Appendix B-8

LAKE TAHOE RESTORATION PROJECTS
ESTIMATED DIRECT COSTS & KEY MILESTONE DATES

Project Name:	Nitrogen Sources and Fluxes in the Lake Tahoe Basin: Isotopic Characterization and Quantification	**Agency:**	USGS		
Prepared by:	Carol Kendall	**Phone:**	650-329-4576	**EIP #:**	10110

Identify estimated costs of eligible reimbursement expenses:

1. **Planning, Environmental Assessment and Research Costs** (specialist surveys, reports, monitoring, data collection, analysis, NEPA, etc.)	$ 35,000	3	%
2. **Direct Labor (Payroll) to Perform the Project**	$ 415,000	38	%
3. **Project Equipment** (tools, software, specialized equipment, etc.)	$ 25,000	2	%
4. **Travel** (including per diem where official travel status required to carry out project, such as serve as COR, experts to review reports, etc.)	$ 15,000	1	%
5. **Official Vehicle Use** (pro rata cost for use of Official Vehicles when required to carry out project)	$ 5,000	1	%
6. **Cost of Contracts, Grants and/or Agreements to Perform the Project**	$ 370,000	34	%
7. **Other Direct Costs** (direct labor for agency personnel to do project procurements; COR; PI; personnel assigned as NEPA lead; personnel assigned to review contracted surveys, designs/drawings, reports, etc.; project manager and/or project supervisor; and contracted costs for project manager and/or project supervisor if contracted separately	$ 218,000	20	%
TOTAL*:	$ **1,083,000**	**100**	%

Estimated Key Milestone Dates:

Milestones/Deliverables: (for a July 2005 start)	**Date:**
Submission of the final sampling plan and QAPP	June 2005
Submission of annual reports	August 2006, 2007, 2008
Submission of final summary report	September 2008
Submission of paper to peer-reviewed journal	November 2008
Final Completion Date:	December 2008

COMMENTS: This project is planned as a 3-year effort with 24 months of data collection and an additional year to complete analyses, interpret results, and write reports. The present request for Round 6 funding includes funding for a specific subset of the total samples collected and archived frozen. If the initial results look promising, a request will be made in a later funding Round to analyze specific sets of archived samples that could not be analyzed with the Round 6 level of funding. The total project cost of $1,1083,000 reflects ~$100,000 in-kind contributions from the the USGS/NRP for salary for permanent employees plus equipment..

Item #3: the major purchase will be a high-efficiency freeze-drier to concentrate dilute waters for isotope analysis.

Item #6: all funds are for expenses of university, and USFS, and other non-USGS collaborators; only a 6% "pass through" overhead was added to the total (ie, no overhead in item #7).

SCIENCE, RESEARCH & MONITORING
TAHOE PROJECT PROPOSAL

Project Name: Nitrogen Sources and Fluxes in the Lake Tahoe Basin: Isotopic Characterization and Quantification **EIP #** 10110

Lead Agency: USGS **Contact:** Carol Kendall

Collaborator: USFS,UCD-TRG,UCSD, DRI,UC Berkeley, EPRI, Stuart Weiss **Phone Number:** 650-329-4576

Threshold: Water Quality **Email Address:** ckendall@usgs.gov

Threshold Standard: WQ-4 **Total Project Cost:** $1,183,000.

Round 6 Funding requested: $1,083,000

Is this a multi-year project? Yes (3 years)

Project Description.

The USGS, in collaboration with scientists at the USDA/USFS, universities (UCD/TRG, UCSD, UCB, and UNV/DRI), and other partners, will use nitrate and ammonium isotopes, other isotopic tools, and nitrogen (N) species data from a dense network of sampling sites to estimate the relative contributions of different internal and external sources of N to the Tahoe Basin. This project is intended to: (1) characterize the temporal and spatial variability in the isotopic composition of nitrate and ammonium (and., to a much lesser degree, selected organics) in samples from Lake Tahoe and other small lakes in the basin, major inflow tributaries, groundwaters beneath the major land use types in the Basin, and wet and dry deposition occurring in the basin; (2) evaluate temporal and spatial variability in the isotopic composition of urban and agricultural pollutant sources external to the basin and upwind of Lake Tahoe; (3) determine if local N sources within the basin have characteristic isotopic signatures that would allow their contributions to be quantified, (4) use the new isotopic data to test current models of N loading to Lake Tahoe and to the basin, and (5) develop new models utilizing isotopic mass balances and other tracer methods, combined with N load data. The data generated, and the tools and models tested, will be of interest to various local stakeholders including lake managers, developers, air pollution agencies, and ecosystem restoration managers. Specific tasks needed to accomplish these goals are:

Task 1. Project management: Build on existing data, infrastructure, and knowledge to identify new and existing sampling locations, share logistical costs, and coordinate field and laboratory work with other researchers (USGS, USDA/USFS, UCD/TRG, UNV/DRI, and UCSD). We will use an adaptive management strategy of piggybacking on current and planned monitoring programs to obtain sample splits and eliminate unnecessary duplication of effort. Until funding decisions are made for new monitoring sites and research proposals, and we have received input on our design from stakeholders, the numbers and locations of sites proposed below (and plotted on the map) are provisional. Develop a detailed workplan and quality assurance plan.

Task 2. Conduct an emissions inventory: Gather existing emission inventory data from CARB, TRPA, and other sources on NO_x emissions, and develop an inventory of NH_3 emissions from vehicles within the Tahoe Basin.

Task 3. Collect dry deposition samples at key locations in the Tahoe Basin and approaches from the Sacramento Valley and Bay area: Approximately 20 former USDA sites established in 2002 (distributed around the basin and along I-50 and I-80) will be sampled for HNO_3, NH_3, NO, NO_2, and O_3 using passive samplers. Additional measurements with honeycomb denuder/filter pack systems will be made during intensive studies on a subset of 4-5 plots. We will continue analysis (Michalski) of weekly archived aerosol samples from 3 CARB sites. We will continue monthly passive monitoring of the same gas species at 9 sites in the SF Bay Area (Weiss & Kendall), supplemented with honeycomb denuder/filter packs samples for intensive sampling periods. Splits for isotope analysis will be obtained for most samples collected in Tasks 3-10.

Task 4. Collect wet deposition at key locations in the Tahoe Basin and from possible sources in the Sacramento Valley: These samples will include monthly samples from the 3 UCD/TRG site

and ~10 other selected sites (to be decided later, depending on what proposals are funded), and monthly composites from the 5 nearby NADP sites. Depending on volumes needed, we will either obtain splits or provide additional collectors for the site; snowcores will also be taken.

Task 5. Collect water samples from major tributaries to Lake Tahoe: We will piggyback on ongoing sampling at 10 PRIMARY sites by USGS/NV plus 3 sites sampled by TRG to obtain splits. We will also obtain splits of storm runoff and snowmelt runoff samples.

Task 6. Collect groundwater samples from major land uses: We will piggyback on ongoing sampling by DRI and the USGS, or proposed sampling of the 32-site USGS groundwater network, to obtain splits from ~30 representative sites.

Task 7. Collect water samples from Lake Tahoe: We will augment ongoing quarterly sampling (by Michalski) to monthly sampling at 6 UCD/TRG buoy sites at 5 depths, in coordination with proposed sampling for colloid and other samples by the proposed Alpers (USGS/CA) phosphate (P) project, and the proposed Bergamaschi (USGS/CA) DON project.

Task 8. Collect water samples from other lakes in the Tahoe Basin: If a project to continue sampling of 8 other lakes in the Tahoe Basin (Lico, USGS/NV) is funded, we will obtain splits of samples 3 times a year.

Task 9. Collect local emission sources using annular denuders: Deploy annular denuders at ~10 USDA and other sites adjacent to major roads to assess the integrated isotopic signatures of vehicle emissions. Also obtain periodic samples of important fixed emission sources (campfires, chimney exhaust, planned burns, dust) using passive samplers or active sampling, as appropriate.

Task 10. Collect ecological samples at key locations: Collect soil and leaf composites at each passive monitoring site, and collect tree-cores along transects perpendicular to major roads in the Tahoe Basin where denuders are deployed to assess local emission sources.

Task 11. Measure concentrations of dry deposition samples: Concentrations of HNO_3, NH_3, NO and NO_2 measured with passive samplers, and concentrations of HNO_2, HNO_3, NH_3, $NH4^+$, $NO3^-$, and O_3 measured on honeycomb denuder/filter pack systems will be determined at the USDA/USFS laboratory at UCR. Duplicate filters and/or splits of extracts from them will be frozen and sent to the MPSIL for isotopic analysis.

Task 12. Measure isotopic concentrations of samples: Nitrate samples will be analyzed for $\delta^{15}N$ and $\delta^{18}O$, and a subset for $\delta^{17}O$. If concentrations are sufficient, ammonium will be analyzed for $\delta^{15}N$, colloid samples collected as part of Alpers' proposed P project will be analyzed for $\delta^{15}N$ and $\delta^{13}C$, and POM samples will be analyzed for $\delta^{15}N$ and $\delta^{13}C$; a subset of organic samples will be analyzed for $\delta^{34}S$. Plant and soil samples will be analyzed for $\delta^{15}N$ and $\delta^{13}C$. All water samples analyzed for nitrate-$\delta^{18}O$ will be analyzed for $\delta^{18}O$, and a subset for $\delta^{2}H$.

Task 13. Interpret data and produce reports: All data will be mapped in ARCGIS and geostatistical models will be used for interpolation. Isotope data will be used to test existing Tahoe N-loading models (LTAM), CMAQ, and other appropriate ecosystem models. Technical reports for specialists and summary reports for decision makers will be written.

Task 14. Integrate our understanding of the N-cycle at the Tahoe Basin to address key management questions: see below.

For Science & Research Projects briefly summarize the current state of knowledge.

The decrease in water clarity in Lake Tahoe is primarily due to increased nutrient loading and subsequent algal growth within the water column. An evaluation of 25 years of bioassay data by Goldman et al. (1993, CJFAS, 50: 1489-96) showed a shift from co-limitation by bioavailable N and P to overwhelming limitation by P in the 1980s (Chang et al. 1992, CJFAS 49: 1206-15), suggesting large anthropogenic fluxes of N to the Lake. Atmospheric deposition can account for about half of total annual N load to Lake Tahoe, with the rest derived from direct runoff, stream runoff, and groundwater (Murphy & Knopp, eds., 2000, Lake Tahoe Watershed Assessment). A study of dry deposition in 2002 at USDA sites in the Sierras indicated that local sources appear to be the main cause of increased nitric acid vapor concentrations in the Lake Tahoe Basin (Bytnerowicz et al., 2004, ARB final report, Contract No. 01-334). However, the dominant source of ammonium and the relative atmospheric contributions from within-basin and external sources have not been established.

Isotopes can often provide "fingerprints" of different sources of N that cannot be determined

by chemical data alone. (See Kendall and McDonnell, eds., 1998, *Isotope Tracers in Catchment Hydrology*, Elsevier, for a text on the topic of watershed applications of isotopes). Furthermore, isotopes can be a very cost-effective "add-on" to the routine monitoring programs by the USGS and TRG, usually requiring little additional effort by the field crews to collect the samples. Also, compared with the costs associated with the field collections and basic chemical measurements, little additional resources are required to analyze selected constituents for isotopic composition. In other words, isotopes provide a "big bang for the bucks". As an independent test of models developed with chemical flux data, these isotope data will be critical for the development of accurate models of seasonal and spatial variations in N sources, and for the development of a scientific TMDL allocation plan. The work will enhance the understanding of the impacts of human activities, land management, and environmental policies on mitigating effects of accelerated N cycling in ecosystems in the basin.

Nitrogen and oxygen isotope variations ($\delta^{15}N$ and $\delta^{18}O$) in nitrate have been used successfully to determine the proportions of stream runoff derived from atmospheric nitrate and microbial nitrate in several dozen watersheds studies over the last decade in North America and Europe (Kendall, 1998, *in* Kendall and McDonnell, eds., *ibid*; Burns and Kendall, 2002, WRR, 38: 14-1-11; and many more). Several years of nitrate isotope data at dozens of sites in the Rockies show a prominent "bull's eye" of high $\delta^{15}N$ values centered on the location of major power plants (Kendall and Campbell, unpub. data). Pilot studies funded by the USGS (to Rowe and Kendall, mid 1990s, using $\delta^{15}N$ and $\delta^{18}O$) and by the CARB (to Michalski, 2003, using $\delta^{17}O$) to investigate the potential usefulness of nitrate isotopes for determining sources of N in the Tahoe Basin, have shown systematic isotopic patterns that suggest that a multi-isotope approach ($\delta^{18}O$, $\delta^{15}N$, and $\delta^{17}O$) would allow the (1) estimation of N loads from different sources and (2) tracing of their transformations within the Tahoe Basin and Lake Tahoe. $\delta^{17}O$ measurements are particularly valuable for tracing the movement of atmospheric NO_3^- in the environment because all atmospheric sources of NO_3^- derived from reactive NO_x emissions are labeled by characteristic and diagnostic non-terrestrial $\Delta^{17}O$ signatures ($\Delta^{17}O = \delta^{17}O - 0.52\ \delta^{18}O$) (Michalski et al. 2002, Anal. Chem. 74: 4989-93).

Preliminary $\delta^{17}O$ data have shown that at least 20% of the nitrate in Lake Tahoe is atmospherically derived (Michalski et al. 2004, AGU abstract); variations in lake $\delta^{17}O$ with season can provide estimates of the flux of the nitrification of organic N. Recent research also suggests that N arising from different combustion processes (i.e., with different oxidation chemistries and degrees of penetration and recycling in the stratosphere) may have characteristic $\delta^{17}O$ values. Hence, a multi-isotope approach can potentially allow researchers to distinguish between atmospheric sources of N that originate from vehicles, power plants, smoke, and agriculture. In addition, time-evolved shifts in $\delta^{15}N$, $\delta^{18}O$, and $\delta^{17}O$ trace biotic uptake and regeneration of N through decay and nitrification, providing vital clues to the residence time of N within the lake's biosphere. Very recent advances in nitrate isotope analytical techniques have reduced the requisite sample sizes by 3 orders of magnitude and drastically reduced manpower requirements. This allows for larger sample surveys and better estimation of N fluxes and cycling at finer spatial and temporal scales than was previously possible.

The major sources of primary NH_3 emissions include animal waste, fertilizer applications, natural ecosystems, industry, power plants, and catalyst-equipped vehicles. NH_3 emissions are one of the more uncertain aspects of emissions inventories. The $\delta^{15}N$ of ammonium can be a useful tracer of N source because volatilization of NH_3 from animal waste, fertilizer, and ecosystems leads to low $\delta^{15}N$ values in emissions, whereas it appears that vehicular emissions have high $\delta^{15}N$ values (Kendall, 1998; *ibid*). NH_3 gas exhibits rapid deposition close to sources and leaves a distinctive isotopic signature in nearby vegetation. For example, several studies have demonstrated that N from car exhaust or power plant emissions can result in emissions, pine needles, and tree-rings that have diagnostic $\delta^{15}N$ values (Heaton 1990, Tellus, 42B: 304-307; Ammann et al. 1999, Oecologia, 118: 124-131; and Sauer et al. 2004, Atm. Envir., 38: 2779-87, respectively). Organic N has recently been attracting attention as a major component in atmospheric deposition; current estimates suggest that 10-30% of wet N-deposition is organic. DON is a major export pathway from ecosystems but relatively little is known about $\delta^{15}N$ of aquatic or atmospheric organic N. However, the $\delta^{15}N$, $\delta^{13}C$, and $\delta^{34}S$ values of particulate organic matter (POM) have been shown to be useful tracers of sources of nutrients and aquatic processes (Kendall, 1998, *ibid*; Kendall et al. 2001, Hyd. Proc. 15: 1301-46), and DON-$\delta^{15}N$ is likely to be equally useful.

A multi-species, multi-isotope, multi-pronged approach, using a combination of well-tested and

relatively new methods, will be used for measuring $\delta^{17}O$, $\delta^{18}O$, and $\delta^{15}N$ in nitrate, $\delta^{15}N$ of ammonium, $\delta^{15}N$ of DOM, colloids, and POM, and $\delta^{15}N$ of tree-rings, foliage, and soils, to address several key management questions related to quantifying the main sources of N to Lake Tahoe. This approach involves the analysis of the isotopic composition and water chemistry of wet and dry precipitation samples collected within the airshed, NO_x and ammonia from potential emission sources, and surface and ground water samples from a variety of environmental settings within the sub-watersheds. It also includes a considerable degree of spatial and temporal sampling of Lake nitrate in order to better understand the overall role of biological cycling to the nutrient patterns.

Coupled with our improved understanding of nitrogen sources and cycling in the Lake Tahoe airshed derived from empirical isotopic data, the proposed research will also utilize ongoing modeling efforts to characterize regional emissions. The complexities of emissions, transport, chemical transformations, and deposition have been incorporated into the state of the art Community Multi-Scale Air Quality (CMAQ) model run by Dr. Gail Tonnesen of CE-CERT at UC Riverside. As of September 2004, model outputs for years 2002 and 1996 are available across California (and the entire US) at 36 x 36 km and provides a first estimate not only of total N-deposition levels, but also provides atmospheric concentrations and deposition by N-species at monthly or finer intervals. At this scale, the model is useful for examining regional transport of pollutants across the state, broad-scale deposition patterns, and potential impacts on sensitive ecosystems and species (Weiss and Davis, in prep). This modeling framework will provide an integral tool for examining key processes at regional and local scales, and ultimately for evaluation against empirical isotope data.

Describe the purpose and need for the project.

Decreasing water clarity at Lake Tahoe is believed to be largely due to increasing inputs of reactive N to the basin from atmospheric deposition. The sources of atmospheric N deposition include natural solutes and dust, and automotive, smoke, and agricultural emissions. Other possibly important in-basin sources include N from fertilizer, old sewage, and soil processes that enter the Lake through groundwater and storm runoff. Reliable data regarding the relative contributions of these sources are needed in order to develop sound strategies for managing and understanding the effects of these and other N inputs to the landscape. However, despite years of data and years of modeling, many questions still remain about the relative contributions of different internal and external sources of N to the basin. It is time to try another approach, one that has proved useful in many other watershed studies: **isotopic tracing of sources.**

Detailed monitoring of nutrient inputs to Lake Tahoe has been ongoing since the 1988s. Rowe et al. (2002, USGS WRIR 02-4030) showed high nutrient levels in storm runoff from urban watersheds. Jassby et al. (1994, WRR, 30: 2207-16) first evaluated the role of atmospheric N to the basin, and concluded that most of the DIN probably originated from urban and agricultural sources upwind of the basin. In contrast, recent studies of aerosols in the basin, especially south of the Lake, suggest that much of the dry deposition N is locally produced. For example, a recent report by Bytnerowicz, Arbaugh, and Padgett (ARB final report, Contract No. 01-334) showed that local generation of photochemical smog appears to be the main cause of increased O_3 and HNO_3 concentrations within the basin. However, adequate flux measurements are difficult to extrapolate from small-scale deposition studies, and little is known of the relative importance of external sources of DIN versus internal sources of dry deposition N to the basin. Furthermore, little is know of the bio-lifetime of the nitrogen once it enters the lake ecosystem. An improved understanding of nitrate and ammonium sources to Lake Tahoe and how they are cycled through the lake biosphere will enable more effective and cost-efficient strategies to be developed for nitrogen load reduction.

The proposed study will provide quantitative evaluations of concentrations and isotopic signatures of key nitrogen sources and pathways, and the magnitude of their ecosystem impact. Only then can the effectiveness of source control and mitigation strategies be quantified in terms of reductions in N-loading, and be evaluated by policymakers against costs in a rational economic framework. The data resulting from the proposed research will provide a new context for evaluating the effectiveness of long-term, ongoing pollution control efforts at statewide and local levels. . Further, an immediate gain will be the consideration of vehicular NH_3, which (as described above) may be a major missing piece of the N story. And finally, the results of this research will provide

another critical tool for assessing the long-term health of the Tahoe ecosystem; a historical perspective using tree rings will provide long-term baseline conditions, and ecosystem measurements will estimate the ability of ecosystems to store N inputs.

Describe the goals and objective of the project (for Science & Research Projects describe Key Management Questions being addressed.

1. Objectives:

Recent advances in isotopic techniques allow researchers to quantify sources of N at finer spatial and temporal scales than have previously been possible. This drastically improves our ability to measure nutrient fluxes using isotopic and mass balance budget approaches. The overall goals of the project are to: (1) apply a suite of well-tested and relatively new stable isotope methods in the Tahoe Basin to characterize the isotopic compositions of the various internal and external sources of dissolved and particulate N to the basin, (2) use these tracers to estimate seasonal and spatial loads from different internal and external sources of N to the Tahoe Basin, (3) provide an independent test of pollutant source models developed with mass balance, remote sensing, or emissions inventory data, (4) evaluate the potential usefulness of isotopic techniques as an adjunct to routine chemical monitoring for assessing the effects of land management changes and pollution mitigation strategies, (5) use isotope signatures to assess the rate of nutrient recycling within the Lake and estimate long-term N residence times, and (6) use the results to address key management questions.

2. Approach:

This project uses a multi-isotope, multi-tracer, isotopic and chemical mass balance approach to characterize and differentiate various sources of nitrate, ammonium, and organic matter from different N sources within and external to the Tahoe Basin. Our conceptual model is that there are multiple discrete sources of N in the basin that cause seasonal and spatial changes in N loads (caused by external N sources, local emission sources, snowmelt runoff, etc) and watershed biogeochemical processes (such as nitrification of ammonium and DON, algal growth and degradation, and denitrification). Furthermore, different sources of N and different biogeochemical processes frequently have characteristic traceable isotopic signatures that, when used in conjunction with relevant chemical and hydrological data, allow these sources and processes to be quantified.

The proposed research is designed to test the hypothesis that naturally occurring isotopes can be used to distinguish between and quantify the various important natural and anthropogenic sources of N in the Lake Tahoe Basin, derived from sources external and internal to the basin. The specific natural tracers to be used are: (1) nitrogen isotopes ($\delta^{15}N$) of nitrate, ammonium, dissolved organic matter (DOM, colloids, and POM), soils, vegetation, and tree-rings; (2) oxygen isotopes of nitrate ($\delta^{18}O$ and $\delta^{17}O$); and (3) carbon ($\delta^{13}C$) and sulfur ($\delta^{34}S$) isotopes of DOM, colloids, and POM to enhance characterization of the N sources and sinks in aquatic systems. It is important to determine and quantify the various sources and sinks of N in the basin because N has been shown to be an important contributing nutrient for the algal blooms that threaten to diminish the clarity of Lake Tahoe (e.g. Hatch et al., 2001, TRG Annual Report).

Most water and deposition sample types described above will be collected for 2 years. All samples will be archived pending analysis. After chemical concentrations are available, the team will use an ongoing adaptive management strategy to decide analysis priorities based on criteria such as completeness of spatial and temporal coverage of specific sources, labor required for different kinds of analyses, and expected value of the data (as based on current findings and our evolving understanding of the system). We have budgeted for at least 1700 nitrate $\delta^{15}N$-$\delta^{18}O$ and 1000 nitrate $\delta^{17}O$, 500 ammonium $\delta^{15}N$, and 1000 total analyses of colloids, POM, and/or DOM for $\delta^{15}N$-$\delta^{13}C$. These represent significantly less than half of the total samples expected to be archived over 2 years. Hence, if the initial results look promising, a request will be made in a later funding Round to analyze specific sets of archived samples that could not be analyzed with the Round 6 level of funding. Several other projects involving isotopic tracing of N sources to the Tahoe Basin are being proposed by collaborators of this proposal (Bergamaschi, Edwards, Fenn); if any of these (or other isotope-related projects) are funded, planned efforts in this proposal to assess the isotopic compositions of DON, snowpack DIN, and wet deposition DIN (respectively) can be reduced to eliminate

unnecessary duplication of effort, and the funding concentrated on other types of archived samples.

Emissions Inventory: We will gather existing emission inventory data from CARB, TRPA, and other sources. For example, estimated year 2000 NOx emissions in the Tahoe Basin (airshed) were 2190 tons/year (Alexin et al. 2001, The 2110 CA Almanac of Emissions and Air Quality, CARB). Large emissions of NO_x and NH_3 from the Bay Area, Sacramento Valley, and foothills are available in gridded form as input to the CMAQ model, and the 4 km inventory in that model will soon be available. We will also develop an inventory of NH_3 emissions from vehicles within the basin. Since the introduction of three-way catalytic converters in the 1990's, vehicles have become a significant source of atmospheric NH_3 (Fraser and Cass 1998, ES&T, 32: 1053-57; Durbin et al. 2002, Atm. Env., 36: 1475-82). Emission factors from these studies range from 49 to 61 mg/km. In 2000, total Tahoe Basin vehicular traffic was ~950,000,000 km (Alexis et al. 2001, *ibid*), leading to a preliminary first-order estimate of 43 tons NH_3-N per year, more than 10% of the total lake N-loading of 418 tons/year. For many reasons, including traffic speeds, vehicle mix, and high altitude, this may be an underestimate, and the magnitude of this flux will be estimated with traffic data (Caltrans), modern emissions modeling, and isotopes.

Atmospheric Deposition Sampling: We will assess the isotopic composition of wet and dry deposition, from both within and outside the Tahoe Basin (Figure 2). To save costs, we plan to piggyback as much as possible on current monitoring programs to obtain samples, including taking advantage of new sites that may be funded as part of Round 6. At least 20 of the 32 sites established by USDA in 2002 (Bytnerowicz et al. 2004, *ibid*) and distributed around the basin and along I-50 and I-80, will be sampled for HNO_3, NH_3, NO, NO_2, and O_3,. Since these gas species exhibit fine-scale spatial variability, the placement of additional 10-12 lakeshore passive samplers for NH_3, HNO_3, NO, and NO_2 will be stratified by geographic location and local urbanization to supplement the existing USDA stations. Additional measurements with honeycomb denuder/filter pack systems will be conducted during intensive studies on a subset of these sites, with samplers deployed for various time periods. We will use the denuders to obtain emissions samples from ~10 sites adjacent to major roads for short-term collections to assess the integrated isotopic signatures of vehicle emissions (summer/winter, low/high elevation, etc). We will also obtain periodic samples of important N species at fixed emission sites (campfires, chimney exhaust, planned burns, dust, etc.) using passive samplers or active sampling (bubbling gas into water, or pumping through chemical strippers), as appropriate. To improve our characterization of urban and agricultural emissions external to the basin, we will also continue to obtain archived aerosol samples from 3 CARB sites (Sacramento, Placerville, and Lake Tahoe) along a transect from urban areas to the mountains, and splits from passive samplers from at least 9 sites in the South Bay and SF Peninsula, chosen to assess the contributions from roads and power plants in the area. Short-term denuder collections will be used at appropriate (to-be-selected) sites to characterize isotopic signatures of vehicle and power plant NO_x and NH_3 emissions, and key Central Valley agricultural emission sources (see below).

Bulk deposition samples are currently being analyzed for nutrients at about 3 UCD/TRG sites (a lake site, a west shoreline site, and a western terrestrial site); we plan to obtain samples from these sites (by piggybacking and/or by providing additional collectors). Allander (USGS/NV) proposes to collect nutrients and measure precipitation volume at ~25 USGS sites co-located with stream gages. Fenn (USDA) proposes to collect monthly wet deposition samples at selected USDA sites using resin collectors to assess N loads. Edwards (UNV) proposes to collect snowpack samples near roads to assess N loads. We are collaborating with all these people and groups, and will piggyback on whatever proposals are funded to obtain monthly splits from ~10 sites within the Tahoe Basin. Otherwise, we will deploy resin collectors ourselves to collect nitrate and ammonium, and also snow cores, at about 10 selected USDA sites chosen to provide spatial coverage of important snowmelt sources to the basin; these data will be compared with results from passive samplers. We will also obtain monthly composited samples from the NADP sites at Davis, Sagehen, Yosemite, and Sequoia CA, and at Smith Valley, NV. Monthly composited archived NADP samples from the Davis, Yosemite, Sequoia, and Smith Valley sites are currently being analyzed for nitrate isotopes as part of an EPRI-funded study (Kendall & Elliott) of regional isotopic signatures of atmospheric deposition in 2000. We will also collect monthly to quarterly sampling of wet and dry deposition in the Central Valley to characterize agricultural and urban (Sacramento/Stockton) N sources, by piggybacking on existing CALFED-funded projects (to Kendall) aimed at assessing sources of N to the San Joaquin

and Sacramento Rivers using isotopic techniques.

Terrestrial Aquatic Sampling: We will piggyback on ongoing and planned sampling of tributaries, groundwater, and lakes in the Tahoe Basin by the TRG and USGS (Figure 1). Our current plan is to obtain splits from approximately monthly samples from 13 main tributaries (10 "primary" USGS/NV sites plus 3 sites sampled by TRG), and from the routine storm runoff and snowmelt runoff samples collected at these sites, and archive them. If there is interest, samples will be archived from other tributary sites ("secondary" and "tertiary"), including ones to be sampled as part of Rosen's (USGS/NV) food web proposal. The runoff sampling is designed by the USGS/NV to assess the nutrient concentrations of the rising limb, peak, and falling limb of one storm, and major fluctuations near peak snowmelt runoff, within each tributary. We will characterize the isotopic compositions of groundwater nitrate from major land uses by piggybacking on ongoing monitoring efforts at representative sites, especially under golf courses or places contaminated by septic tank leakages or treated effluent (Thodal 1997, *ibid*), or major stands of N-fixing alders. We are currently analyzing the nitrate $\delta^{15}N$ and $\delta^{18}O$ of samples collected by Jim Thomas (UNV) from a suite of wells; these data will be evaluated before selecting the final sites. If the Alvarez (USGS/NV) proposal to resample the 32 USGS well sites is funded, we will obtain splits from these sites; sites that showed appreciable seasonal variability (per Thodal 1997) will be sampled more than once. If Lico's (USGS/NV) lake proposal is funded, we will obtain splits of samples from his 8 lakes, 3 times a year. Otherwise, our lake sampling will focus only on Lake Tahoe where we will collect monthly samples at 6 UCD/TRG sites at 5 depths. We will also obtain splits of colloid and other samples collected as part of Alpers' (USGS/CA) proposed phosphate project. Waters will be filtered through 0.2 um pre-combusted GFF and frozen; if immediate filtration is not possible, samples will be frozen and filtered later. Filters and most frozen water samples will be shipped overnight to the USGS Menlo Park Stable Isotope Lab (MPSIL) for archiving. The main purpose of collecting these samples is for analysis of nitrate isotopes (mainly $\delta^{15}N$-$\delta^{18}O$, but a subset for $\delta^{17}O$). However, if concentrations allow, samples will also be analyzed for ammonium $\delta^{15}N$, and organic isotopes. If the Bergamaschi DON project is funded, it will provide a much more complete assessment of the role of DON using $\delta^{15}N$ than would be possible with the resources of our proposal.

Ecological Indicator Sampling: Soil samples and foliage samples can be sensitive indicators of ecosystem N-status, and can reflect the $\delta^{15}N$ of deposition inputs, thus providing an indication of the relative role of local vs soil sources of N. Tree rings record long-term trends in emissions and deposition, including the "pristine" background, as well as more discrete events such as the construction of major roads because traffic produces a distinctive increase in the $\delta^{15}N$ of plants within a few 100 ft of roads (Amman et al. 1999, *ibid*; Sauer et al. 2004, *ibid*). We will core trees and collect soil and leaves/needle composites along transects near major roads, adjacent to passive monitoring stations, and elsewhere in the Tahoe Basin, to develop a historical record of vehicular N emissions and potential vegetative uptake. Three cores will be taken from each tree with a 0.5 cm increment borer. Wood from separate rings will be homogenized, translocatable N removed by Soxhlett extraction, and the resulting wood combusted using EA-IRMS for $\delta^{15}N$ and % N (Sauer et al. 2004, *ibid*). We have budgeted for 600 tree-ring analyses for $\delta^{15}N$.

Laboratory Analyses: Concentrations of major N species of most samples will be obtained as part of routine monitoring efforts by the USGS, UCD, or DRI. Concentrations of HNO_3, NH_3, NO, NO_2, and O_3 from passive deposition samplers, and concentrations of HNO_2, HNO_3, NH_3, NH_4+ and NO_3- from honeycomb denuder/filter pack systems will be measured at the USDA Forest Service laboratory in Riverside, using conventional methods. Methods to produce NOx samples suitable for $\delta^{15}N$ analysis are described in Ammann et al. (1999); these methods will need to be tested for $\delta^{18}O$ and $\delta^{17}O$. Methods for analysis of aerosol and soil extracts for $\delta^{17}O$ are reported by Michalski et al. (2002, *ibid*). Duplicate filters from the passive samplers, or extracts from them, will be frozen and sent to the USGS MPSIL for analysis. Ammonium samples on suitable filters can be directly combusted and analyzed for $\delta^{15}N$. Non-filter ammonium samples with sufficiently high concentrations (or volumes sufficient to allow pre-concentration) will be analyzed for $\delta^{15}N$ using the ammonium volatilization technique. The rest will be archived until a microbial nitrifier or other method requiring only tens of nanomoles of NH_4 is perfected (nitrifier method development in progress at Princeton).

Nitrate extracts will be frozen and sent to MPSIL for analysis for $\delta^{15}N$ and $\delta^{18}O$, using the

Casciotti et al. (2002, Anal. Chem.74: 4905-12) microbial method that requires only 20-100 nanomoles of N. A subset of nitrate samples will be analyzed for $\delta^{17}O$. Depending on sample type and location, these may be analyzed using (1) the Michalski et al. (2002, *ibid*) procedure of precipitating the nitrate as silver nitrate (Silva et al. 2000, J. Hydrol. 228: 22-36), followed by thermal decomposition to O_2 and analysis at UCSD, or (2) a new method that converts the N_2O produced by the microbial method to O_2 at MPSIL [Wankel and Kendall have tested a prototype version of the method, and another version is described by Kaiser et al. (2004, fall AGU abstract)]. The advantage of these new microbial methods is that they require much less nitrate than earlier methods for $\delta^{15}N$-$\delta^{18}O$-$\delta^{17}O$. Many samples (< 0.1 mg N/L) will need to be concentrated by partial evaporation or concentration on exchange resins (Silva et al. 2000, *ibid*) before analysis using the microbial methods.

Because little is known about the potential contributions of organic sources of N in the basin, we will analyze splits of colloid samples collected as part of Alpers' proposed phosphate project. He intends to collect 25-100 L samples from the Lake Tahoe and tributary sites, and concentrate (by ultrafiltration) the colloids for phosphate-$\delta^{18}O$; splits will be freeze-dried, and analyzed for $\delta^{15}N$-$\delta^{13}C$-$\delta^{34}S$ at MPSIL. When concentrations are sufficient, surface water, groundwater, and deposition samples will be analyzed for DON-$\delta^{15}N$ [prepared using persulfate oxidation to nitrate (Knapp et al., in press), and then analysis using the Sigman et al. (2001, Anal. Chem.73: 4145-53) microbial method]; and for DOC-$\delta^{13}C$ (using an automated DOC analyzer connected to an IRMS). If the Bergamaschi DON proposal is funded, it will provide a much more intensive assessment of DON-$\delta^{15}N$ as a tracer of DON sources and sinks than the preliminary survey planned in our proposal. POM samples collected during filtration of surface waters will be analyzed for $\delta^{15}N$ and $\delta^{13}C$ (per Kendall et al. 2001, *ibid*), and a subset for $\delta^{34}S$, if concentrations suffice. All water samples analyzed for nitrate-$\delta^{18}O$ will be analyzed for water-$\delta^{18}O$. Because Lake Tahoe and many groundwaters plot along evaporation lines on $\delta^{18}O$-$\delta^{2}H$ plots, Lake waters and groundwaters, and a subset of other waters, will also be analyzed for $\delta^{2}H$ to test Thodal's hypothesis (Thodal 1997, *ibid*) that $\delta^{18}O/\delta^{2}H$ might be useful for calculating groundwater recharge of Lake Tahoe, and to assess runoff processes. At one selected lake site, monthly samples at 5 depths will be analyzed for O_2-$\delta^{18}O$ and DIC-$\delta^{13}C$ to provide baseline data on BOD status (per our current CalFed-funded study in the San Joaquin River).

Data Interpretation and Reporting: All data will be mapped in ARC-GIS and geostatistical models will be used for interpolation. We will estimate fluxes to and between various components of the ecosystem, including N-deposition, hydrologic transport, and ecosystem processing using existing Tahoe N-loading models, other ecosystem models, CMAQ, and other models. The work will enhance the understanding of the impacts of human activities, land management, and environmental policies on mitigating effects of accelerated N cycling in the basin ecosystems.

We anticipate significant collaboration in data collection and analysis between ongoing and proposed Lake Tahoe research projects, and hence will make our data accessible. We will write technical documents for specialists, produce draft summary reports targeted towards decision makers, and will collaborate in organizing scientific and policy forums to present data and interpretation to stakeholders and the general public. We will integrate our understanding of the N-cycle at the Tahoe Basin to address key management questions.

3. Key Management Questions:

This project proposes to collect isotope and chemical data and provide interpretation to help answer several of the key questions related to identifying the sources and magnitudes of dissolved and particulate N loads that affect lake clarity, air quality, and water quality:

1.1.1. *What and where are the sources of these pollutants and in what quantities and relative contributions are they entering Lake Tahoe?* The proposed research takes a multi-pronged approach to distinguishing sources and loads of nitrogenous species to Lake Tahoe. Both wet and dry deposition monitoring in the Bay area, the Central Valley, and in the Lake Tahoe Basin will be used to examine spatial and temporal patterns of isotopes in NO_3-, HNO_3, NO, NO_2, and NH_3. Coupled with direct isotopic analysis ($\delta^{15}N$, $\delta^{18}O$, $\delta^{17}O$) of emissions samples from major NOx sources, the results of this research will provide a means to "fingerprint" atmospheric N sources to Lake Tahoe. The use of a third isotope, $\delta^{17}O$, greatly enhances our ability to assess the contribution and ultimately the cycling of atmospheric N to the Lake Tahoe watershed. These

isotopic data will provide the foundation for geographic-based modeling efforts that will assess watershed loadings from various N sources.

1.1.2. *What is the linkage of human disturbance and nutrient loading to Lake Tahoe?* Several possibly important N loads are influenced by human disturbance. In specific, we will quantify N loads from local smoke, dust, and vehicle emissions; groundwater affected by fertilizer and old sewage; and external atmospheric N from agricultural and urban sources to Lake Tahoe.

1.1.7. *What spatial and temporal factors affect the deposition of air pollutants to the lake and forest, and ultimately how do these pollutants contribute to lake clarity reduction?* By monitoring both wet and dry deposition at numerous sites around the Tahoe Basin, we will directly measure potential deposition inputs. The roadside studies with ecosystem (tree rings, soil, and foliage) measurements will provide an estimate of vegetation and soil uptake rates. The CMAQ model explicitly uses meteorology and chemistry and deposition dynamics to track the factors that drive deposition.

1.1.8. *What are the specific sources that contribute to atmospheric deposition of nutrients and sediment to the surface of Lake Tahoe?* This research will characterize the isotopic composition of major NOx and ammonium sources to Lake Tahoe, including from roadsides, tailpipes, campfires, and chimney exhaust. Isotopic analysis of stream POM samples will provide sediment source information.

1.1.9. *How are air-borne pollutants transported and distributed throughout the basin?* The dense passive sampling network in the basin will provide details on transport and chemical transformations. Primary emissions such as NO and NH_3 rapidly disperse away from roads and have fine-scale spatial patterns. NO_2 is intermediate, and HNO_3 and N-particulates show regional scale gradients. The 4km CMAQ model provides enough spatial resolution to capture local transport and chemical transformation patterns, and will complement the existing LTAM efforts.

1.1.10. *What is the fate of air pollution produced in the basin?* This research uses multiple isotope tracers of wet and dry atmospheric deposition to trace the transfer and cycling of nitrogenous species through the various watershed components of Lake Tahoe, including: deposition to road surfaces and in snowpacks, and the transfer of nitrate to the Lake via snowmelt, storm runoff, streamflow, and groundwater. The ultimate contribution of atmospheric deposited N to the Lake ecosystem will be assessed by analyzing isotopes in lake water nitrate, POM, DOM, and colloids. In addition, the assimilation of NOx emissions by trees will be evaluated using a survey of $\delta^{15}N$ isotopes in tree rings from several strategic transects. The CMAQ model will provide regional scale views of transport out of the basin.

1.1.11. *What is the relative contribution of in-basin versus out of basin pollutant sources at Lake Tahoe?* In addition to monitoring the temporal and spatial variability in the isotopic composition of local smoke and vehicle emissions and in wet and dry deposition in the Tahoe region, this research will extend deposition monitoring over a large potential source area, including the Bay area and Central Valley. Monitoring the spatial and temporal patterns over this large area will illuminate how pollutant sources can change seasonally within each region and how seasonal atmospheric transport patterns can variably affect N sources to Lake Tahoe. The CMAQ model provides a unique integration tool for regional-scale transport questions.

1.1.13. *What are the limnological, watershed and atmospheric processes that affect lake clarity and water quality?* Initial $\Delta^{17}O$ data ($\Delta^{17}O = \delta^{17}O - 0.52\ \delta^{18}O$) from Michalski show that there are temporal and spatial variations in the oxygen isotopes of Lake Tahoe nitrate. This is an indication of nitrification within the water column and the recycling of internal bioavailable N. The data indicate that up to 20% of the nitrate retains its atmospheric isotope signature. Because this signal is lost via uptake followed by nitrification, changes in $\Delta^{17}O$ over the course of the year are a marker of the rate of internal recycling of N. The initial 2003-04 study was designed to demonstrate the utility of $\Delta^{17}O$ for such purposes, and the expanded lake sampling proposed here is designed to understand the behavior of the entire system. Such data will enable hydrological modelers to determine the long-term fate of anthropogenic N inputs.

1.1.14. *What pollution is produced by vehicle emissions and from road surfaces and how do they affect lake clarity?* The production of NH_3 from vehicles is a major missing link in the emissions inventory. As part of this research effort, we will directly measure and determine the isotopic composition of NOx and NH_3 emissions from vehicle traffic along major thoroughfares in the Lake Tahoe area using annular denuders. In addition, this research will analyze isotopes in stormflow samples from at least 13 tributaries to Lake Tahoe. In particular, stormflow samples from tributaries

containing major roadways will reflect pollution deposited to road surfaces between events. These data, coupled with isotopic characterization of groundwater, snowmelt, and lake water will allow tracing of atmospheric N through the various components of the Lake Tahoe ecosystem. Ultimately, these isotope data will indicate the relative importance of different sources of atmospheric N in producing the algae that has reduced water clarity in Lake Tahoe.

Describe the anticipated project accomplishments

Completion of this project will provide an independent test of existing Tahoe N-loading models (LTAM) and other ecosystem models such as CMAQ. While emissions inventories average over long times and large areas, isotopic characterization of sources can be made at any temporal or spatial scale desired. This modeling framework will provide an integral tool for examining key processes at regional and local scales and ultimately for evaluation against empirical isotope data. The project will provide managers with data that can be used to defend land-use and pollution mitigation decisions for watersheds that contribute N to Lake Tahoe. Other specific task accomplishments are below:

Task 1. Coordinate and integrate with related projects. Because most of the sampling in this project piggybacks on routine monitoring programs conducted by the USGS, USFS, TRG, and NADP, the isotope data produced are directly relevant to the agencies collecting the samples. All these groups are primarily using monthly or event-based data on chemical concentrations to describe spatial and temporal patterns in nitrate and ammonium loads to the environment. While nutrient **isotopic** measurements are a relatively common tool in eutrophic environments or ones affected by acid rain, they have not been much applied to sensitive oligotrophic environments like the Tahoe Basin because the low N concentrations made the samples extremely difficult to analyze. However, with the development of new nitrate methods that require little nitrate, it is now easy to archive small samples (20-50 ml) for later analysis. Therefore, since this study piggybacks on routine monitoring programs, the data produced will provide the respective agencies with a direct test of the potential usefulness of isotopic characterization techniques to their monitoring programs in the Tahoe Basin.

Tasks 2-12. Sample collection and analysis. These tasks will provide high quality data that will be used in models and in combination with land use and emissions inventories to estimate the contributions of N from various internal and external sources to Lake Tahoe. These tasks provide a holistic approach so that all the likely sources, and the variables that affect seasonal and spatial changes in the sources, will be evaluated and accounted for. Uncertainty about atmospheric loadings to Lake Tahoe will be reduced because nitrate derived from tropospheric sources has a characteristic $\delta^{17}O$ (and to a lesser degree $\delta^{18}O$) signature. Uncertainty about the relative contributions from internal emissions sources will be reduced because this study will add considerably to the body of knowledge of the effect of local emission sources such as vehicle exhaust and smoke on forests and air quality. Although ammonia emissions have become a significant source of atmospheric NH_3 since the introduction of three-way catalytic converters in the 1990's and are also a major precursor to PM (especially NH_4NO_3), they has not received much attention in emissions inventories. Preliminary results indicate that vehicular NH_3 has a high $\delta^{15}N$ signature that is distinctive relative to agricultural and natural sources. Uncertainty about groundwater contributions to Lake Tahoe will be reduced isotopic characterization of the nitrate in groundwater in different watersheds, and by monitoring changes in nitrate and water isotopic signatures during periods of lake stratification.

Task 13. Interpret data and produce reports. All data will be mapped in ARC-GIS and geostatistical models will be used for interpolation. Empirical results will be compared to modeled estimates from LTAM and CMAQ. Deliverables from the project will include: (1) annual reports detailing the project progress and preliminary results, (2) a final comprehensive report on the studies findings at the end of the three-year project, (3) publication of the results of the study in appropriate peer-reviewed journals, (4) all data sets generated by the project including chemistry, isotopes, and modeling results, and (5) team members will make presentations about the study and results at local stakeholder meetings.

Task 14. Integrate our understanding of the N-cycle at the Tahoe Basin to address key management questions. The proposed study will provide quantitative evaluations of fluxes and isotopic signatures of key nitrogen sources and pathways, and the spatial and temporal variability in the magnitude of their impacts on the ecosystem. Only then will policymakers be able to judge the relative effectiveness of various source control and mitigation strategies to reduce N-loadings.

Describe the "readiness" of this project to move forward.

Our project is ready to move forward immediately. We intend to collaborate closely with USGS, UCD/TRG, USDA, UNV/DRI, and others on field sampling, sample processing, and analysis. This collaboration includes isotope analysis of samples collected as part of proposals by Alpers, Bergamaschi, Fenn, Edwards, and several USGS monitoring proposals. We have identified a strong, interdisciplinary team of collaborators, and this project would provide us with the opportunity to work together to combine our various hypotheses and methods of probing the N cycle.

We began collecting and analyzing samples from a few basin sites in 2003. Michalski has been analyzing nitrate-$\delta^{17}O$ for several years. We can start analyzing most isotope samples immediately at the MPSIL because we have considerable analytical capacity and years of experience with most of the methods described above. In specific, for several years we have been analyzing 50-100 nanomole nitrate samples for $\delta^{18}O$-$\delta^{15}N$ (using the microbial method), DOM and POM for $\delta^{15}N$-$\delta^{13}C$, and high concentration-ammonium samples for $\delta^{15}N$. However, small ammonium samples (<1 umole N) will need to be archived until a suitable method is developed, our version of a nitrate $\delta^{17}O$ method is still being tested, and we have limited experience with the new microbial DON-$\delta^{15}N$ method.

Describe potential partnerships for this project.

We have assembled an impressive team of experts on Tahoe environmental issues, field studies, N emissions, and isotope hydrochemistry. The project will be a collaborative effort involving several USGS offices, the USFS, the Tahoe Research Group, the UNV, several UC campuses, and scientists at environmental consulting groups. The general contributions of each group are described below.

USGS/WRD, National Research Program, Menlo Park, CA (Carol Kendall, Cecily Chang, Emily Elliott, Scott Wankel) – Project management, project design, coordination and integration of team members and sampling efforts, methods development, analysis of most of the isotope samples, data interpretation, and reporting.

USDA/USFS, Riverside, CA (Pam Padgett, Andrzej Bytnerowicz, Mark Fenn) – Maintenance and sampling of dry deposition using passive collectors and denuders, sampling of wet deposition using resin collectors and snowcores, analysis, data interpretation, LTAM, and reporting.

USGS/WRD, Nevada District, Carson City, CA (Tim Rowe, Kip Allander, Michael Rosen, Nancy Alvarez, Mike Lico) – Assistance with getting us splits of samples (collected from tributaries, groundwaters, precipitation, and small lakes), data interpretation, and reporting.

USGS/WRD, California District, Sacramento, CA (Charlie Alpers, Brian Bergamaschi) – Sampling, splits of Lake Tahoe samples, data interpretation, and reporting.

TRG, UC Davis, Davis, CA (John Reuter and colleagues) – Assistance with lake water sampling, data interpretation, and reporting.

UCSD, San Diego, CA (Greg Michalski, Mark Thiemens) – Project design, assist in lake water collections, analysis of isotope samples, testing our new nitrate-$\delta^{17}O$ method by comparison with his method, data interpretation, and reporting.

UNV/DRI, Reno, NV (Jim Thomas, Alan Gertler, Ross Edwards) – Assistance with obtaining various samples (runoff, snowpack, and groundwaters), collection of vehicle exhaust samples near major roads, data interpretation, reporting.

UCB, Berkeley, CA (Beth Boyer; starting at UCB in January) – Assistance with cross-comparisons with UC Sierran watersheds, watershed N modeling, data interpretation, and reporting.

EPRI, Palo Alto, CA (Rick Carlton) – Assistance with emission inventories and obtaining samples.

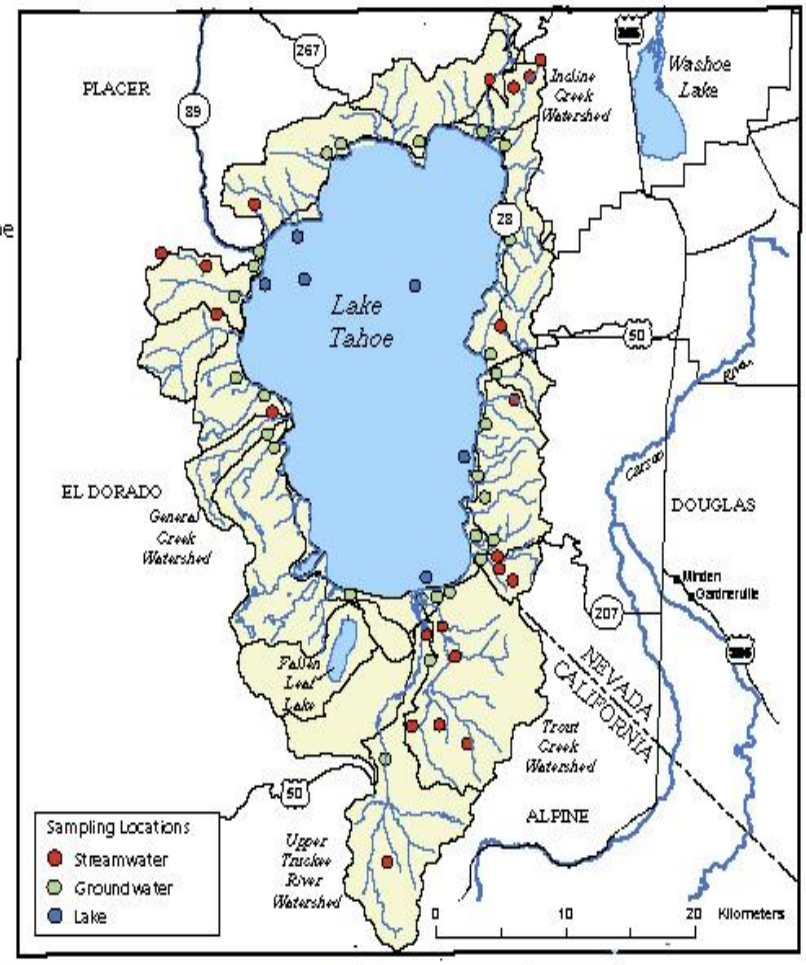
Stuart Weiss (environmental consultant) – Project design, Bay area and Tahoe Basin dry deposition samples, emissions inventories, data interpretation, CMAQ modeling, and reporting.

For Science & Research Projects describe how this project will guide future management activities.

An improved understanding of the sources and pathways of nitrate and ammonium to the basin -- entering as wet and dry deposition, tributaries, groundwater, and local emissions – will help the management of these key nutrients. In specific, the data will help in understanding nutrient cycling within Lake Tahoe, the extent of potential contamination from runoff and groundwaters from land uses with elevated N levels from fertilizer and/or old sewage, and the relative contributions of different types of within-basin and external sources of atmospheric N. Small changes in the magnitude and timing of N inputs of various kinds and sources could occur as a result of changes in land use (e.g., urbanization), altered runoff patterns, and climate changes. The data collected as part of this project would help in the development of models of the impacts of different scenarios on algal production and water clarity in Lake Tahoe. The ability of local ecosystems to filter, store, and transform N can prevent or enhance delivery to the lake itself, and land management decisions can be assessed for N-related impacts. Management options to reduce key sources can be assessed in terms of quantitative impacts on N-loading, and compared with costs.

Because of the comprehensive isotopic and chemical characterization of temporal and spatial variability in N sources planned in this proposal, funding requirements rapidly escalated well beyond our original budget to the point that we had to eliminate plans for the kind of extensive watershed N modeling of the data that we are doing for our large NY-funded N isotope study (PIs: Kendall, Burns, Boyer, Elliott, Carlton, & Michalski). However, this type of spatial modeling of watershed N fluxes is needed to take maximum advantage of all the data we will be generating in the Tahoe Basin. Once the project starts, we hope to submit a follow-up proposal that will integrate the data collected with a series of modeling approaches (led by E.W.Boyer). For example, we will make use of the knowledge gained about the spatial distribution of atmospheric N (and its precursor sources) to conduct high-resolution spatially referenced regression modeling. This will allow us to consider the role of atmospheric N deposition and to quantify total N fluxes in watersheds in the basin, providing estimates of incremental (local) N yields to each stream reach and total yields delivered downstream to Lake Tahoe. Simulations will provide information about the role of delivery of atmospheric N from the terrestrial landscape to surface waters, and the role of in-stream processing in altering N loads during transport. Further, we will use a mechanistic watershed modeling approach using the USGS modular modeling system and a nitrogen module currently being developed by Boyer (personal communication). Simulations will provide a spatially explicit template for exploring flow paths of water, the associated transport of N species, and transformations of N along flow paths (such as denitrification in riparian zones, in tributaries, and in the lake). Co-investigator Boyer has extensive experience using these hydrological modeling approaches (e.g., Boyer et al. 2002, Biogeo. 57: 137-169) which will provide a uniform framework for interpreting atmospheric inputs and their fate within the Lake Tahoe region.

Figure 1:
Proposed Lake Tahoe water sampling locations, including streamwater, groundwater, and lake sampling sites.



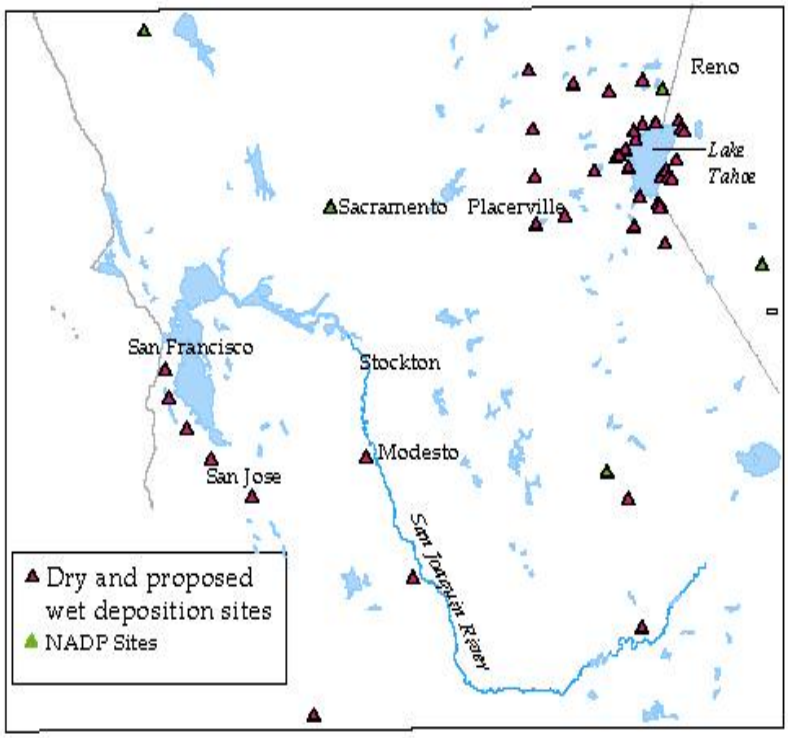


Figure 2:
Cross-section of proposed dry and wet deposition sampling locations from the San Francisco Bay area to Lake Tahoe.