State of California
Department of Food and Agriculture
Fertilizer Research and Education program

PROPOSAL COVER PAGE

Project Title:

Nitrogen Fertilizer Loading to Groundwater in the Central Valley.

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Project Budget:

Year	Funding Request	Matching Funds/In-Kind Contributions
2012	$ 52,755	$ 15,955
2013	$ 49,478	$ 15,849
2014	$ 47,766	$ 16,694
TOTAL	$150,000	$ 48,499

EXECUTIVE SUMMARY

Nitrate is the most common pollutant found in aquifers of the Central Valley, California. This project will provide the first long-term assessment of past and current nitrate loading to groundwater on irrigated lands across the entire Central Valley of California; assess the long-term implications for groundwater quality in the Central Valley (Sacramento Valley, San Joaquin Valley, and Tulare Lake Basin); and provide a planning tool to better understand local and regional groundwater quality response to specific best management practices and policy/regulatory actions. The project outcome will provide critical information about the link between management practices, policy, and future groundwater nitrate conditions to growers, agricultural organizations, agricultural consultants and extension groups, to policy makers, and to regulatory agencies. In particular, we envision that this assessment will provide an important and critically needed scientific framework for the implementation of the salt and nutrient basin plan amendment and of the "irrigated lands regulatory program". These are regulatory programs under California's Porter-Cologne Act that will increasingly focus on the regulation, assessment, protection, and monitoring not only of surface water but also of groundwater quality below irrigated lands and elsewhere.

The target audience for the project outcome include growers, agricultural commodity groups, researchers in irrigation and crop nutrient management and in water quality (including universities, U.S. Geological Survey), agricultural consultants, Natural Resource Conservation Service, UC Cooperative Extension, Resource Conservation Districts, regulatory agencies including local planning agencies, Central Valley Regional Water Quality Control Board, State Water Resources Control Board, and U.S. Environmental Protection Agency Region 9.

This project builds upon our extensive experience in groundwater modeling, nonpoint source pollution modeling in groundwater and surface water, and nitrate fate and transport assessment in deep alluvial vadose zones. It also builds upon intensive groundwater nitrate monitoring efforts in the Central Valley, including the USGS's Groundwater Ambient Monitoring Assessment (GAMA) "basin assessment" of public water supply wells, the SWRCB's GAMA domestic well survey in select counties of the Central Valley, the "nitrate" GAMA special projects efforts by the Lawrence Livermore National Laboratory, and our own groundwater monitoring efforts to assess long-term nitrate pollution from fertilizer and manure use in dairies and in dairy forage crops.

The core of this project will be an extensive field-scale assessment of the historic and current (1940-2010) crop- and irrigation-method specific nitrogen leaching from irrigated lands in the Central Valley. The primary tool for this assessment will be a field-scale nitrogen mass balance. Key information for the mass balance includes historic fertilizer sales (by county), annual crop harvest reports (by county), recommended fertilization practices, historic animal and human waste-nitrogen production, atmospheric nitrogen deposition, and a literature-based review of soil- and region-specific atmospheric soil-nitrogen losses due to volatilization and denitrification. Groundwater loading of nitrogen will be determined, in principle, as the closure term to the mass balance, that is, groundwater loading will be assumed to be the difference between field nitrogen applications (from atmospheric, fertilizer, animal, and human sources) and field nitrogen removal (harvest removal, atmospheric losses). For some landuses for which such a mass balance cannot be reasonably made, literature review of likely leaching rates will be conducted (e.g., CAFO animal housing areas, biosolids and wastewater land applications, land application of food processing wastes, septic leach fields, urban areas).

We are currently developing a groundwater nitrate transport modeling tool that allows us to compute long-term transport of nitrate to individual domestic/municipal/irrigation wells, based on the spatially distributed, field-by-field, annual nitrogen loading to groundwater. The high-resolution nitrate transport model operates within a lower resolution regional groundwater flow model. We will apply the nitrogen loading rates obtained from the mass balance assessment and from the literature review to this nitrate transport modeling tool, which in turn will be operated within regional groundwater flow models with explicit, three-dimensional representation of field-scale groundwater recharge and groundwater dynamics. 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. We will focus on the upper aquifer units of the Central Valley that are most vulnerable to nitrate pollution and appear to have little intrinsic capacity for nitrate attenuation. A thorough statistical analysis of the modeling results will be key to understanding long-term trends and regional/sub-regional differences in groundwater impacts, and to assess and contrast fertilization practices and various landuse contributions across the region of interest. Key BMP and policy scenarios will be developed and evaluated as part of this project. Our project results, particularly the modeling data, will become the basis for a separately funded effort to provide interested users with a web-based GIS toolbox for evaluating landuse/crop-specific groundwater nitrate impacts of user-designed management practices/policies, without the need for redesigning or recomputing an expensive groundwater transport model.

JUSTIFICATION

1. *Problem Statement*

Nitrate is the most commonly found groundwater contaminant in the Central Valley, California. Nitrate (NO_3) has a "maximum contaminant level" (MCL) in drinking water of 45 mg/L (California Department of Public Health and U.S. Environmental Protection Agency, http://www.epa.gov/safewater/contaminants/index.html#primary), which corresponds to 10 mg/L of nitrate reported as nitrogen (henceforth referred to as "NO_3-N"), that is, counting only the mass of nitrogen (N) in the nitrate (NO3) molecule. In a recent survey of public groundwater quality data, primarily from public drinking water systems, more than 5% of all wells were reported as exceeding the nitrate MCL in 2007 (Ekdahl et al., 2009). During that same year, in Tulare County, nearly 15% of public supply wells and over 40% of domestic wells exceeded the nitrate MCL (*ibid*). Domestic wells have no reporting requirements and only limited surveys are available. Hence, the Tulare County survey is of particular importance. Domestic wells are typically completed in and drawing groundwater from shallower depth than large municipal or irrigation water supply wells. Nearly 70% of public supply wells and nearly 90% of domestic supply wells in Tulare County had elevated nitrate concentrations (more than 10 mg/L, considered the upper limit of natural background). In a 1985 survey of domestic wells in Hilmar, more than half of domestic wells exceeded the nitrate MCL (Polly Lowry, Central Valley RWQCB, personal communications). In contrast, a survey of domestic wells in Tehama County, Sacramento Valley showed relatively lower percentage of wells affected by elevated nitrate (http://www.swrcb.ca.gov/gama/voluntary.shtml#tehama).

Under natural environmental conditions, groundwater nitrate may occur in concentrations up to 10 mg/L. Naturally, nitrate may be released as part of the natural nitrogen cycle during the decay and mineralization of plant litter, roots, and animal excretia. Nitrate may also originate from weathering of shale or other rocks rich in organic materials (Holloway et al., 1998; Holloway and Dahlgren, 2002). However, only anthropogenic sources of nitrate are strong enough to generate nitrate concentrations in groundwater that exceed 10-15 mg/L. Anthropogenic sources include fertilizer, organic wastes (biosolids, animal manure, treated wastewater), septic systems, atmospheric nitrogen deposition, and irrigation water nitrate (Nolan et al., 2002).

Fertilizer is the single largest source of nitrogen in groundwater. In 2007, nitrogen fertilizer sales amounted to 740,000 tons of nitrogen (CDFA, 2008), which were applied to 6.9 million acres of mostly irrigated cropland (2007 National Ag Survey). On average, this amounts to over 200 lbs of nitrogen applied per acre. At an average nitrogen use efficiency of nearly 50%, over 100 lbs of nitrogen are left unused by the crop. While approximately 5% - 25% of the applied nitrogen will volatilize (as ammonia) or gas off after denitrification, an average of well over 50 lbs of nitrogen remains to annually leach out of the biologically vey active root zone and into groundwater. Typical annual recharge rates in irrigated systems are on the order of one acre-foot per acre per year. 54 lbs of nitrogen (from annual fertilizer losses to groundwater) in one-acre-foot of annual recharge yields a concentration of 90 mg/L of nitrate – twice the drinking water limit. It is therefore not unreasonable to expect that many of the Central Valley's fertilized, irrigated crops produce recharge water that significantly exceeds the MCL for nitrate. In an extensive GIS analysis of Tulare County data, Zhang et al. (1998) demonstrated the strong correlation between land use, soils, and groundwater nitrate concentrations. Similarly, Nolan et al.

(2002) showed strong statistical correlation between elevated nitrate concentration in groundwater and the use of fertilizer for agriculture, based on nationwide data from various groundwater basins including the Central Valley.

2. CDFA/FREP Goals

This project addresses the following key FREP research areas:

Fertilizer and water interactions #3: This project examines the groundwater nitrate loading from nitrogen fertilizer applications in major crops in the Central Valley in relation to the nitrate loading from manure, septic systems, municipal, and other sources.

Education and public information #7: This project provides information (in form of web-accessible extension communications, tables, maps, and public/extension presentations, but also in form of reports and publications) to growers, consultants, environmental stakeholders, the public, local and state and federal agency personnel. The project results will provide critical information to stakeholders involved in source control policy formulation (e.g., irrigated lands regulatory program, Central Valley salt and nutrient basin plan amendment), growers deciding on fertilizer management practices, and the public, which is seeking a better understanding of the role of agriculture in water quality protection and degradation.

Other areas #8: Water quality. This project concerns itself with one of the most widespread groundwater contaminants in California, nitrate.

3. Impact

This project will provide an accounting of the likely range of historical and current nitrate contributions to groundwater from fertilizer applications as a function of county, landuse, irrigation and fertilization method, and regional denitrification (attenuation) potential; and compare the nitrogen fertilizer contributions to those from other sources. Based on existing data, reports, and literature survey, this project will provide the most extensive assessment of fertilizer as a source of groundwater nitrate in the Central Valley to date. More importantly, this project will not only consider current contributions, but also the contribution of historical fertilizer use and practices on current and future groundwater quality. This project will provide a major contribution to ongoing regulatory efforts of the Central Valley Regional Water Quality Control Board, which is currently considering to regulate nitrate discharges from irrigated agricultural lands as part of the "irrigated lands regulatory program" (http://www.waterboards.ca.gov/water_issues/programs/agriculture/); and which will also be considering regulating nitrate sources as part of its efforts to add a salt and nutrient amendment to its existing basin plan (www.cvsalinity.org). Both these processes involve a broad range of stakeholder groups including farmers, farm organization representatives, agricultural consultants, environmental consultants, environmental stakeholders, urban and industrial stakeholders, water and irrigation districts, and regulatory/planning agency personnel at the local, state, and federal level. The stakeholder processes are looking 1.) to better understand the geography of nitrate sources (spatial and temporal distribution of nitrate sources to groundwater), 2.) to better understand the processes affecting nitrate transport from the source (landuse) to the receptor (domestic well, irrigation well, municipal well), and 3.) to integrate the best available science to develop regulatory policy to manage, control, and monitor nitrate sources in agriculture and elsewhere. Our project will provide a major contribution to these two program developments, not only with respect to the science, but also with respect to education and outreach. Our efforts will complement and feed into ongoing data collection and interpretation efforts conducted as part of these two programs. We anticipate that our results will have direct impact on the policy formulation within these two programs and related programs elsewhere in California (e.g., Central Coast Regional Water Quality Control Board).

This project will also contribute to anticipated outcomes under the UC Davis Agricultural Sustainability Institute's (ASI) *California Nitrogen Assessment Project*, funded through the David and Lucile Packard Foundation (see section 5). This includes contributing to raising public awareness of nitrogen impacts and policy management options and strengthening connections with the farm community, extension specialists and advisors, the media, and policymakers to amplify attention on salient issues related to nitrogen pollution and management.

4. Long-term solutions

Project outcomes will provide the basis for assessing individual crop/fertilizer management practices impacts on groundwater quality and therefore the foundation for the formulation and implementation of improved fertilizer management practices and nitrogen policies that will effectively mitigate nitrate leaching to groundwater. The work will be part of a longer-term effort to develop a web-based tool-box that allows landowners, growers, consultants, or regulatory agencies to assess the long-term dynamic impact of management practice recommendations, policy recommendations, and regulatory controls. In particular, this project will provide scientifically based information to aid in the choice of management practices and – equally important – in the assessment of future groundwater quality changes resulting from management improvements and the time horizon within which such changes can be expected. We see this project also as part of a continued effort to ensure that the University of California, and in particular, University of California Cooperative Extension remain the place where farmers and ranchers, extensionists, community organizations, policymakers, the media and the public turn to first for information and for scientific innovations that are of direct value in California and across the U.S. and are useful for productive and effective policy formulation.

5. Related research and extension/education

The project builds upon our combined, extensive experience in groundwater modeling, nonpoint source pollution modeling in groundwater and surface water, nitrate fate and transport assessment in deep alluvial vadose zones, agronomic nitrogen management in crops, and socio-economic aspects of nitrogen management. It also builds upon intensive groundwater nitrate monitoring efforts in the Central Valley, including the USGS's Groundwater Ambient Monitoring Assessment (GAMA) "basin assessment" of public water supply wells, the SWRCB's GAMA domestic well survey in select counties of the Central Valley, the "nitrate" GAMA special projects efforts by the Lawrence Livermore National Laboratory, see: http://www.swrcb.ca.gov/gama/), and our own groundwater monitoring efforts to assess long-term nitrate pollution from fertilizer and manure use in dairies and in dairy forage crops.

A detailed nitrogen budget was recently established for a Fresno County tree-fruit orchard that was monitored over more than a decade (Onsoy et al., 2005a). In the FREP-funded study, the nitrogen budget was coupled with the hydrologic budget to estimate nitrate losses to groundwater and nitrate concentrations in the deep unsaturated zone. We found that deep unsaturated zone nitrate concentrations were significantly lower than projected from the nitrogen budget analysis, possibly due to heterogeneous fluxes and resulting preferential flow (Harter et al., 2005). The simulated nitrate concentrations in groundwater recharge were found to be consistent with shallow groundwater nitrate-nitrogen (N) concentrations – on the order of 10 mg N/L to 40 mg N/L (Onsoy et al., 2005b) depending on fertilizer management practices in the orchard. Improved fertilizer management practices not only showed little effect on fruit yield, but significantly lower nitrate levels in the vadose zone and nitrate loading to groundwater.

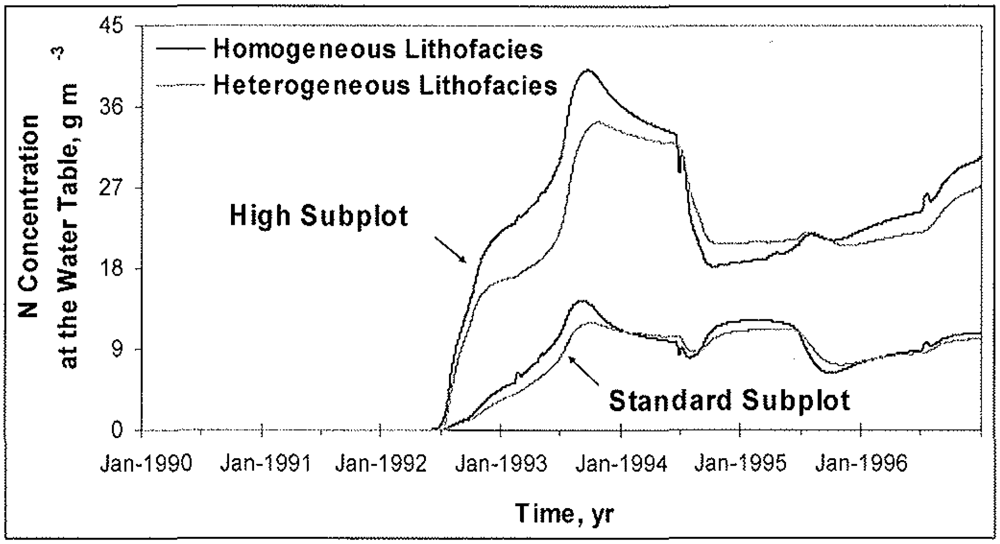


Figure 1: Average NO3-N concentration at the water table of the standard (recommended fertilizer practice) and high (historic fertilizer practice) subplots during the simulation period (1990 – 1996) in the homogeneous and heterogeneous lithofacies models (from Figure 51, Onsoy et al., 2005b). Note that 1 g m^{-3} = 1 mg/L. The maximum contamination level for drinking water is 10 mg/L of nitrate-N.

We recently also analyzed the fate and transport of nitrogen in a manured cropping systems with a double-crop of corn and winter-grain on dairies in the Northern San Joaquin Valley (Nakamura et al., 2007). The study was specifically designed to estimate nitrogen transformation rates (mineralization, nitrification) and atmospheric nitrogen losses in the root zone (ammonia volatilization and denitrification). Observational data included measurement of all water, mineral fertilizer, and manure nitrogen applications, frequent measurement of the organic and inorganic nitrogen content of the manure, and bi-weekly soil nitrogen and soil moisture level monitoring over two years. In a companion study, Harter et al. (2001), demonstrated the use of new management practices for fertilization with dairy manure and their beneficial impact to groundwater quality. The proposed practices were based on improving the nitrogen balance in manured field. The field data were corroborated by a detailed groundwater modeling analysis that was capable of predicting both, the development of nitrate levels at the water table (regulatory horizon) and in domestic wells (VanderSchans, 2001) based entirely on the annual nitrogen budget in relevant crops. The analysis provided significant insight into the importance of a nitrogen budget for estimating nitrate losses to groundwater. In the work of Zhang et al. 2006, we further explored the long-term fate of nonpoint source pollutants (salt, nitrate) in deeper aquifer systems and the role of alluvial aquifer structure in potentially accelerating the downward transport of nonpoint source pollutants to irrigation and other wells.

Zhang et al. (1998) investigated the spatial variation of groundwater nitrate concentrations in Tulare County, which is one of the counties with the most serious groundwater nitrate contamination in California. The spatial distribution of groundwater nitrate concentration was explained by spatial collocation with particular soil leaching potential characteristics, specific agricultural land uses, and depth to groundwater. High-risk nitrate leaching and contamination sites were most prevalent in townships where citrus, nut orchards, and vineyard crops were grown on coarse-textured soils. The spatial analysis provided important information to policy makers and farming consultants to formulate farm-management practices and land use strategies that minimize nitrate contamination risks in groundwater.

A dynamic simulation of stream flow and water quality was developed for the northern San Joaquin Valley watershed based on the Soil and Water Assessment Tool (SWAT) (Luo et al., 2008). The model simulates three major forms of nitrogen in soils: organic nitrogen associated with humus, mineral forms of nitrogen held by soil colloids, and mineral forms of nitrogen in solution. Loss processes include plant uptake, leaching, volatilization, denitrification, and erosion and are considered as part of the nitrogen fate and transport pathways. In-stream kinetics of nitrogen species in both dissolved and adsorbed forms are simulated by the equations adapted from QUAL2E. Dissolved and adsorbed nitrogen are transported with the water flow in soil, shallow groundwater, streams, wetlands, and canals, while those sorbed to sediment are also allowed to be deposited with the bed sediment of the channel. Comparisons of predicted and observed in-stream concentration of nitrogen species indicated that the model could be reliably used to simulate nitrogen fate and distribution at the watershed scale (Ficklin et al., 2009).

ASI recently launched a new interdisciplinary initiative to assess the tradeoffs involved in agricultural nitrogen management in California agroecosystems. The *California Nitrogen Assessment Project* will develop a nitrogen budget to identify major pools and fluxes of N in California (including atmospheric fluxes), develop conceptual models of N cycling processes in California ecosystems (in the atmosphere, plant, soil, and hydrologic systems), and perform policy analysis of alternative management practices to identify interventions for N reductions. The project also will foster interdisciplinary research and support career development of junior faculty and young professionals and includes strategic communications to disseminate information and strengthen connections with the farm community, policymakers, extension advisors, and the public.

6. Contribution to knowledge base

This research will contribute to our knowledge base by compiling and evaluating information from a wide variety of existing sources in a way that will allow for a comprehensive understanding of the field-by-field nitrogen mass balance in the Central Valley's agricultural landscape with a particular focus on groundwater leaching of nitrate. The mass balance is implemented through careful evaluation and mapping of anthropogenic and other nitrogen applications documented in agricultural statistics databases, research studies, and farm extension publications. Resulting excess nitrogen in soils becomes available to runoff in streams, leaching to groundwater, or volatilization to the atmosphere. A detailed nitrogen load map increases public awareness and can be used to motivate the public to reduce nitrogen inputs in nitrogen management practices. Most importantly, our work product will provide stakeholders with the necessary scientific information to formulate policy on the management of nitrogen sources under the requirements of the California Porter-Cologne Act.

Seeking to contain threats to environment and human health, numerous monitoring and modeling studies have been developed for nitrogen fate and distribution in agriculturally dominated regions. Most of the existing studies considered nitrogen transport only in canopy-soil system at specific plots or fields. Some of those microscopic investigations successfully determined the concentration profile of nitrogen species along soil profile. However, understanding processes such as nitrate transport in shallow aquifer, atmospheric deposition, and spatial variability in agricultural management strategies at larger spatial scales has not been addressed or with only very limited and large-scale evaluation of nitrogen fluxes. Therefore, some important nitrogen budget components have yet to be established to better understand loading and pollution assessment in groundwater: (1) nitrogen mass balance in terrestrial systems with a wide variety of crops and cross-media transport pathways taken into account; (2) long-term prediction of nitrate concentration in groundwater based on spatially distributed nitrogen leaching as inputs; and (3) a web-based interactive GIS system for nitrate pollutant assessment. These research goals can only be reached by incorporating field nitrogen mass balance and regional groundwater modeling under a GIS spatial framework.

Specifically,

A) this project will provide a comprehensive review of data available to understand historic and current field-by-field fertilizer nitrogen budgets in the Central Valley.
B) as part of the nitrogen budget development, this project will provide the most comprehensive assessment of potential nitrate loading from agricultural lands to groundwater in the Central Valley.
C) the project will identify weaknesses in the approach, identify the uncertainty in making predictions of nitrate loading to groundwater, and furthermore allow for an assessment of potential data gaps, knowledge gaps, and monitoring gaps needed to further refine predictions of potential nitrate loading to groundwater, as agriculture moves into a significantly altered regulatory environment under current efforts to apply waste discharge requirements to irrigated agriculture and efforts to develop a comprehensive framework for controlling salts and nutrients within the Central Valley.

7. Grower use

Growers will benefit from this project in two ways:

A) Growers will learn about their approximate historic and current nitrate contributions to groundwater, which provides them with important information needed to make environmentally sound agronomic decisions, and to provide a basis for informed participation in the ongoing regulatory processes described above. Growers can learn to promote higher nitrogen use efficiency crops and to install best management practices where there is high nitrate leaching potential to avoid future problems.
B) The project will generate newsletters and publications which will be disseminated to growers as scientifically-based extension information to assist their farm management practices.
C) For the agricultural community, this project will insert significant and important technical and scientific insight into ongoing regulatory processes, which may have major ramifications for their business practices. This project will assure that best science is available to these regulatory and policy-making processes (irrigated lands regulatory program, salt and nutrient

basin plan amendment) and that weaknesses, data gaps, and knowledge shortcomings are clearly identified.

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 NPS assessment tool (currently in development) 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.

WORKPLAN AND METHODS

The following tasks will be implemented during this three year project period. For each task, we indicated in which project year it will be active and reported on. The project consists of several groups of tasks to meet the project objectives:

- Tasks 1) – 10) are designed to develop the information on individual elements of the field scale nitrogen mass balance: nitrogen application by fertilizer, but also by manure and atmospheric deposition; nitrogen use and removal by crops; atmospheric nitrogen losses from volatilization, denitrification; nitrogen losses in runoff. These nitrogen budget elements will compiled for both current and historic (1940 to current) periods.
- Tasks 11) and 12) will perform the actual nitrogen mass balance (current and historic) and compute the groundwater loading rate history on a field-by-field basis; and assess the benefit of alternative management practices to nitrate groundwater loading.
- Task 13) will perform the long-term groundwater quality assessment for the pilot study areas.
- Task 14) focuses on the web-based publication of relevant GIS maps from this project and the development of outreach activities.

1. <u>Develop GIS database structure. Year 1.</u>

The first task will be to establish a spatial framework for data compilation and model simulation. All spatial data and maps will be converted into a uniform coordinate system using California Albers projection. Base maps include 1:24,000 scale 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. We will use

ArcGIS® as the GIS platform. A similar GIS database has been developed for the San Joaquin Valley watershed, and details were documented in Zhang and Luo, 2007.

2. Compile landuse data that are available in GIS format; historic and current, by CDWR landuse unit / field (crop classification I). Year 1.

Data will be collected from existing California Dept. of Water Resources (CDWR) landuse surveys that are available in digital format. These landuse surveys have been done by county, typically every seven years. GIS-based surveys are available for approximately the last 20 years for all counties within the Central Valley. We will only be considering the valley floor and not adjacent foothills or mountain ranges within the Central Valley watersheds (Sacramento, San Joaqüin, Tulare Lake). The CDWR landuse classification system ("crop classification I") recognizes nearly 50 major agricultural landuse units, some of which have further sub-categories for irrigation method, crop type, crop rotation, etc. The surveys are conducted based on the analysis of aerial photos and a subsample of visual inspections on the ground. Alternative landuse surveys maybe considered as they become available (e.g., from Landsat imagery).

3. Compile fertilizer sales, historic and current; by county. Year 1.

Fertilizer sales data by county are available through the National and California Agricultural Statistics Service. The primary data source is the semi-annual tonnage reports by the California Department of Food and Agriculture (CDFA, 2009). These will be compiled by county and by year and digitized into a spreadsheet/database linked with the GIS database.

These sales data need to be adjusted. Without corrections, the tonnage report data are of only limited usefulness at the spatial scale of this study: Information on the magnitude of out-of-county sales will need to be collected. We plan to interview experts in the fertilizer industry to find out, e.g., how much of the fertilizer is sold directly to farmers (out of county) rather than through (in-county) retailers and to adjust county numbers in recent fertilizer tonnage reports. Possibly industry insiders would provide reasonable estimates on the magnitude of the difference between where the sale occurs (which is what is reported) and where the use occurs. If feasible, we will adjust county-based fertilizer sales to account for sales across county-lines (e.g., Potter et al., 2001).

4. Compile crop acreage and crop production; historic and current, by county (crop classification II). Year 1.

Annual crop acreages and crop production are compiled by county agricultural commissioner offices. We will collect these reports from all Central Valley counties for the period 1940 to current. Most of these reports will be in printed, not in digital format. We will digitize data by major individual crops, although the county commissioner reports classify crops into a highly detailed classification system ("crop classification II") that is much more detailed then, e.g., the CDWR landuse survey. Because the crop-type of the GIS landuse survey from CDWR dictates the resolution, we will focus on the major crops within the agricultural commissioner reports that most closely correspond to the CDWR crop classification system. For digitization of the tabular data, we will establish a procedural protocol. Undergraduate students will be hired for data entry after being trained on the procedural protocol.

5. Compile crop fertilizer practices recommendations; historic and current for major crops, by regions as appropriate (crop classification III). Years 1 and 2.

This task requires a review of relevant agronomic literature and of extension reports for California (or the Southwest, where California-specific data are not available, or the United States, where U.S.-Southwest-specfic data are not available). A similar review was recently completed by Potter et al. (2001), who interviewed field specialists and fertilizer industry representatives to estimate nitrogen application rates, from which ammonia emissions were computed. Their survey focused on the 12 major crop groups listed in the 1993-1999 CDWR landuse survey. Our review will cover a longer historic period and be done by major crop-type (several crops per major crop group, if data are available, "crop classification III"). Additional data on minor crops or sub-type of crops will be collected, if they are easily available as part of the literature/reports reviewed for the major crop-types. We will also interview UC Cooperative Extension Specialists and county Farm Advisors as needed to further supplement our review. The work product of this task is a table of major crops with the recommended amount of annual nitrogen fertilizer application, by major fertilization practices and irrigation practices, as appropriate. For some crops only one major fertilization and irrigation practice may apply. To the degree that recommendations have changed historically, this will be reported as well. We expect that fertilizer recommendations will be divided into as many as two to three historic periods.

Fertilizer recommendations will be used to determine the use of nitrogen fertilizer on a specific crop relative to other crops grown in a county. Actual annual applications for each major crop type will be corrected to match the actual amount of fertilizer sales in a given year and county (and adjacent counties depending on typical purchasing patterns, as obtained from county farm advisor and fertilizer sales personnel interviews). Actual fertilizer sales will be distributed among crops according to the relative use of nitrogen fertilizer between crops obtained from fertilizer recommendations. This allows for a mass conservative allocation of actually known fertilizer sales, while preserving the relative usage difference between different crop types.

A hypothetical example illustrates this method: County A consists of 3 landuse units (fields), each of which measures 1,000 acres: one vineyard, one citrus orchard, and one triple-cropped vegetable field. Total fertilizer sales to County A are 10,000,000 lbs in the year 1990. The recommended amount of fertilizer for the vineyard is found to be 50 lbs N/acre/year (50,000 lbs N/year in County A), for the citrus orchard it is 200 lbs N/acre/year (200,000 lbs N/year in County A), and for the triple-cropped vegetable field, it is 1,000 lbs N/acre/year (1,000,000 lbs N/year in County A). The total recommended amount of fertilizer use is 1,250,000 lbs N per year. Actual fertilizer sales for that year were 1,000,000 lbs N, which is 20% less than recommended. The estimated actual fertilizer applied to each field is obtained by applying a downward adjustment of 20% to all recommended fertilizer amounts across the county: 40,000 lbs N on the vineyard field; 160,000 lbs N in the citrus orchard; and 800,000 lbs N in the vegetable field.

6. Compile crop nitrogen uptake estimates by major crops from literature review, extension reports; historic and current (crop classification IV). Year 2.

For this task, we will review the scientific literature and extension reports for data that allow us to estimate the nitrogen content of the removed harvest on a per unit basis (weight or volume depending on typical crop-specific reporting protocols). Actual harvest removal will be computed by applying estimated N removal rates to the harvest amounts reported in the agricultural commissioner's reports. As with other literature reviews/extension report analysis, this review will be done by major crop type and focus on California-specific data, where available ("crop classification IV"). Otherwise we will use either U.S. Southwest or national reports. We will seek feedback from extension personnel on whether or not non-California data need to be adjusted for California conditions. Where appropriate, a range of uptake value and/or uncertainty bounds on the uptake values will be considered.

7. Review data/literature on atmospheric deposition from literature review; historic and current, by air basin. Year 2.

Spatially distributed atmospheric deposition of nitrogen is reported in Tonnesen, 2003. Historic data will be obtained from further literature review.

8. Review literature to quantify nitrogen volatilization and denitrification and develop atmospheric loss rate (range) as function of major fertilization practices, irrigation practices, and major soil groups; historic and current. Year 1.

We will implement a literature review to determine a reasonable range of nitrogen volatilization and denitrification rates in the soil-plant system that is reasonably specific to major soil type, crops, and irrigation methods, to the degree possible given current status of research (e.g., Potter et al., 2001). Importantly, this review will also account for atmospheric nitrogen losses from crop residuals left in the field after harvest, e.g., leaf drop in permanent orchard and vineyard crops, and also nitrogen loss due to burning/plant removal. Field nitrogen losses due to runoff will be obtained from the hydrologic modeling performed with the SWAT model for the San Joaquin Valley and Sacramento Valley (Luo et al., 2008; Ficklin et al., 2009; Sobota et al., 2009). In addition, we will review recent and ongoing studies by the California Air Resources Board (CARB) and the California Energy Commission on gaseous losses of nitrogen from dairies and fertilizer sources (e.g., http://www.arb.ca.gov/ag/fertilizer/fertilizer.htm). N2O emissions, while an important GHG and highly variable, are expected to be only a minor fraction of the total gaseous, runoff, and leaching losses from soil (on average 1.25% of total applied N).

9. Develop unified crop classification scheme. Year 1.

We expect some variation in the crop classifications associated with the various tasks due to differences in data collection, research, and reporting. In the previous work tasks, we identified four potential crop classifications (I – IV) associated with various data collection efforts. In this task, we develop a unified crop classification system that maps the various crop classifications I – IV onto a single unified crop classification system ("crop classification V"). This system will be used for computing the field nitrogen balance via GIS analysis.

10. Develop and test simplified methodology to account for year-to-year landuse changes (historic and future) in a GIS framework. Year 2.

A methodology needs to be developed that allows us to account for year-to-year or at least decadal changes in landuse within individual counties as farmers adjust to market demands and change agronomic practices and as urban areas expand. The spatial distribution of crop and other landuse patterns changes over time. These dynamic changes will be captured into a single GIS layer such that a historic nitrogen mass balance can be computed for individual land parcels, even if landuse within a parcel has changed. A protocol of this mapping methodology will be developed and the GIS analysis will be performed accordingly. The work product will be a GIS map of landuse parcels with individual landuse histories.

11. Implement field nitrogen balance and estimate (range of potential) groundwater nitrate loading through recharge; historic and current. Year 3.

Using the unified crop (or landuse) classification scheme and the landuse parcel map, a GIS analysis will be performed to compute the field nitrogen mass balance and estimate groundwater nitrate loading. For the nitrogen mass balance in agricultural crops, we will consider the root zone of individual fields. Groundwater nitrate loading potential will be computed based on the following conceptual model:

$$N_{leach} = N_{atm} + N_{irrig} + N_{fertil} + N_{manure} + N_{muni} - N_{volat} - N_{denit} - N_{uptake} - N_{runoff} - \Delta N_{storage}$$

Where:

N_{leach}:	annual nitrate-nitrogen mass leachable to groundwater
N_{atm}:	annual atmospheric nitrogen deposition
N_{irrig}:	annual nitrogen mass delivered as nitrate in the irrigation water
N_{fertil}:	annual amount of nitrogen fertilizer applied
N_{manure}:	annual amount of manure nitrogen applied
N_{muni}:	annual amount of urban wastewater and biosolids nitrogen applied
N_{volat}:	annual amount of nitrogen volatilization losses
N_{denit}:	annual amount of soil denitrified nitrogen
N_{uptake}:	annual amount of nitrogen uptake into the harvested portion of the crop/plant
N_{runoff}:	annual amount of nitrogen in runoff
$\Delta N_{storage}$:	annual change in total nitrogen storage in the root zone

A critical part of the nitrogen mass balance analysis will be a thorough analysis of data gaps, data quality, and data uncertainty as well as a thorough assessment of research gaps and opportunities. To the degree that data are uncertain or associated with quantifiable and justifiable upper and lower limits rather than single numbers (e.g., volatilization rates of ammonia from the land surface may vary in one particular region from 10-15%), such uncertainty will be taken into account in the mass balance to quantify the uncertainty about the nitrate loading rates to groundwater.

12. Develop a list of prominent alternative management practices in high loading crops and evaluate loading rates. Year 3.

A literature review will be performed for some of the crops with the highest current groundwater nitrate loading rates to identify potential alternative management practices that have been developed and to evaluate groundwater nitrate loading rates from these alternative management practices.

13. Apply nitrate loading rates to NPS groundwater assessment tool to predict statistical distribution of nitrate in production wells, especially domestic wells, 1940-2100. Store results in GIS database. Year 3.

We will apply the nitrate loading rates to a groundwater transport modeling tool that allows us to track nitrate travel paths and travel times from the recharge zone to the groundwater capture in domestic wells, irrigation wells, and municipal wells. The transport model will be based on currently existing groundwater flow models for Tulare County, Merced County, and Stanislaus County (Ruud et al., 2004; Phillips et al. 2007). An additional Sacramento Valley groundwater model will be selected. Alternatively, if we can secure additional funding, we may use and modify the new USGS Central Valley Hydrologic Model (to be published in the summer of 2009) to provide the basis for the transport modeling and nitrate tracking. The nonpoint source transport assessment tool will allow us to statistically analyze the range and distribution of nitrate concentration within various major subregions and the long-term dynamic changes of nitrate concentrations in domestic, irrigation, and municipal wells as a function of their depth and of surrounding major landuses. For the pilot areas, we will predict nitrate concentrations for 1940-2100 based on historic, current, and projected nitrogen management scenarios.

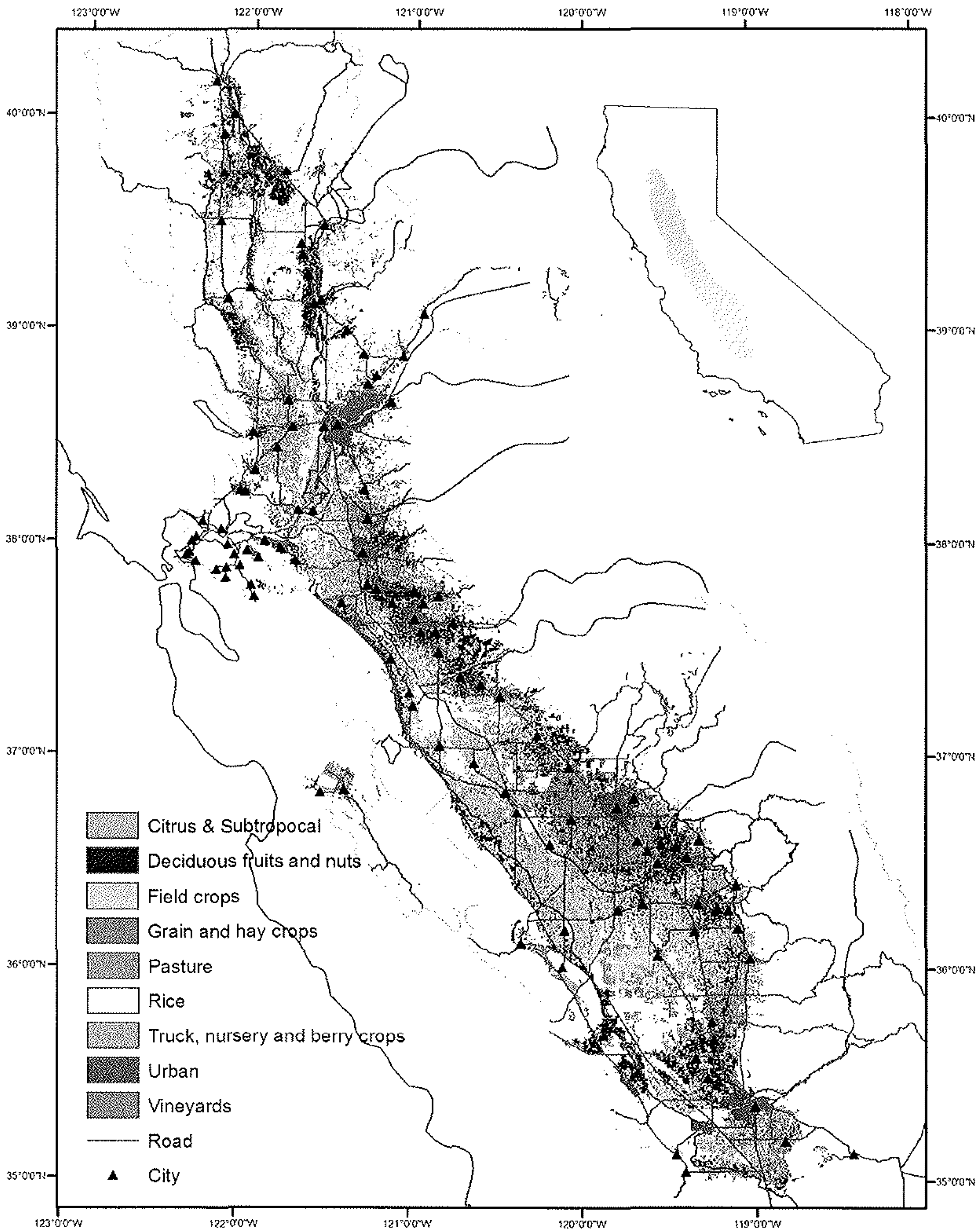
14. Publish all relevant data on web-accessible GIS database

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 will be organized into a GIS database framework. We will publish maps of important selected data as part of our outreach activities on the web.

In addition, with separate funding from the Packard Foundation, the Agricultural Sustainability Institute (ASI) will be developing a web-based information hub on nitrogen management. We anticipate collaborating with ASI to make the results of this project available through their interactive web-based portal. In preparation, spatial data will first be categorized by their types (raster versus vector - polygon, polyline, point) and their resolutions. In addition to the spatial data in its native format, more information for the data relationship and indexing will be associated with each dataset to facilitate map viewing and querying. Nitrogen related features to be published from the project will be selected and assigned with pre-designed display settings. For example, high-resolution data at section level, such as field-based cropping information, would only be displayed at a certain scale. The web-based interface will be developed for the data dissemination using ArcGIS® server or similar. The interfaces (web pages) will be designed user-friendly, with menu bars, query frame, report frame and graphic frame. The major functions to be accomplished in the web-accessible GIS databases include: data storage and exchange, user-friend viewing and querying, and data updating and maintenance. Security and updating issues will be dealt in the system design as well.

Other outreach activities include newsletters, magazine and journal articles, web-based information, and presentations at conferences, stakeholder meetings, and grower meetings (see "Outreach" below).

Map of Project Area with Major Land Use Categories



PROJECT MANAGEMENT, EVALUATION, AND OUTREACH

1. Management

Thomas Harter will be the overall project leader and is in charge of coordinating the activities and leading the conceptual design of the data collection, GIS modeling, and groundwater assessment efforts to be implemented by the project team. Together with Dr. Minghua Zhang, he will oversee and mentor a Ph.D. student that will implement the various data collection, evaluation, and archiving activities, the GIS and numerical model programming, and the groundwater assessment. Undergraduate student help will be sought as needed, in particular for data digitizing and data entry tasks. Dr. Harter will also be responsible for the preparation of the interim and annual progress reports, any oral progress reports requested, and for the preparation of the annual "interpretive summary".

Minghua Zhang will be the leader of all GIS-related activities and of the technical aspects related to developing, testing, and implementing the GIS databases and GIS web applications. Dr. Zhang will co-supervise a Ph.D. student with Dr. Harter. Dr. Zhang's research group will also provide expertise with estimation of nitrogen in surface runoff and any interfaces that need to be created between our nitrogen budget GIS database and existing efforts with regional water quality modeling using the programs SWAT or WARMF.

Thomas P. Tomich is the principal investigator of the Agricultural Sustainability Institute's (ASI's) *California Nitrogen Assessment Project* and in that role is leading that project team, with co-leadership provided by senior faculty (Kate Scow, deputy director, ASI and past-director, Kearney Foundation; Dan Sumner, director, Agricultural Issues Center; Randy Dahlgren, director, Kearney Foundation). To provide effective integration of the proposed study with the *California Nitrogen Assessment Project*, Thomas Harter is part of the technical steering committee with all of the above senior faculty of the nitrogen project. Dr. Tomich's role in this project is to ensure continuity between the ASI nitrogen project and this project; and to provide agronomic and ag-economic expertise in the development of the various project components, particularly some of the historic aspects of nitrogen usage.

Dr. Tomich is overseeing a team of postdoctoral researchers, the Packard Fellows, which will bring their unique roles within ASI's *California Nitrogen Assessment Project* also to this project: Colin Bishop is responsible for Communications and Outreach; Antoine Champetier is working on Policy Options, Daniel Liptzin is working on biogeochemical flows, Yuzhou Luo is responsible for GIS database management and modeling (e.g., water quality modeling of the Sacramento and San Joaquin Valleys using SWAT), Stephanie Ogburn is responsible for Communication and Outreach, and Todd Rosenstock is responsible for Best Practices and Technical Options. Under leadership of Dr. Tomich, the expertise of the Packard Fellows will contribute towards an efficient implementation and integration of the proposed project with the California nitrogen project.

G. Stuart Pettygrove is Soil Fertility Cooperative Extension Specialist in the Department of Land, Air, and Water Resources. His primary role as co-investigator will be as scientific and technical advisor to the team, particularly with respect to the compilation, analysis, and assessment of the various nitrogen balance components. Dr. Pettygrove will support the team also by providing appropriate contacts through his extensive knowledge of and networking within the soil fertility and nutrient management scientific, technical, consulting, and industry community.

Our project team, including the students working on the team and the Packard Fellows will meet for a kickoff meeting during the first quarter of the project, and annual meetings thereafter to discuss project progress, project challenges, and to outline the annual tasks and activities during the upcoming year, as well as discuss areas of collaboration and integration with the Packard nitrogen project.

Funding from the David and Lucille Packard Foundation for the California Nitrogen Assessment has enabled the Agricultural Sustainability Institute at UC Davis to recruit three post-doctoral fellows (one each in biogeochemistry, agronomic practices, and policy options) and two communication and engagement fellows, plus administrative support. These "Packard Fellows" together with other ASI staff, including the Director, Deputy Director, Academic Coordinator, and Communication Coordinator, each are deeply involved in assessment of various aspects of nitrogen in California, with an emphasis on reactive nitrogen in agriculture. ASI will manage the budgets as two distinct projects, but our collaborative set-up will allow significant synergies. Specifically, ASI's N assessment and communication activities, funded by Packard and other sources, will (a) strategically frame the work proposed for FREP funding, by establishing its significance within a broader context; (b) will leverage greater impact from the proposed FREP funding through complementary activities in engagement with stakeholders and communication with key audiences, and (c) in turn, the proposed FREP activities will strengthen and deepen a key dimension of the N assessment, taking the ASI team's work on N fertilizer loading in groundwater well beyond what was envisioned with Packard Funding alone.

2. *Evaluation*

The success of this project will be measured by:

a) Timely and successful completion of individual tasks.
b) At outreach workshops or extension meetings conducted, we will use evaluation forms to solicit feedback from the audience, which will include a ranking of instructors and a grading of the usefulness of information provided.
c) Acceptance of the nitrogen mass balance calculations and its spatial distributions by technical peer-reviewers.
d) Maintaining web hits and statistics of downloads of web-based extension publications and information generated by this project.
e) Tracking the information delivery (by extension meetings, presentations, written feedback, technical advising) and adoption of the project information within the policy making processes mentioned earlier (irrigated lands regulatory program, salt and nutrient basin plan amendment).

3. Outreach

The following outreach activities will be conducted for this project:

a) At least one peer-reviewed scientific article or article in a trade journal or popular agricultural media each year. Topics: field nitrogen balance elements, field nitrogen balance method, historic and current groundwater nitrate loading estimates for major crops grown in the Central Valley, overview of groundwater quality impacts from fertilizer use and other nitrogen sources in the Central Valley

b) At least two presentations each year at workshops, grower conferences, field days, stakeholder meetings, grower meetings, conferences (including the annual FREP conference) involving agricultural policy makers and regulatory agency personnel involved in policy and regulatory decision making. Topics: *same as under a)*

c) Website to host the web-GIS based toolbox for the nitrogen field budget assessment.

Furthermore, ASI's *California Nitrogen Assessment Project* includes a number of additional outreach activities which will complement this project. This includes a web-based tool to provide for large-scale stakeholder input, face-to-face consultations, and events to bring together researchers and extension specialists with users (e.g. farmers, NGOs, policymakers) and other stakeholders for listening sessions and discussions. As well, the longer-term plan is to create a web-based portal and interactive tools.

BUDGET ITEMIZATION

1. Justification:

Personnel:

1 graduate/doctoral student researcher (GSR) for 3 years including resident fee. The student will work 46% during the school year (9 months) and 100% during the summer (3 months). Student benefits are 1.3% during the school year and 3% during the summer. An additional GSR will be hired in year 1 and year 2 during the summer periods for 2.5 months (each summer) at 100%. The University of California will provide 25% of the student fee as matching funds. Fee increases after year 1 are 9.3% annually. The GSR salary is adjusted for annual increases of 2%. In-kind matching funds from UCD are provided through salary cost share for Tom Tomich at 2% effort level and Thomas Harter at 5% effort level. Benefits are computed at 33% for year 1, 34% for year 2, and 36% for year 3 per University of California policy
(http://research.ucdavis.edu/home.cfm?id=OVC,3,1158,1159,1308).
Annual salary increases of 2% are included after year 1.

Travel:

We request $6,810 for student and investigator travel for outreach, extension presentations, and conference attendance. The travel budget is based on the following number of trips:
Year 1, 2:

- 4 day trips, 100 miles roundtrip to visit agencies, farm advisor offices, or extension meetings in the greater Sacramento region (2 trips by GSR, 2 trips by one of the investigators)

- 5 two-day trips, 400 miles roundtrip to visit agencies, farm advisor offices, extension meetings, FREP conference in the northern Sacramento Valley, central and southern San Joaquin Valley, Salinas Valley (1 trip by GSR, 2 trips by Harter, 1 trip by Zhang, 1 trip by Tomich)

Year 3:

- 4 day trips, 100 miles roundtrip to visit agencies, farm advisor offices, or extension meetings in the greater Sacramento region (2 trips by GSR, 2 trips by one of the investigators)
- 7 two-day trips, 400 miles roundtrip to visit extension meetings, FREP conference, Groundwater Resources Association conference, ACWA conference or similar in the northern Sacramento Valley, central and southern San Joaquin Valley, Salinas Valley (1 trip by GSR, 2 trips by each of the investigators)

Per trip cost:

- 1 day trip: 100 miles x $0.55/mile = $55
- 2 day trip: 400 miles x $0.55/mile + hotel $100 + per diem for two days $90 = $410

Supplies:
We will need to purchase software licenses for programming software (MATLAB), GIS software (ArcGIS), and for groundwater modeling software (Groundwater Vistas). Estimated cost is $1,000 per year.

Equipment:
We will need to purchase one new personal computer for use by the GSR during the duration of the project. Estimated cost: $2,000.

2. Budget Table

See attached project budget, task budge and payment provision in EXCEL.

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