESE PROCESSING PLANT	Dairy	22	0.25	117	7,599	65	-	-	-	-
Tulare	PACKING HOUSE, ORANGE COVE, TRI-COUNTY CITRUS	Fruit+Nut	42	-	-	-	-	0.01	7.7	835	109
Tulare	PORTERVILLE CITRUS PACKING HOUSE	Fruit+Nut	42	0.01	26	465	18	0.07	0.2	4,186	19,934
Tulare	PORTERVILLE CITRUS PACKINGHOUSE, MAGNOLIA CITRUS	Fruit+Nut	42	-	-	-	-	0.01	0.4	349	943
Tulare	SEQUOIA ORANGE CO PACKINGHOUSE	Fruit+Nut	42	-	-	-	-	0.01	0.1	430	3,073
Tulare	SETTON PROPERTIES PISTACHIO PROCESSING PLANT NO 2	Fruit+Nut	58	0.14	91	10,884	120	-	-	-	-

County	Facility	Type	mg N/L	IRRIGATION MGD	ha	Kg N/yr	kgN/ha/yr	PERCOLATION MGD	ha	kg N/yr	kgN/ha/yr
Tulare	SETTON PROPERTIES TERRA BELLA FACILITY	Fruit+Nut	58	0.09	91	7,222	79	-	-	-	-
Tulare	SUN PACIFIC EXETER PACKINGHOUSE	Fruit+Nut	42	-	-	-	-	0.03	7.7	1,744	228
Tulare	SUN PACIFIC WOODLAKE PACKINGHOUSE	Fruit+Nut	42	-	-	-	-	0.01	7.7	326	43
Tulare	SUNKIST GROWERS TIPTON PLANT	Fruit+Nut	48	0.55	100	36,478	363	-	-	-	-
Tulare	SWORLCO LAND APPLICATION SITE	Fruit+Nut	43	0.33	87	19,572	224	-	-	-	-
Tulare	THE WINE GROUP FRANZIA WINERY0TULARE	Wine	30	0.08	5	3,119	604	-	-	-	-
Tulare	TREEHOUSE CALIFORNIA EARLIMART ALMOND PLANT	Fruit+Nut	57	-	-	-	-	0.03	0.3	1,969	5,791
Tulare	VENTURA COASTAL VISALIA DIVISION	Fruit+Nut	49	-	-	-	-	0.05	24.3	3,703	152

Appendix Figures

Appendix Figures 1 – 5: Landuse maps of landuses with fixed or facility-specific groundwater nitrate loading rates ("fixed rate lands") for 1945, 1960, 1975, 1990, and 2005

Appendix Figures 6 – 109: 14 nitrogen flux maps for each of 8 simulation periods: 1945, 1960, 1975, 1990, 2005, 2020, 2035, 2050. For each period, the set of maps include:

Atmospheric nitrogen deposition

Irrigation nitrogen

Potential synthetic fertilizer application (typically recommended rate)

Synthetic fertilizer application (actual use after accounting for manure or effluent applications)

Land-applied manure, effluent, or biosolids nitrogen

Manure sale

Potential harvest

Actual harvest

Actual runoff

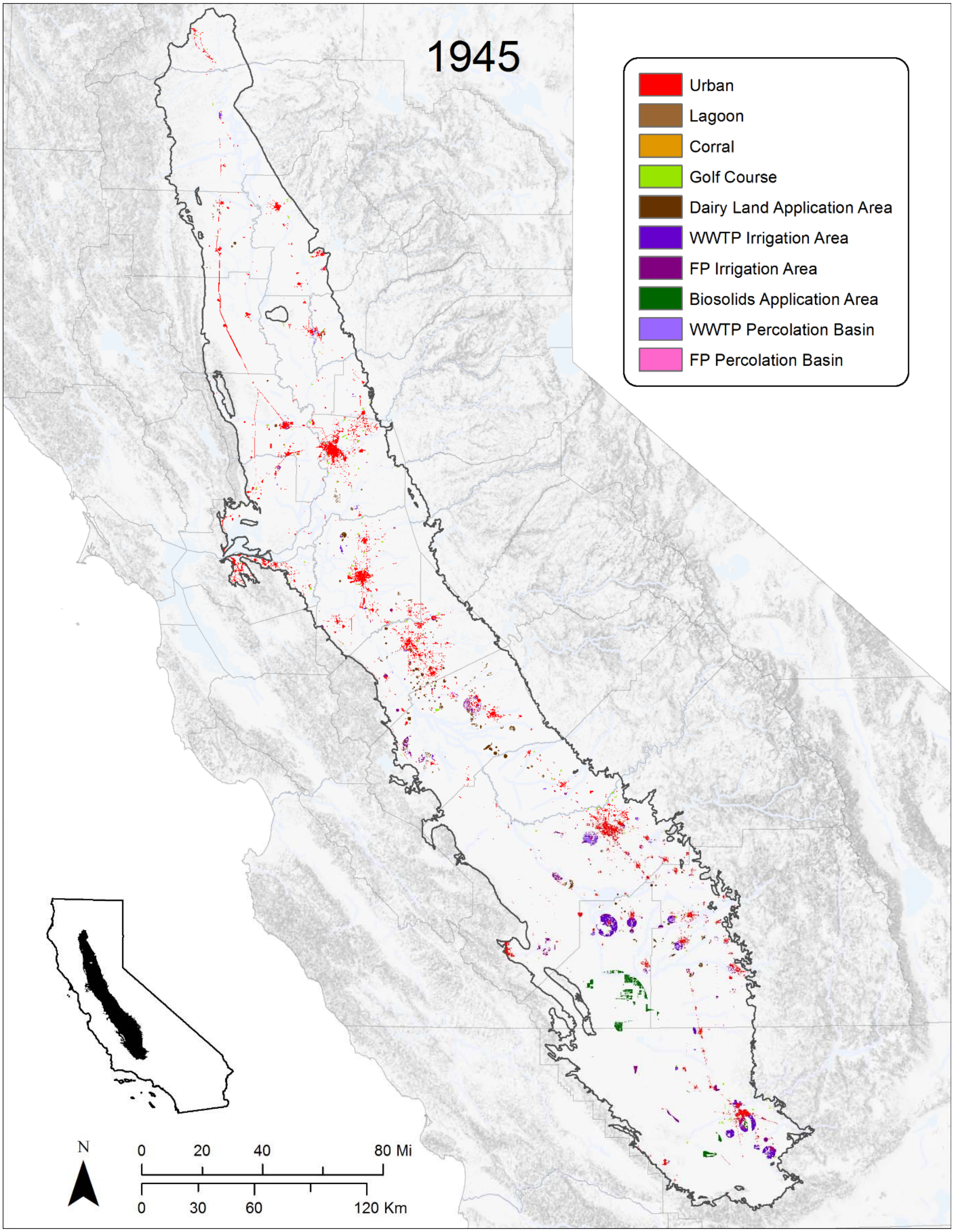
Atmospheric losses

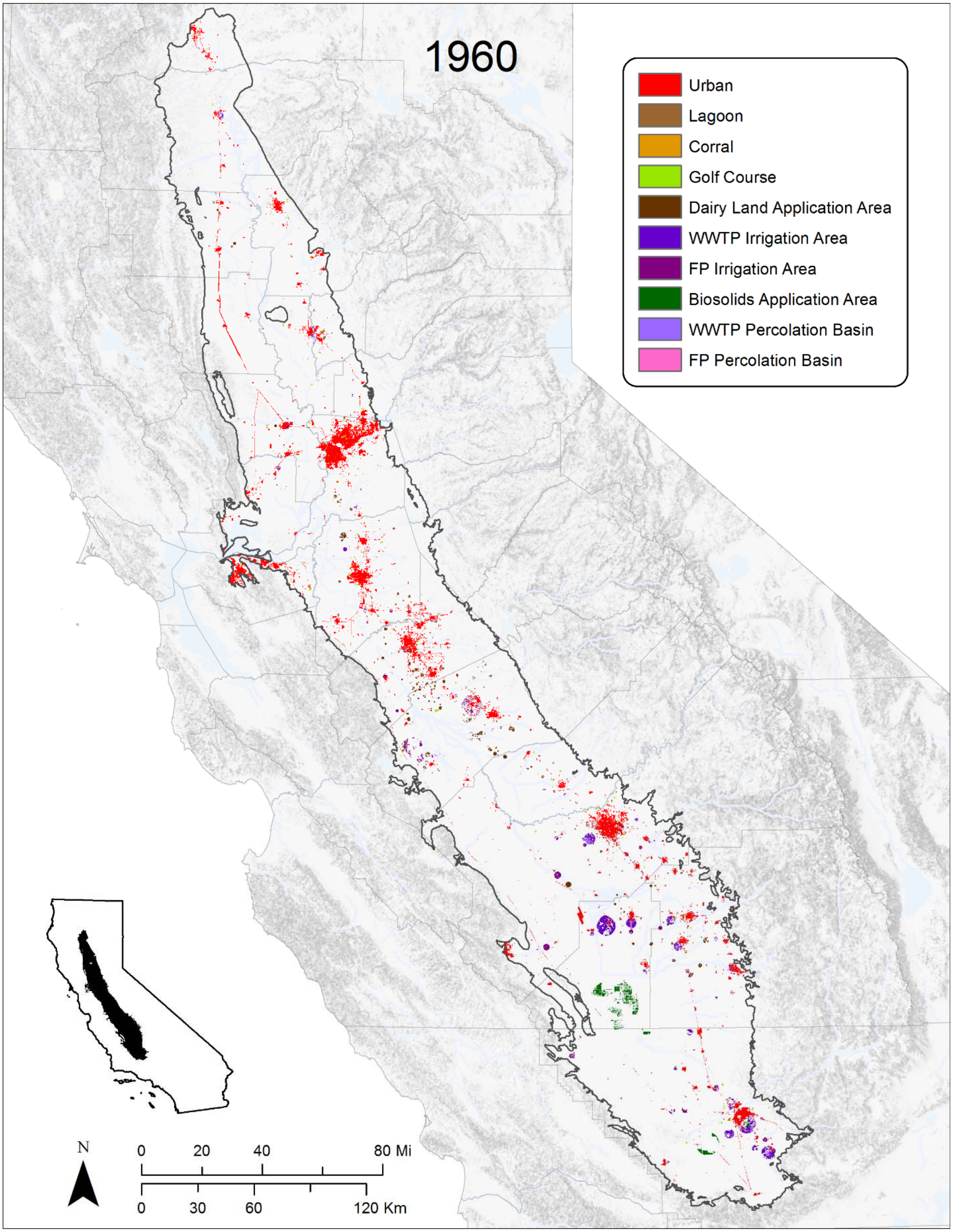
Potential groundwater loading from crops and natural vegetation

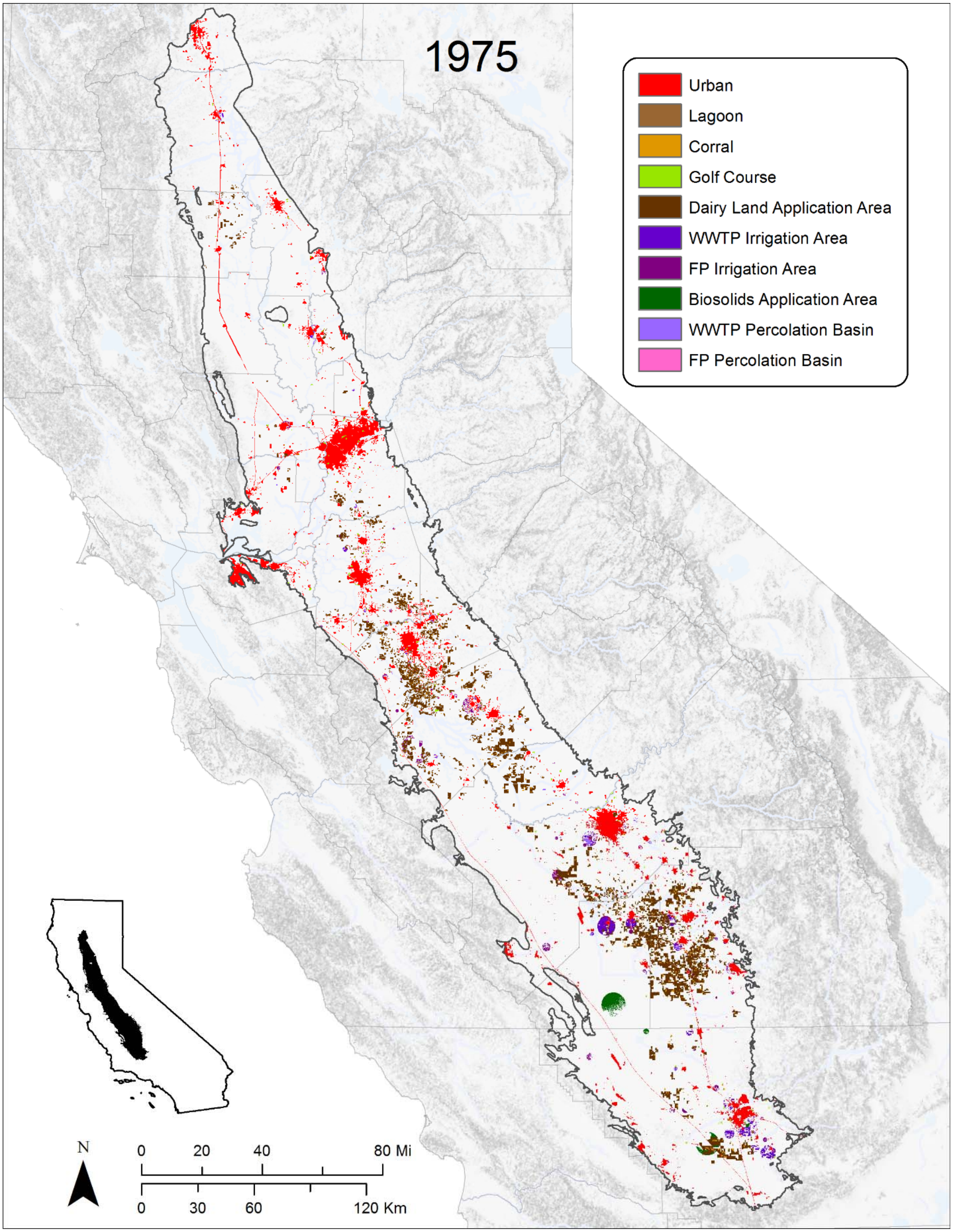
Potential groundwater loading from septic systems

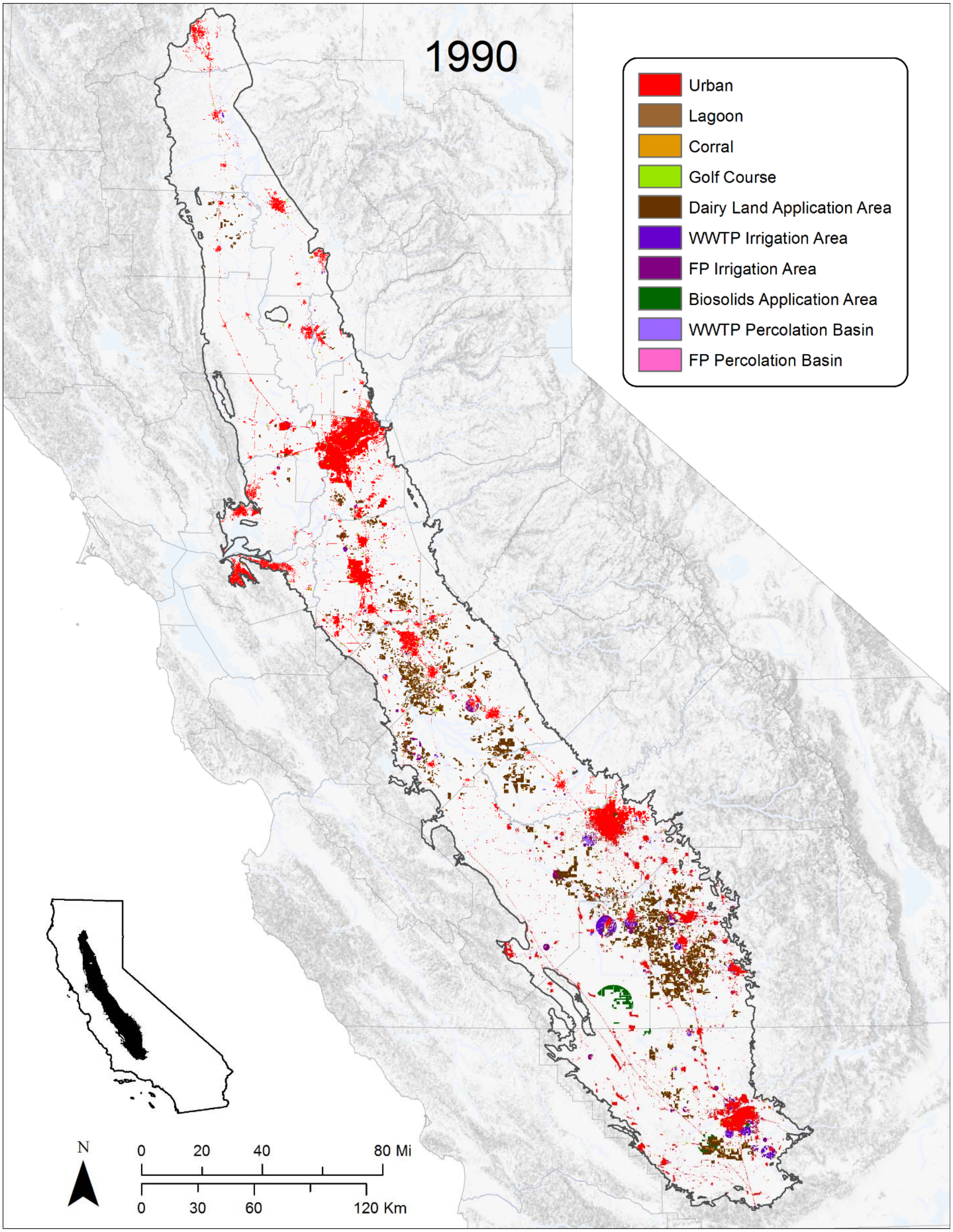
Potential groundwater loading from urban areas, golf courses, wastewater lagoons, corrals, and alfalfa/clover

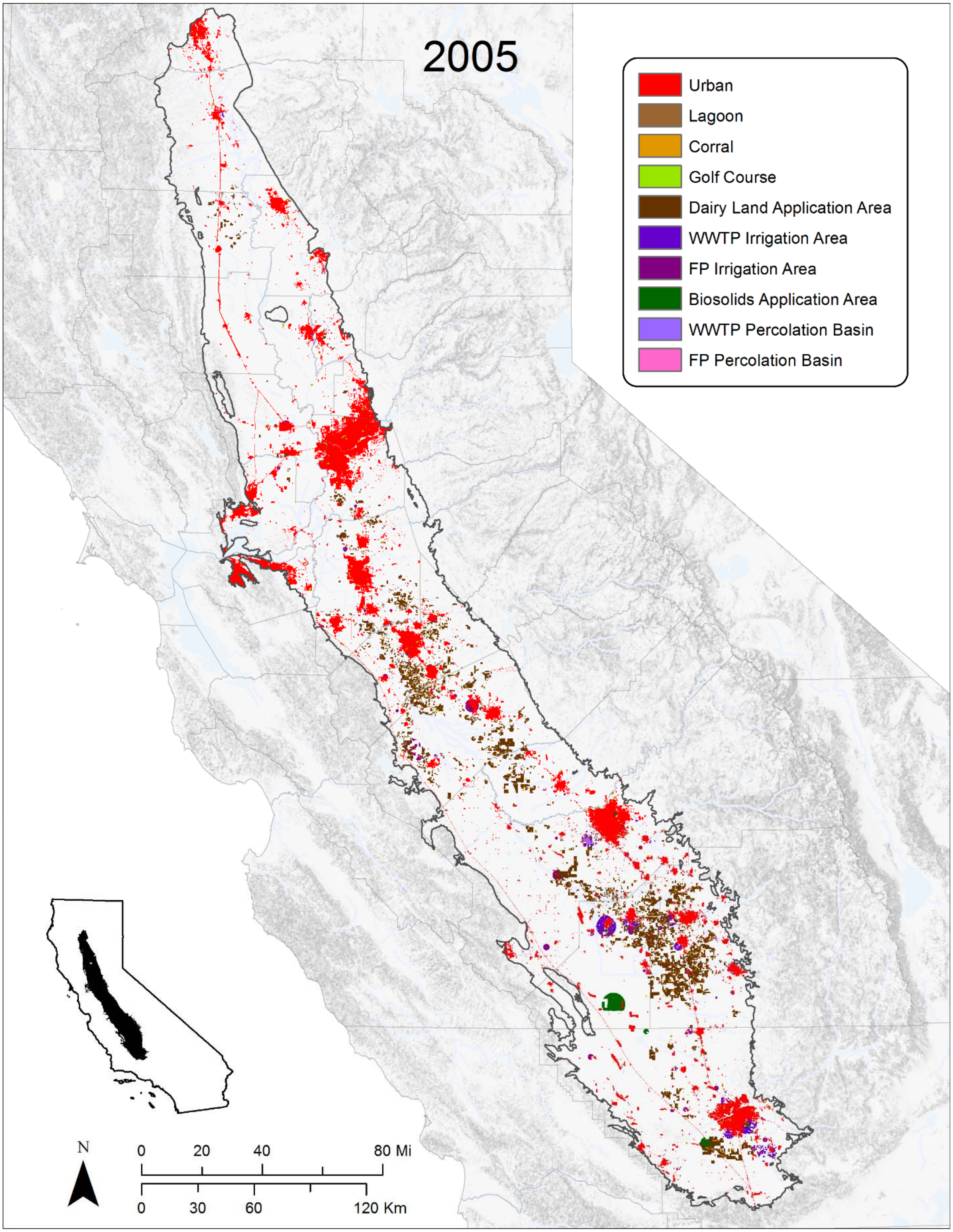
Potential groundwater loading from all sources combined


1945
Urban
Lagoon
Corral
Golf Course
Dairy Land Application Area
WWTP Irrigation Area
FP Irrigation Area
Biosolids Application Area
WWTP Percolation Basin
FP Percolation Basin
N
0 20 40 80 Mi
0 30 60 120 Km


1960
Urban
Lagoon
Corral
Golf Course
Dairy Land Application Area
WWTP Irrigation Area
FP Irrigation Area
Biosolids Application Area
WWTP Percolation Basin
FP Percolation Basin
N
0
20
40
80 Mi
0
30
60
120 Km


1975
Urban
Lagoon
Corral
Golf Course
Dairy Land Application Area
WWTP Irrigation Area
FP Irrigation Area
Biosolids Application Area
WWTP Percolation Basin
FP Percolation Basin
N
0
20
40
80 Mi
0
30
60
120 Km


1990
Urban
Lagoon
Corral
Golf Course
Dairy Land Application Area
WWTP Irrigation Area
FP Irrigation Area
Biosolids Application Area
WWTP Percolation Basin
FP Percolation Basin
N
0
20
40
80 Mi
0
30
60
120 Km


2005
Urban
Lagoon
Corral
Golf Course
Dairy Land Application Area
WWTP Irrigation Area
FP Irrigation Area
Biosolids Application Area
WWTP Percolation Basin
FP Percolation Basin
N
0 20 40 80 Mi
0 30 60 120 Km