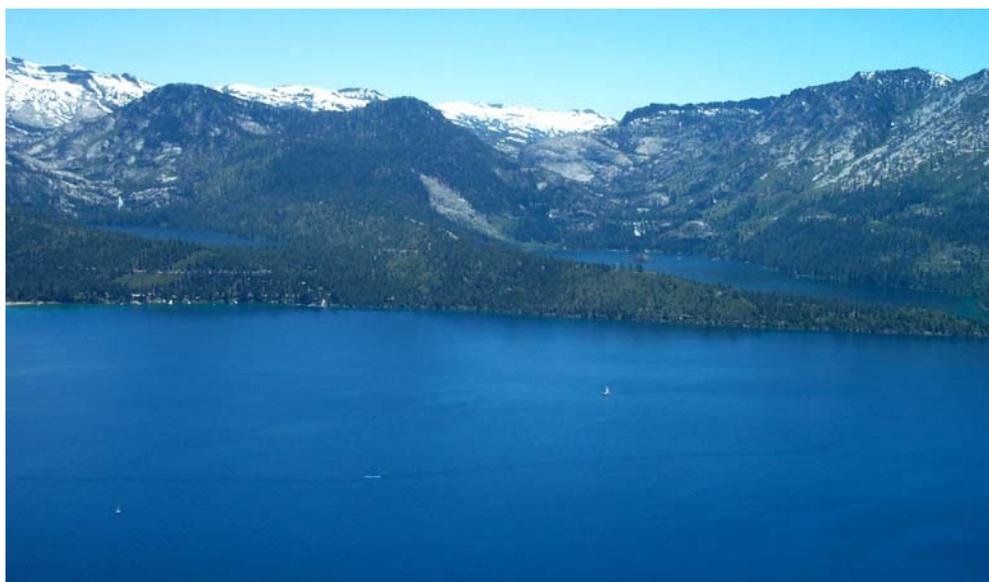


**Work Plan
for the
Lake Tahoe Atmospheric Deposition Study
(LTADS)**



JUNE 10, 2002

CALIFORNIA ENVIRONMENTAL PROTECTION AGENCY



AIR RESOURCES BOARD

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**WORK PLAN
For the
Lake Tahoe Atmospheric Deposition Study
(LTADS)**

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ABSTRACT

Atmospheric deposition is a potentially important, though poorly characterized, mechanism for the addition of nutrients and materials to a watershed. This is particularly true for a popular place such as Lake Tahoe, which is at high elevation, ringed by mountains, and generally downwind of major urban centers. Year-round activities attract a significant number of visitors and support a local population of several tens of thousands. Although the Lake is on the lee side of the Sierra Nevada, it is generally downwind of the San Francisco Bay Area and the greater Sacramento urban area. Because the clarity of this pristine alpine lake has declined significantly since monitoring began in the 1960s, the Tahoe Regional Planning Agency (TRPA) and the Lahontan Regional Water Quality Control Board (LRWQCB) have been tasked with identifying and characterizing the cause(s) of the accelerated eutrophication of Lake Tahoe. It is believed that phosphorus and nitrogen, respectively, are the two main nutrients contributing to the growth of algae and an associated decline in Tahoe's water clarity. Furthermore, particles in the water can scatter light, thereby reducing water clarity. These nutrients and particles can enter and affect the Lake via direct atmospheric deposition, direct runoff of precipitation and snowmelt, stream runoff, shoreline erosion, and underground migration of materials.

The California Air Resources Board (CARB) proposes to apply a hybrid approach to study air quality and atmospheric deposition in the Tahoe Basin. This approach will include direct measurement of important pollutant species, meteorological conditions, and source-specific emissions; the construction of a basin-specific emission inventory; the use of a variety of data analysis techniques to elucidate the atmospheric processes and to reduce the assumptions necessary when extrapolating measurements at, and calculations for, specific locations to the Basin; the adaptation of mechanistic models to extrapolate those measurements into basin-wide deposition calculations; and the application of a chemical mass balance model for additional source-apportionment.

The ambient measurement effort (collection and analysis), the models, and the basin emission inventory are complementary efforts that can effectively address the relative contributions of various factors to declining water clarity and forest health. Initial seasonal estimates and measurements of deposition will be supplemented later by modeling efforts. The photochemical model will enable the joining of long-range transport and local emissions into a single, source-aware analytical framework. The measurement program will serve both to refine model inputs (especially meteorology) and to calibrate and evaluate the model's performance (air quality and deposition). Specialized source-oriented field measurements will also be used, in conjunction with the model and source-apportionment studies, to validate and refine the emission inventory.

Using the refined air quality model based on improved characterizations of Basin-specific meteorology and emissions, modelers will be able to project basin air quality and deposition impacts under a range of conditions and hypothetical emission control scenarios. Such simulations will enable the basin's regulators (i.e., TRPA and RWQCB)

to determine what categories of emission reductions will be most effective, and least costly, to reach the goals of stabilizing and restoring the Lake's water clarity, and also preserving the basin's air quality and forest health.

EXECUTIVE SUMMARY

The Lake Tahoe Basin (comprised of the Lake and the mountain basin it is set in) is world famous for its picturesque beauty. From serving as a summer home for the Washoe Indians, to supplying the lumber needs of the silver mining rush in the late 1800s, to serving as a summer playground, to hosting the world at the 1960 Winter Olympics, to providing year-round entertainment and recreational opportunities, this pristine environment has increasingly been subjected to the impacts of the humans benefiting from it. Routine measurements of the Lake's clarity since the late-1960s document a shocking decline from 100 feet of visibility depth to less than 70 feet in three decades – a loss of one foot per year! One of the environmental thresholds that the Tahoe Regional Planning Agency (TRPA) has adopted to help preserve this national environmental treasure is water transparency or water clarity. The State of California's Lahontan Regional Water Quality Control Board (LRWQCB) and the State of Nevada's Department of Environmental Protection (NDEP) are developing a Total Maximum Daily Loading (TMDL) to establish the amount of material that can enter Lake Tahoe without violating the environmental threshold for water clarity (1970/71 level or 92 feet).

To assist in the development of the water clarity TMDL for Lake Tahoe, the State of California's Air Resources Board is investigating the contribution of atmospheric sources of materials contributing to the water clarity decline. The primary objective of the Lake Tahoe Atmospheric Deposition Study (LTADS) is better quantification of the atmospheric deposition of particulate matter (PM) and algal nutrients (phosphorus and nitrogen) to the Lake Tahoe Basin. The nutrients can be deposited as gases, particles, or soluble ions in rain and snow. LTADS will address the relative contribution of local (within basin) and regional (transport into the basin) sources of PM, gases that can be precursors to secondary PM, and biotic nutrients. A component of LTADS will also investigate the distribution of ozone concentrations and this pollutant's impact on the health of Tahoe's pine forest. The specific informational needs of the LRWQCB, NDEP, and TRPA that LTADS will address are: 1) improved estimates of the annual and seasonal loading of phosphorus, nitrogen, and particulate matter from atmospheric deposition to Lake Tahoe and its watershed, 2) improved attribution of the in-basin and out-of-basin sources (categories) of these materials, 3) assessment of the effects of control programs already in place and potential future regulations to further reduce the atmospheric loading, 4) assessment of the effect of ozone concentrations on forest health, and 5) the confidence levels associated with these estimates and assessments.

The work plan, interim reports/calculations/estimates, and the final report for LTADS will be subjected to peer review, in phases, by five experts in the University of California system, by the Tahoe Basin Scientific Advisory Group, and by other interested research groups and study participants to ensure that the efforts are comprehensive, coordinated, and yield pertinent results within the context of the available resources and short timeline for guiding control strategies.

The major issues LTADS seeks to address in a scientific and cost-effective manner are briefly summarized below.

First, what are the amounts of nutrients and PM being deposited directly from the atmosphere to Lake Tahoe and its watershed and how does the deposition vary during the year? To address this question, CARB is enhancing the current monitoring network, both in terms of location and equipment. Because deposition is the integral of concentration, deposition velocity, and contact time, the ideal sampling strategy is to collect hourly concentration and meteorology data throughout the year with sufficient spatial density to characterize the spatial variations. The total deposition would simply be the spatially-weighted sum of the hourly deposition calculations. Obviously, the cost of such a monitoring program would be prohibitive.

To work within the constraints of available funding, adopted the following priorities and measurement strategies. The highest priority is to quantify the atmospheric deposition to Lake Tahoe to help the Lahontan RWCQB set the water clarity TMDL through the Lake response model. Interrelated to the setting of the TMDL is the reassessment of environmental thresholds by TRPA and the setting of thresholds compatible with the TMDL. The second priority is to determine and quantify the general source categories responsible for the atmospheric deposition. Better understanding of these categories is needed by Lahontan and TRPA to guide the development of general planning strategies and planning documents. The third and lowest priority is to resolve the individual sources of deposition. The potential deferral of the identification of individual sources of deposition is consistent with the "adaptive management" model for basin management as outlined in the USFS/USGS Lake Tahoe Watershed Assessment. Until the relative contributions of major source categories are known, it is not possible to properly prioritize detailed source resolution research.

The backbone of the particulate monitoring network will be the Two-Week-Sampler (TWS) in general conjunction with Beta Attenuation Monitors (BAM) which provide hourly data. The TWS will provide two-week integrated samples of ammonia, nitric acid, PM_{2.5}, PM₁₀, and TSP. By continuously sampling throughout the year, sampling will not only capture pollutants associated with common emission sources (e.g., chimney smoke, vehicle exhaust, road dust) but also those associated with sporadic emission sources (e.g., wind blown dust, wild fire smoke). One hundred percent of all three sizes will be gravimetrically analyzed for total mass (concentration). To reduce laboratory costs associated with analysis of very low concentrations, samples representing the highest total concentrations at each site during each quarter (3 months; i.e., top 70% or 4-5 samples out of 6-7 samples per quarter) will be analyzed in the laboratory for chemical composition. The unanalyzed filters will be stored for potential future analysis. The compositional information is necessary for quantifying P and N deposition and for conducting complex data analyses (e.g., principle component analysis, PCA; chemical mass balance, CMB, modeling) to identify the relative contributions of different source categories.

Time-and size-resolved ambient concentrations will be combined with continuous meteorological data to refine estimates of the temporal variations in deposition amounts and origins. In addition to surface meteorological sites, three mini-sodar sites will be

located around the Lake to enable refined estimates of the convergence and divergence of air flows over the Lake. In addition to characterizing conditions around the Lake, measurements near the upwind boundary of the Basin will characterize the composition and frequency of air being transported to the Tahoe Basin. Measurements on buoys and a research vessel on the Lake will help characterize horizontal variations in conditions on the Lake.

Estimates of N deposition during summer will first be available in the fall of 2003 via photochemical modeling associated with the Central California Ozone Study (CCOS). Estimates of P and PM deposition during the fall and winter will first be available in the summer and fall of 2003 based on data analysis of the Tahoe field study. Modeled P and PM results based on the California Regional Particulate Air Quality Study (CRPAQS) will not be available until the summer of 2004. In general, most of the initial deposition estimates will be based on calculations based on the field study data and will occur 6-9 months after the data were collected. Thus, full seasonal characterization of the deposition will not occur until mid-2004 and modeling work will not be completed until late 2004 or 2005.

Second, what types of activities or sources produce these materials? A major effort of LTADS is to refine the current emission estimates for the Tahoe Basin by collecting Tahoe-specific source profiles and activity data. The focus of the efforts will be on motor vehicles, road dust, road sanding/salting during winter, wood smoke from fireplaces and stoves, and prescribed fires. Various data analyses including PCA and CMB modeling will yield insights into the major contributors to the materials observed in the air.

Third, what proportion of the deposition is produced locally (i.e., within the Tahoe Basin) and what is due to transport from upwind source regions? The relative contribution of local and upwind sources likely varies by compound and season. The local (intra-basin) versus regional (extra-basin) contributions will be addressed via air parcel trajectory analyses, exercising of validated airshed modeling, emission inventory analysis, and other data analyses. The limited number of previous examinations indicate that transport from upwind regions in California can be significant during summer, less frequent during spring and fall, and is probably negligible during winter. Furthermore, transport of dust from Asia can be significant during the spring. To document the quality of the air entering the Tahoe Basin and to establish the background concentrations upon which local emissions are added, a full monitoring site near the Sierra crest and distant from significant local emissions is needed. Analysis of the meteorological and air quality data from this site and other sites in the region will help elucidate the frequency of transport to the Tahoe Basin. An additional, but more difficult, link to document is the frequency with which the transported air is mixed with air inside the Basin and the magnitude to which it impacts air quality at the Lake and ground level.

Fourth, what insights can be provided as to where efforts need to be focused to effectively reduce the amount of deposition (e.g., what has been the effect, or what is the potential effect, of any additional local or regional actions to reduce deposition)?

Data analysis of the refined emission inventory (e.g., source strength, diurnal activity cycle), the size distribution and proximity to the Lake, and the typical corresponding wind patterns will be used to identify relative source strengths but also relative source contributions. Reasonable changes in source profiles and emission activities will be considered to estimate the potential changes and potential impacts. After a photochemical model has been validated for the Basin, the model can be exercised to estimate the impacts of potential emission reductions under a limited number of meteorological conditions.

Fifth, what is the current status and trend of ozone concentrations in the Tahoe Basin and how has the health of the forest changed? The ozone monitoring network has been stable for a few years and some limited trending of concentrations will be possible for locations within and upwind of the Tahoe Basin. Furthermore, forest health assessment studies have been conducted about every five years recently and significant changes in conditions can be observed. The LTADS effort calls for 32 passive ozone samplers in 24 forest plots to assess ozone conditions and forest health. Furthermore, additional information on nitric acid concentrations in the forest may be available from another contemporaneous study.

Finally, what levels of confidence can be associated with the various estimates of emissions, meteorological scenarios, transport, deposition, modeling, etc.? Best estimates and upper & lower bounds will be provided with each type of estimate. Individual estimate methods may have rather large uncertainties but it is anticipated that the use of multiple approaches will provide corroborating results and improve the confidence in the central estimates. It is impossible *a priori* to specify the confidence levels in the final results. The confidence level will depend on a variety of factors including: the performance evaluation of the various meteorological and air quality modeling efforts, the spatial homogeneity in conditions observed around the Lake, how well conditions (emissions, meteorology, air quality, etc.) during the field study represent typical conditions (i.e., historical context), and so forth.

In addition to these major issues, many additional issues and uncertainties will need to be addressed. For example, although air quality modeling efforts will provide estimates of the amount of materials being deposited around the Tahoe Basin, additional modeling and analytical efforts will be needed to characterize what part of that material actually makes it into Lake Tahoe. Furthermore, what is the fate of particles directly deposited to the Lake? Do they sink, flocculate, ionize, break into smaller particles, etc.? These are not questions that LTADS will be able to address. Some of the additional issues to be addressed by LTADS are listed below by general categories.

Emissions

- 1) How do motor vehicle emission factors at Lake Tahoe differ from standard settings because of the large proportion of tourist vehicles operating at high altitude?
- 2) How do motor vehicle activity patterns at Tahoe differ from standard settings (e.g., different diurnal, day of week, and seasonal patterns)?

- 3) How do special emission sources (e.g., road sanding, wood burning) impact air quality and depositions?
- 4) What source categories contribute significantly to declining water clarity?

Meteorology

- 1) How do meso-scale meteorological processes (e.g., up-slope/down-slope air flow patterns) influence air quality and deposition?
- 2) How does air flowing over the Sierra Nevada interact with air inside the Tahoe Basin?

Air Quality

- 1) How does air quality vary, temporally and spatially, within the Tahoe Basin?
- 2) With Tahoe having clean air relative to most urban areas, will the measurement methods have appropriate levels of detection to ensure that most measurements are above the LODs?
- 3) What are the background concentrations of material entering the Tahoe Basin and what are the seasonal variations?

Deposition

- 1) How do the various dry deposition measurement methods compare?
- 2) How do concentrations (& deposition) vary near the shore and over the Lake?

The goal of LTADS is to support the environmental information needs of the LRWQCB, TRPA, USDA/USFS, and ARB in a cost-effective and timely manner.

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Glossary of Terms and Abbreviations

INTRODUCTION

1.1 BACKGROUND

1.1.1 Setting

Lake Tahoe is a beautiful lake ringed by mountains. The lake surface covers 191 square miles and is at an elevation of 6225 feet (MSL). The average water depth is 1000 feet and the maximum depth is 1645 feet, making it the 2nd deepest lake in the U.S. and the 10th deepest in the world. This unique alpine lake is world-renowned for its rich blue color. The unique color of the lake is due to its high altitude and pristine water clarity. Objects more than 100 feet deep could be seen through the water. The water clarity is so good because 40% of the precipitation within the Lake Tahoe watershed falls directly on the Lake; furthermore, the remaining precipitation in the basin drains through granitic soil, which is relatively nutrient sterile and filters material.

However, the water clarity of this once pristine lake, with 63 tributaries draining into and only one draining out of the Lake, has been declining (see Figure 1). Between the mid-1960s and the mid-1990s, the water clarity has decreased from 100 feet to 65 feet, a decrease averaging over one foot per year! Data for recent years suggest an improvement but additional study is needed to clearly understand the factors impacting water clarity and to ensure environmental thresholds are attained. Increasing inputs of biologically accessible forms of phosphorus (P) and nitrogen (N) cause algal growth in the Lake which is a major factor in the decline of water clarity. The sources of these elements that enter the Lake are not well known. Water runoff containing fertilizers, seepage of contaminated groundwater into the Lake, and direct atmospheric deposition are likely contributors to the phosphorus and nitrogen loading of Lake Tahoe. Initial estimates indicate that about half of the total N loading and one-quarter of the P loading to the Lake enters via atmospheric deposition (Table 1). Direct atmospheric deposition of particulate matter (PM) may be the primary factor reducing water clarity. Likely sources of nutrients, PM, and gases that can convert to PM include smoke from planned and unplanned vegetative fires, wood stoves, and fireplaces; vehicle exhaust, roadway dust (e.g., dirt, sanding material), and transport from regional sources.

The focus of this study is better quantification of the direct atmospheric deposition of nutrients (P & N) and particulate matter. The nutrients can be deposited as gases, particles, or soluble ions in rain and snow. The study will also address the relative contribution of local (within basin) and regional (transport into the basin) sources of nutrients and PM. This study will also provide information on the atmospheric deposition to the Lake Tahoe watershed where runoff from rain storms and snow melt contribute to the P & N loading of the Lake. The specific informational needs of the Lahontan Regional Water Quality Control Board (LRWQCB) and the Tahoe Regional Planning Agency (TRPA) are: 1) improved estimates of the annual and seasonal loading of phosphorus, nitrogen, and particulate matter from atmospheric deposition to Lake Tahoe and its watershed, 2) improved attribution of the in-basin and out-of-basin sources (categories) of these materials, 3) assessment of the effects of control programs already in place and potential future regulations to further reduce the loading,

4) assessment of the effect of ozone concentrations on forest health, and 5) the confidence levels associated with these estimates and assessments.

Table 1. Annual nutrient loading to Lake Tahoe (metric tons).

INPUTS	NITROGEN	PHOSPHORUS
Atmospheric Deposition	233.9 (56%)	12.4 (26%)
Stream Loading	81.6 (19%)	13.3 (28%)
Direct Runoff	41.8 (10%)	15.5 (33%)
Groundwater	60 (14%)	4 (8%)
Shoreline Erosion	1.8 (<1%)	2 (4%)
TOTAL	419.1 (100%)	47.2 (100%)

Sources: Murphy and Knopp (2000); Adams and Minor (2000)

1.1.2 Environmental Improvement Program

In 1982, the Tahoe Regional Planning Agency (TRPA), in cooperation with the States of California and Nevada, federal government representatives, the scientific community and local stakeholders, established nine categories for the Lake Tahoe Region which are considered unique and desirable to sustain. These categories became known as “environmental thresholds” and are defined as the environmental standards necessary to maintain significant scenic, recreational, educational, scientific, or natural values of the Region or to maintain public health and safety within the Region. The categories are:

1. Water Quality
2. Soil Conservation
3. Air Quality (see Table 2 for listing)
4. Vegetation
5. Fisheries
6. Wildlife
7. Scenic Resources/Community Design
8. Recreation
9. Noise

In 1996, the TRPA determined that the majority of threshold indicators remained in non-attainment. In fact, some measures, such as water clarity, have declined at an alarming rate (Figure 1). In response to these findings, the Environmental Improvement Program (EIP) was developed to identify restoration activities that are intended to reverse environmental decline and increase the pace at which environmental thresholds are attained. The EIP is a dynamic process containing several components including capital projects, research/science, program support, operations, and maintenance. The coordination of these components and the subsequent information enables a

comprehensive strategy for restoration and improvements in the Tahoe Basin. The EIP strategy builds upon the regulatory and capital improvement programs that have been underway for more than ten years. This strategy is designed to achieve, maintain or surpass the environmental goals and develop a more integrated and proactive approach to environmental management. Partnerships with all stakeholders, including the private sector and the various local, state, and federal agencies, will be the key to the success of this strategy. Table 3 is a summary of the air quality improvement that has occurred in the Tahoe basin during the last two decades. As shown, CO concentrations have declined over 80% and now meet the TRPA-established air quality threshold. Ozone concentrations have declined much more slowly but are approaching the established threshold for ozone.

Table 2. TRPA-adopted air quality thresholds.

AQ-1	Carbon Monoxide	6.0 ppm for 8-hr avg.
AQ-2	Ozone	0.08 ppm for 1-hr avg.
AQ-3	PM10	
AQ-4	Visibility: Regional	171 km, 50% of the year 97 km, 90% of the year
AQ-4	Visibility: Sub-Regional	87 km, 50% of the year 26 km, 90% of the year
AQ-5	Highway 50 Traffic Volume	7% Reduction From 1981 Levels
AQ-6	Wood Smoke	15% Reduction From 1981 Levels
AQ-7	Vehicle Miles Traveled	10% Reduction From 1981 Levels
AQ-8	Atmospheric Nutrient Loading	20% Reduction From 1981 Levels

Table 3. Air quality change (1980 – 2000)

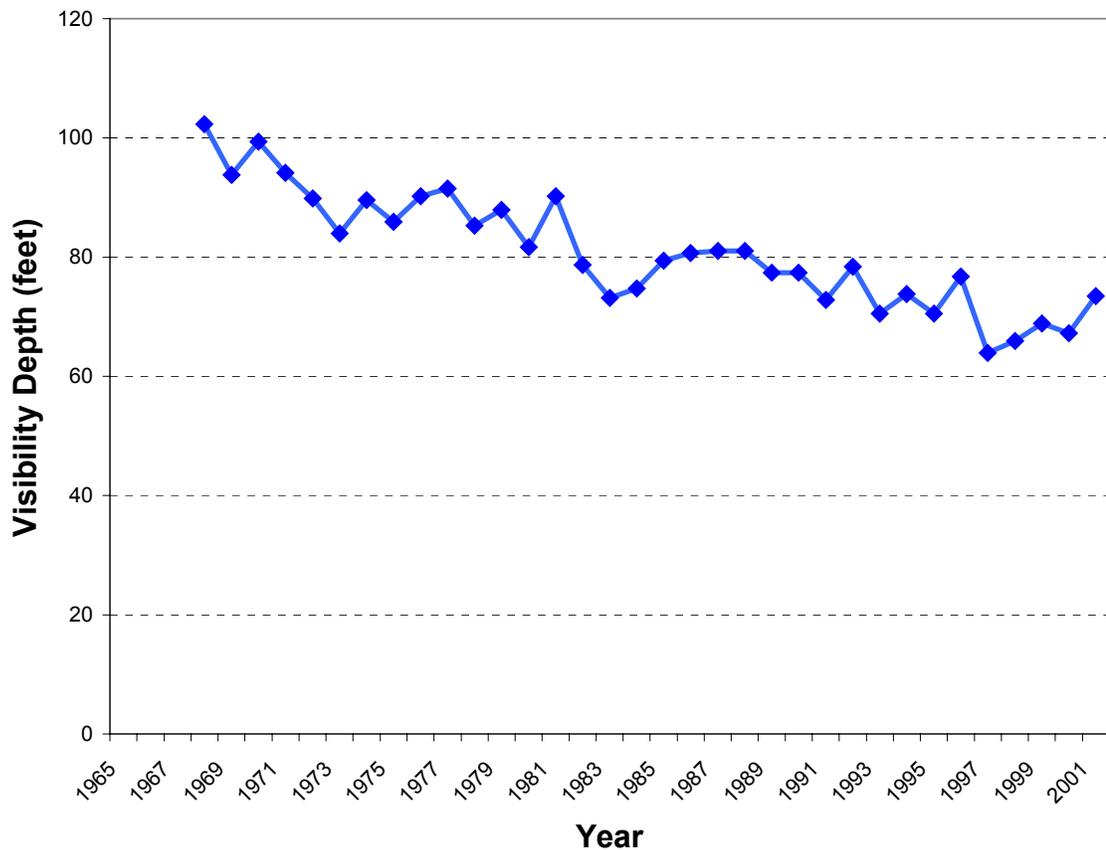
Pollutant	1980	2000	Δ (%)
CO (8-hr, ppm)	13.7	2.1	-85
O ₃ (1-hr, ppm)	0.089	0.089	0
NO ₂ (1-hr, ppm)	0.077	0.058	-25
NO ₂ (annual, ppm)	0.015	0.011	-27
PM10 (24-hr, µg/m ³)	95	50	-47
PM10 (annual, µg/m ³)	26.0	17.6	-32

The EIP is a 20-year plan that includes a budget of \$980 million in 1997 dollars. Funding for this program is provided from over 80 federal, state, local, and private sources. Table 4 outlines the original EIP commitment along with California’s proposed share in 1997 dollars.

Table 4. EIP commitments (in millions of 1997 dollars)

	Total EIP	California's Commitment
Capital Projects	908	275
Science	59	23
Continuous Program	12	8

Figure 1. Average winter water clarity (Secchi Depth) for Lake Tahoe.



1.1.3 Total Maximum Daily Load Concept for Water Clarity

A Total Maximum Daily Load, or TMDL, is a watershed-based tool for eliminating water quality impairments. A TMDL is the amount of a specific pollutant that a specific body of water can receive and maintain applicable water quality standards. TMDLs are the sum of the allowable loads of a single pollutant from all contributing point and non-point sources. They include a margin of safety and consider seasonal variations. They provide an analytical basis for planning and implementing pollution controls, land

management practices, and restoration projects needed to protect water quality. States are required to include approved TMDLs and associated implementation measures in State water quality management plans or basin plans. Because of this responsibility, each state, along with their associated territorial water quality agencies, is responsible for implementing the TMDL process. In California, Regional Water Resources Control Boards (WRCB) have developed "surface of water body" TMDLs. California's State WRCB, parent to the nine regional boards, committed to completing 100 TMDL programs statewide within five years. However, there are currently no court orders underway in the Lahontan Region.

The purpose of a TMDL is to identify and mitigate all significant stressors that cause, or threaten to cause, impairment of the uses of a water body. To this end, a TMDL :

1. Identifies Quality Limited Waters. Currently, California has over 1,500 water bodies on this list; seventy-five of those are in the Lahontan region.
2. Establishes Priority Waters and Watersheds. Lake Tahoe is considered a Priority Watershed.
3. Achieves water quality standards. A TMDL is a quantitative assessment of water quality problems, contributing sources, and load reductions or control actions needed to restore and protect individual water bodies.

A TMDL will determine the causes and extent of impairment. It creates a flexible assessment and planning framework for identifying load reductions or other actions needed to attain water quality standards. A typical TMDL will account for all individual waste load allocations for point and non-point sources, natural background pollutants, and an appropriate margin of safety.

Typical components of a TMDL include the following:

Problem Statement: A description of the waterbody/watershed setting, beneficial use impairments of concern, and pollutants or stressors causing the impairment.

Numeric Target(s): For each stressor addressed in the TMDL, appropriate measurable indicators and associated numeric target(s) based on numeric or narrative water quality standards which express the target or desired condition for designated beneficial uses of water. This is a critical juncture where questions need to be answered, such as:

- What are the water quality standards?
- Are numeric criteria already in place and are they relevant to the water body impairments?
- Can the numeric criteria be related to the pollutants and sources?

- What other relevant or supplementary indicators are appropriate?
- Does the indicator relate to the critical conditions of the water body?

Loading Capacity Estimate: An estimate of the assimilative capacity of the water body that assures attainment of the standards for the pollutant(s) of concern.

Source Analysis: Identifies the amount, timing, and origin of the pollutant. It includes point, non-point and natural sources. Each source is then evaluated to assess its contribution to the problem. Analytical tools are often used for this including Geographic Information System (GIS) overlays and models, and watershed landscape models.

Linkage Analysis: Establishes the cause-and-effect relationship between the selected targets and the identified pollution sources. This is the “heart” of the analytical discussion.

Load Allocations: Allocation of allowable loads or load reductions among different sources of concern. These allocations are usually expressed as waste load allocations to point sources and load allocations to non-point sources. Allocations can be expressed in terms of mass loads or other appropriate measures. The TMDL equals the sum of allocations and cannot exceed the loading capacity.

Margin of Safety: This is similar to all health and safety rulemaking. A margin of safety must be allowed. This is provided as part of the load allocated to account for uncertainties of models and analytical procedures used. This can be done explicitly, i.e., 10% below target, or implicitly through conservative assumptions.

Implementation Elements: Description of best management practices, point source controls or other actions necessary to implement TMDL. Usually a plan describing how and when necessary controls and restoration actions will be accomplished, and who is responsible for implementation. Other issues of the plan address waste discharge prohibitions; state/local laws, regulations, and ordinances; and local/regional watershed management programs.

Monitoring Plan: Plan to monitor effectiveness of TMDL and schedule for reviewing and (if necessary) revising TMDL and associated implementation elements.

Complete TMDL programs include implementation plans and require basin plan amendments. These amendments would comply with requirements of a scientific peer review, CEQA, public participation and approvals by the regional water board, SWRCB, Office of Administrative Law, and EPA.

The Tahoe TMDL will set “the number” for allowable loads, determine sources by category and general location, outline general options for load reductions, and give direction and act as the basis for all water quality related plans in the Basin (208 Plan, Forest Plan, etc.). This atmospheric deposition work plan supports the development of the Tahoe TMDL program by addressing critical informational needs regarding atmospheric deposition. The end products of the CARB program will include:

- 1) characterization and quantification (as well as possible within funding, timing, and technical constraints) of the N, P, & PM deposition to Lake Tahoe from the atmosphere (i.e., load and timing),
- 2) identification of the N, P, & PM sources (e.g., local vs. regional, categories, locations) and assessment of the potential to reduce N, P, & PM loading from those sources, and
- 3) recommendation of methods for achieving load reductions from those sources.

The LRWQCB timeline for the development of the Lake Tahoe TMDL calls for initial products by January 2004 and refined products by September 2004. Because the year-long field study will conclude in late summer of 2003 and data submittal, validation, and modeling take many months, preliminary results based on less sophisticated analyses are scheduled to be available in early 2004. Estimates based on more sophisticated approaches (e.g., emission inventory and modeling) might not be provided until late 2004 and the final results will not be reported until 2005.

1.1.4 Deposition Estimates

Understanding the impacts of air quality on nutrient loading of the Lake requires quantification of the deposition of both particles and gases under both wet and dry conditions. To be useful the estimates must be accompanied by a definition of their numerical uncertainty. The goal is to provide the rate of nutrient loading (total mass entering the lake surface per unit time, e.g., kg/month). But the rate of deposition to the Lake is highly variable by location, time of day, and season.

Particles and soluble gases are both removed by wet deposition. Compared to dry deposition, wet deposition is relatively easy to observe and quantify, subject only to the ability to measure the volume of precipitation and its chemical composition. Two obvious simple concerns are that 1) some methods and siting situations will not provide representative volume collection and 2) contamination of samples during collection must be considered.

On the other hand, dry deposition is difficult to measure directly. Specification by indirect methods is also complicated. Indirect methods relate the amount deposited to the observed concentrations, meteorological conditions, and surface characteristics. For quantification of dry deposition a suite of approaches is possible to provide redundant answers. Convergence of the results of seemingly redundant approaches is necessary to provide confidence in the results.

Some definitions are needed for meaningful discussion. The term deposition rate defines the nutrient loading at a specific location and time. Deposition rate has units of mass, area, and time, e.g., grams/m²/second. For a specific substance deposition rate divided by atmospheric concentration (i.e., deposition rate normalized for concentration) is defined as the deposition velocity. Thus, deposition velocity has units of velocity (distance/time; e.g., m/sec). However, the deposition velocity must be specified for a set of conditions. It is not unique to a substance and surface, because it is also highly dependent on meteorological conditions.

When considering large particles we can define a settling velocity, which is the rate of fall resulting from the balance between frictional and gravitational forces. Though deposition velocity and settling velocity both have units of velocity (e.g., cm/second) deposition velocity is **not** the equivalent of settling velocity. Thus a clear distinction should be made between the meanings and use of these two terms. Deposition rate changes in time and location because it depends on many factors, including the efficiency of the surface for removal of the substance of interest, the degree of meteorological mixing that either permits or denies surface contact for air originating from a particular height above ground level.

Deposition rates may be directly observed by the eddy covariance method if fast response (~10 measurements per second) instruments are available for chemical species of interest. Alternative direct observation is possible by eddy accumulation methods if slow response instruments are available that are capable of very accurately resolving small concentration differences (< 5% of the mean concentration). Similarly profile methods (measuring the difference in concentration at two elevations) can be employed without fast response instruments, but again the measurements must be capable of accurately characterizing very small differences in concentration. To calculate a deposition rate, measured vertical gradients of concentration must be accompanied by an estimate of eddy diffusivity (based upon measured or modeled meteorological parameters). A variant of the profile method is the Bowen ratio technique, which reduces one source of uncertainty by directly observing the eddy diffusivity. The vertical flux of heat or water vapor is measured directly and measured differences in concentration, temperature, and humidity at two heights are used to calculate the flux of the species of interest.

Results of studies of deposition to surrogate surfaces are frequently reported. However, because the controlling property of the uptake is determined either by the surface itself or the configuration of its exposure in the environment, surrogate surfaces can rarely provide reliable deposition data (Wesely and Hicks, 2000). The use of surrogate surfaces is a reasonable approach when gravitational settling is the principal mechanism of deposition (i.e., for large particles). However, the depositional mechanism of impaction and interception is important for vegetative canopies.

Observation (measurement) of deposition requires great care in site selection and choice of instrument heights. Spatial homogeneity of the surface over sufficient upwind fetch is essential. The best opportunity for direct measurements will be over water or at

the water's edge with onshore winds (airflow from the Lake toward land). For large bodies of water sufficient fetch is available for the development of breaking waves and spray. This is significant, because the presence of breaking waves and spray constitutes an entirely different regime for deposition as compared to a smooth water surface. (Jielun Sun, 2001 personal communication)

Deposition rates are highly variable between chemical species, with meteorological conditions. Thus they will be highly variable with time of day. For that reason, diurnal resolution of concentration and deposition rates is highly desirable. The Lake will provide some benefits to calculations. Lake Tahoe provides 1) a long upwind and spatially homogeneous fetch, 2) well-defined surface temperatures for contrast with air temperatures in calculation of stability, and 3) the opportunity to utilize the Bowen technique by measurement of water vapor.

The California Acid Deposition Monitoring Program (Watson et al., 1991) provided deposition estimates for a variety of locations in the state (Blanchard et al., 1996). A summary of dry deposition estimates of selected nitrogenous species during 1988-1992 (the most extensive part of the program) is shown in Figure 2. The results for Yosemite and Sequoia are most likely to represent the situation at Lake Tahoe because they are sites in the Sierra Nevada and include local effects as well as regional transport from upwind urban areas. At these two sites, the nitrogen deposition is primarily from nitric acid (HNO_3) and ammonia (NH_3) and totals less than 2 kilograms/hectare/year (about half of the deposition estimate shown in Table 1). The contribution of the various N species to the total N deposition is shown in Figure 3 and illustrates the relative significance of biological sources and transport in the Sierra Nevada.

Figure 2. Annual dry deposition rates of major nitrogenous species in California.

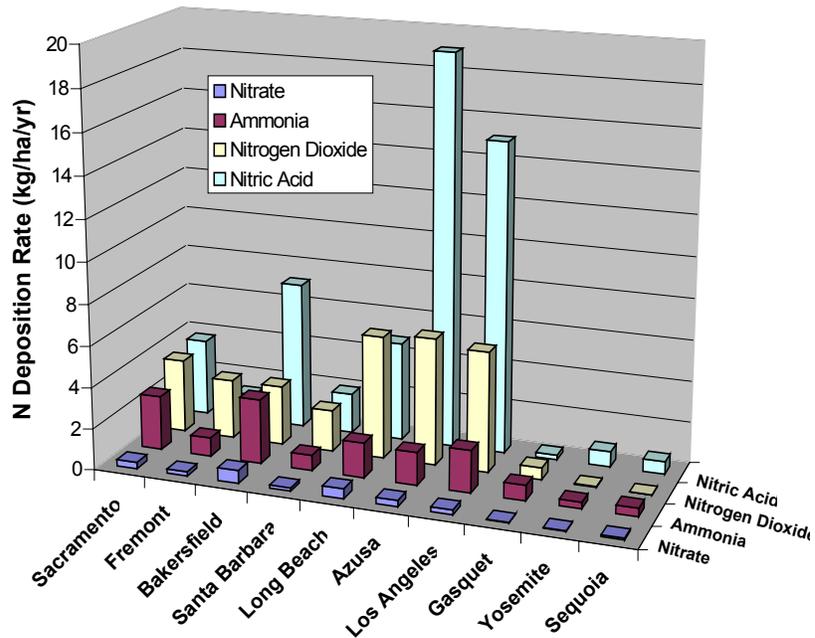
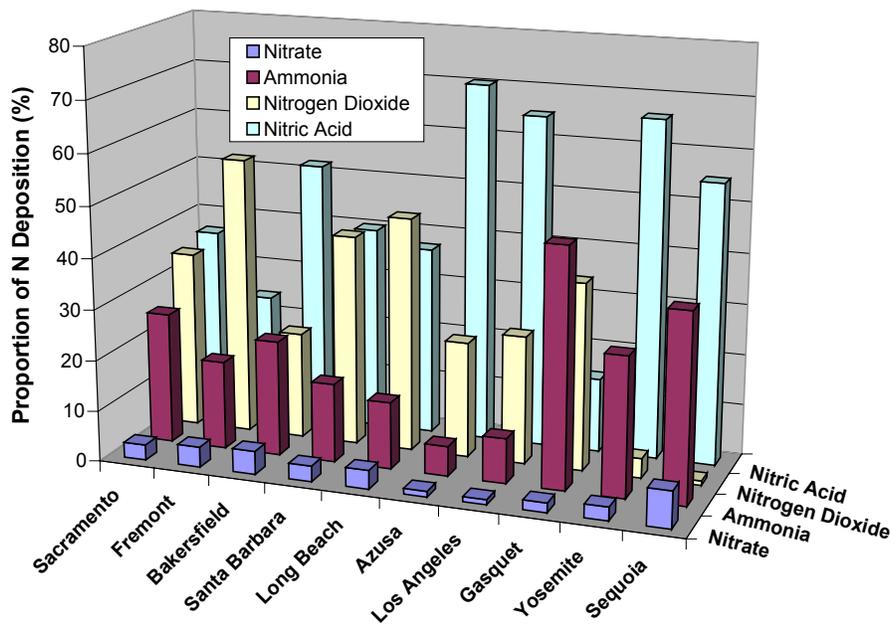


Figure 3. Proportion of annual dry deposition from major nitrogenous species in California.



1.2 OBJECTIVE, GOAL, AND STRATEGIES

The objective of this study is to meet the regulatory informational needs of TRPA and LRWQCB with respect to air quality and atmospheric deposition of phosphorus, nitrogen, and fine particulate matter to Lake Tahoe and its watershed. These informational needs will be addressed through issue-oriented tasks such as:

1. Obtain documented data sets of specified precision, accuracy, and validity that support modeling and data analysis efforts.
2. Review existing data sets and publications to document background concentrations of ozone, N, P, and PM and to determine how these have changed over the past few decades.
3. Identify and describe transport pathways and estimate the fluxes of ozone, N, P, and PM transported at ground level and aloft under meteorological conditions associated with seasonal variations.
4. Quantify the uncertainty of emissions rates, chemical compositions, locations, and timing of N, P, and PM that are estimated by emission models.
5. Quantify the uncertainty of meteorological models in simulating transport and local mixing of precursors and products within and between air basins.
6. Quantify the uncertainty of air quality models in simulating atmospheric transformation and deposition.
7. Provide the meteorological and air quality measurements needed to estimate, with stated uncertainty intervals, the contributions from background, regional mixing and transport, and local emitters to N, P, and PM deposition in the LTAB.
8. Provide the meteorological and air quality measurements needed to estimate the effects of different emission reduction strategies within and outside the Lake Tahoe Air Basin, and identify those that cause the greatest reduction in deposition for the least cost.

The goal of this study is to provide the information in a timely manner. Because of the LRWQCB's tight schedule for quantification of the deposition and characterization of its sources, the information will necessarily be provided in stages with increasingly refined estimates.

The general strategies to achieve the objective and goal are:

1. To reach a technical consensus on the monitoring/sampling methods sufficient and necessary to meet the informational needs and schedule of TRPA and the LRWQCB but also within the resources available;

2. To enhance the monitoring/sampling network for at least a one-year study period in a manner that will enable scientists to collect and analyze the appropriate emissions, meteorological, and air quality data to:
 - Quantify deposition of N, P, and PM to Lake Tahoe and its watershed at least seasonally, and
 - Identify and quantify the source categories by region (out-of-basin, in-basin region) that contribute to the seasonal loading;
3. To update and refine the trend in forest damage possibly related to air quality (i.e., ozone damage) and to identify the sources of the ozone by region (out-of-basin, in-basin); and
4. To estimate the change in atmospheric deposition and ozone levels expected due to current, and potential, regulatory programs.

The specific approaches taken to implement the strategies evolve in the context of new information regarding specific needs, limitations, and resources. There is always tension between doing the ideal approach with unlimited time and resources versus doing what is necessary and possible within the existing fiscal and personnel constraints.

1.2.1 Overview of Sampling Methods Strategy

Ideally, to address the deposition issues, one would want at least hourly-resolved air quality and meteorological data. The deposition of particles depends on a variety of factors including their chemical nature and size, the sources and physio-chemical transformation of the material, the meteorological conditions, etc. Because the emission sources and meteorological conditions vary seasonally and diurnally, an annual study would be very expensive and time consuming. Furthermore, the instrumentation and laboratory analysis needed to provide the necessary resolved size, composition, and time information are either not available or too expensive. In addition, the generally clean air in the Tahoe Basin challenges the detection limits of many monitoring/sampling methods. The combination of low concentrations and the desire for fine temporal resolution creates a unique field study challenge in the Tahoe Basin.

To address the particulate data needs, the CARB strategy is to make the Two-Week-Sampler (TWS) the cornerstone of its sampling program. The TWS has a simple design, has participated in previous field studies, and has been validated against federal reference methods (Taylor et al., 1996; Motallebi et al., in progress). The TWS continuously collects PM samples in three size ranges (PM_{2.5}, PM₁₀, and TSP) during a two-week period. With the long sampling period, it is practical to collect samples for laboratory analysis throughout the one-year field study. By essentially sampling every hour of every day, the TWS eliminates the uncertainties and complexities raised by intermittent sampling and extrapolating to estimate total seasonal and annual loadings of pollutants.

One difficulty associated with the use of the TWS is its relatively low flow rate design of about 1.3 liters/minute. If the flow rate is too great, a large loading of particles on the filter could reduce the flow rate and possibly damage the pump. Given the relatively pristine air quality at Lake Tahoe, this is not likely to be a problem during the study, except for possibly a long stagnant period in winter in an area where fireplaces are used extensively. On the other hand, too low of a flow rate will not enable sufficient mass to be collected to detect the presence of some elements/compounds and to accurately determine the concentrations of others. This is likely to be a problem in the Tahoe Basin. To reduce the likelihood of this occurring, CARB staff will mask the filters down to 29mm (same size as dichot filters) to enable a greater density of material for analysis by x-ray fluorescence (XRF).

Another limitation associated with the use of the TWS is that the sampling period spans the much shorter variations in source activities and in meteorological processes. Thus, each sample represents a gross average of the many details needed to investigate atmospheric processes and to isolate the major sources of emissions contributing to the presence and deposition of materials adversely impacting the water clarity of Lake Tahoe. To temporally refine the TWS measurements and subsequent data analyses, CARB staff is generally collocating continuous Beta Attenuation Monitors to provide hourly total mass measurements of PM_{2.5}, PM₁₀, and TSP. Assuming the relative mix of emission sources does not change significantly during the two-week period, the chemical species can be prorated by the day and the hourly data can be compared with the meteorological data to improve deposition estimates and implicate potential source areas and categories. Knowing the average composition in each two-week period and the daily and diurnal variations in total mass, and the concurrent meteorology will enable refined estimates of seasonal loading and the relative contribution of different sources.

The total mass of N and P nutrients being deposited to the Lake is important in assessing the impact on water clarity via algal growth. In fact, large particles are probably more important than the small particles because of their greater mass. However, when considering the effect of particles themselves on water clarity, the small particles are of greater interest because of their greater light scattering. Furthermore, the physical structure of the particle can be important if the original particle disintegrates into smaller particles when it deposits in the water. Settling velocity, which depends on a particle's size, shape, and density, is also a factor in water clarity. Thus, in addition to the total mass of particles and the fractions that serve as bio-available nutrients, the number of particles and the size distribution also affect water clarity. To address this concern, the work plan includes an optical particle sizing counter that will be located at various sites around the basin during each season to characterize the spatial and seasonal variations in particle numbers and sizes. In addition, the particle sizing counter will be installed on the UC Davis airplane (flights will probably be limited to summer and fall) and boat (primarily during winter) to provide critical information on the vertical and horizontal variations in particle counts and sizes.

Earlier analytical work indicated that algal growth in Lake Tahoe was N-limited initially but has become P-limited in the last decade or two. It remains important though to understand the N-balance in case N ever becomes the limiting nutrient again. Knowing the N-balance is also an important tool for validating model performance and that it is getting reasonable results for the correct reasons. To this end, ammonia, nitric acid, organic nitrogenous compounds, and nitrates are significant components of the field measurement program. A laser-induced-fluorescence instrument for NO_2 , HNO_3 , and organic nitrates as well as a continuous nitrate analyzer will operate at the transport detection and characterization site. In addition, most sites will have an oxides of nitrogen (NO_x) or a total oxides of nitrogen (NO_y) analyzer in operation. Lastly, in addition to $\text{PM}_{2.5}$, PM_{10} , and TSP measures of N and NO_3^- , the TWSs are equipped with denuders to provide measurements of NH_3 and HNO_3 concentrations.

Analytical assessments and interpretations of the ambient data and modeling results will be highly dependent and enhanced by a good understanding of the complex meteorological processes associated with the unique Tahoe Basin. A large cold lake surrounded by mountains is an ideal setting for meso-scale meteorological processes to exert a significant role in the movement of pollutants from sources and to the Lake. To this end, the existing meteorological network will be enhanced by additional surface stations and continuous remote sensing systems for characterizing the wind and temperature conditions above ground level. The thickness of the surface layers into which the pollutants are emitted is a critical factor in the concentrations of materials and the probability of contact with the lake surface. Radar wind profilers that can detect the winds from a few hundred meters above ground level to above the Sierra crest is critical for understanding the dynamics of the air flow over the Sierra and mixing with the air inside the Tahoe Basin.

1.2.2 Overview of Monitoring Network Strategy

The monitoring network must be sufficiently comprehensive to characterize the major source categories of N, P, and PM and the predominant meteorological processes. Furthermore, an item of major interest is the relative contribution of emissions in regions upwind of the Tahoe Basin to air and water quality issues within the Basin. A variety of factors make the establishment of a monitoring network in the Tahoe Basin difficult. Many areas are undeveloped and lack power and phone lines to operate the monitoring equipment. Some of the remote sensing equipment generate sounds that may be unacceptable in close proximity to homes. The dense pine forest makes it difficult to find locations that are representative of larger areas. At higher elevations, snow accumulation during winter will bury the equipment if it is not elevated on platforms or the snow is not removed routinely.

Meso-scale meteorological processes are likely to have a major influence on air flow patterns and the deposition of materials influencing water clarity. To capture the magnitude of the convergence or divergence of air over the lake surface, a minimum network of three mini-sodars distributed around the Lake are necessary.

The network of air quality monitoring/sampling stations must also characterize various categories of sources and provide representative spatial coverage. Because deposition of material into the Lake is the primary focus of the study, particulate monitoring sites are distributed around the edge of the Lake to capture the full impact of materials that could be advected over the Lake. Three “super” monitoring sites are proposed around the Lake: South Lake Tahoe, Lake Forest (NW shore), and Thunderbird Lodge (NE shore). Air quality and meteorological monitoring on a buoy near the center of the Lake would be ideal for characterizing the spatial variations in concentrations (particularly particulate matter) and the convergence of down slope air flows. Although meteorological data are being collected on several buoys and locations around the Lake, the power requirements for extensive air quality monitoring on the Lake will limit air quality sampling to occasional PM sampling on two buoys.

Although a monitoring station is currently in operation near the Sierra crest to document any pollutants being transported up the Sierra and into the Tahoe Basin, it is also exposed to local influences. An effort will be made to reduce the local impacts but another monitoring site in a more pristine location is needed to definitively quantify the amount and frequency of significant transport up the Sierra slopes. A promising location recommended by various air quality experts to detect transport along a likely route is near the Sierra crest at the top of Homewood Ski Resort. This site however would be inaccessible 3-4 months of the year during spring and fall when the mountain is too wet for vehicles and the ski lifts are not operating. Spring is the season when the transport of Asian dust and pollution tends to peak while summer and fall are the seasons when surface transport up the western slopes of the Sierra Nevada is greatest. Some low maintenance monitoring equipment is proposed for the mountaintop site at Homewood but a site with year-round access is highly recommended to document the magnitude and frequency of transport to the Sierra crest. A promising option is Loon Lake where equipment was located in a 1979 study of ozone transport up the western Sierra. The data from this site would provide an upper limit to the quantity and frequency of transport to the Tahoe Basin because of the additional distance and elevation necessary to get to the western edge of the Basin. Furthermore, the actual impact of the transport to the Basin is not known without understanding the mixing processes of air near ground level in the Basin with the air at the crest of the Sierra. Because the proposed Loon Lake site would be on the western slope about 1400' below the Homewood site, a fourth mini-sodar (in addition to the three within the Tahoe Basin) would be needed at the Loon Lake site to detect the depth of the upslope air flow and to associate pollutant concentrations and meteorological variables with those observed at the top of Homewood.

Another option to establishing a transport site at Loon Lake is to establish it at a slightly lower elevation and further southwest on Big Hill (elevation 6200'). This location has an advantage that it is ideally suited for exposure to transported material coming up the slope of the Sierra. This area was burned during the Cleveland Fire and was salvage logged subsequently. The site is on a bare hill as opposed to a small, forested valley where: 1) air flow could be channeled and potentially impacted by campfires in the drainage area and 2) the forest could bias air quality and meteorological measurements.

The lower elevation and greater distance from the Sierra crest would almost necessitate the use of a radar wind profiler with RASS (temperature) to effectively characterize meteorological conditions to altitudes above the Sierra crest.

Because the long-term record of dry deposition data is based on an unvalidated method, CARB staff proposes to conduct a 3-way deposition method comparison. Staff will collocate two traditional wet/dry deposition samplers (one with water (standard TRG method) and one without (standard acid deposition method)) with a water surface deposition sampler aerometricly designed to minimize disturbance of the air flowing over the sampler. This sampler design was used in the Lake Michigan Ozone Study and comparison of data from the three dry deposition sampling methods will indicate whether any sampling biases might exist and, if so, under what general conditions they occur. Assuming any bias is method dependent and not site dependent, the results could be used to adjust historical data and trends and to serve as a reference point for the calculations (estimates) of dry deposition from the collocated TWS.

A number of short-term sampling studies are planned to supplement the monitoring network and to provide critical information to support the data analysis, calculations, and extrapolations of the data collected during the field study. These include: 1) mid-lake sampling on buoys on Lake Tahoe, 2) a near-shore study of the falloff in concentrations with distance from particle source areas, 3) measurements via an instrumented aircraft of air quality and meteorological conditions above the Lake during spring, summer, and winter to characterize vertical and horizontal variations, 4) measurements via an instrumented boat during the winter to characterize horizontal variations on the Lake, 5) continuous meteorological and particle sampling (BAM) and some limited collection of materials with a TWS (and compositional analysis) during the summer at the top of Homewood to relate observations of transport at the Sierra slope site to what arrives at the western edge of the Tahoe Basin, and 6) a limited number of snow samples collected in the early spring and analyzed in the laboratory to estimate the total deposition of materials during the winter.

1.2.3 Overview of Forest Damage Assessment Strategy

Ozone is an oxidant that damages cells. Ozone exposure stresses plants and makes them more susceptible to additional damage from drought and insects. Pine trees, the dominant specie of trees in the Tahoe Basin, are particularly susceptible. Previous assessments of the forest health in the Basin occurred in the 1980s, 1992, and 1997. The current strategy is to continue the assessments every five years and to gather additional information on the magnitude and spatial distribution of ozone and other chemical stressors such as nitric acid.

1.2.4 Overview of Program Effectiveness Strategy

Models when properly validated and exercised are a useful tool for predicting the effects of various future scenarios and designing a control strategy for meeting various environmental goals in a timely and cost-effective manner. However, a complete assessment of the effectiveness of any actions, must include retrospective analyses.

Refinements in the emission inventory for the Tahoe Basin and improved understanding of the magnitude and frequency of atmospheric processes (meteorology) and the subsequent impact on the composition and ambient concentrations of materials will greatly improve the data analyses necessary to assess the effectiveness of past actions and validation of modeling efforts to estimate the effectiveness of any future actions.

1.3 HYPOTHESES

The key management questions compiled and raised by various stakeholders and experts have been considered in development of this plan. A subset of those questions will be investigated within the scope of this work plan to address air quality and atmospheric deposition at Lake Tahoe. In considering these questions, we consider, in decreasing order of priority:

1. **Phosphate and phosphorus** because the Lake is currently phosphorus limited for algal growth.
2. **Fine particulate matter (0.5-5 micron)** because this size fraction is capable of light scattering and relatively long-term suspension in water.
3. **Nitrogen compounds** because the algal growth in the Lake could become nitrogen-dependent in the future if effective controls are instituted to reduce phosphorus loading. For atmospheric deposition, the highest priority nitrogen species are gaseous nitric acid, ammonia, particle-phase ammonium, and nitrate ions, because of relatively high concentrations and their high surface conductances.

The subset of key questions provided by the Scientific Advisory Group to researchers in the Tahoe Basin are listed below in priority order for this plan.

1. How reliable are the preliminary estimates of phosphorus and nitrogen loading to Lake Tahoe?
2. What are the specific sources that contribute to atmospheric deposition of nutrients and sediment to the surface of Lake Tahoe?
3. Answers to the following questions may be needed to adequately answer the two key questions above:
 - What spatial and temporal factors affect the deposition of air pollutants to the lake and forest?
 - How are air-borne pollutants transported and distributed throughout the basin?
 - What is the fate of air pollution produced in the basin?
 - What is the relative contribution of in-basin versus out-of-basin pollutant sources at Lake Tahoe?

Although there are several chemical species of interest, in broad terms two types of information are needed and two types of hypotheses must be tested. The first type requires information on the magnitude of atmospheric deposition of the various

chemical species. The second requires information regarding the sources of emissions of those chemical species to the atmosphere.

1.3.1 Hypotheses Regarding the Magnitude of Deposition

1. The magnitude of phosphorus and phosphate deposition is consistent with the wet and dry bucket observations and is significant relative to other inputs to the Lake.
2. The calculated deposition of phosphorus and phosphate (based upon the concentration of ambient particle phase phosphorus and phosphate and the size fraction of the particles) is consistent with the historically reported accumulation of phosphorus and phosphate in the buckets.
3. The magnitude of deposition of fine particles (0.5 to 5 microns) is sufficient to account for a significant fraction of those fine particles found in Lake Tahoe surface waters.
4. The magnitude of nitrogen deposition is consistent with the wet and dry bucket observations.
5. The forms of nitrogen deposited to the Lake are primarily ammonia, nitric acid, gas- and particle-phase N-containing organic compounds, and particles with an ammonium cation.

1.3.2 Hypotheses Regarding the Sources of Species Deposited

1. The phosphorus and phosphate contribution is primarily from local sources.
 - a) Geological dust is a significant source of phosphorus.
 - b) Dust from paved roads and unpaved shoulders are a significant source of phosphorus.
 - c) Dust from road sanding operations is a significant source of phosphorus.
 - d) Wild fires are a significant source of phosphorus or phosphate.
 - e) Residential wood combustion is a significant source of phosphorus or phosphate.
2. Emissions from within the LTB are the primary source of atmospheric nitrogen deposited to the Lake.
3. Although the nitrogen deposited to Lake Tahoe originates primarily from local LTB emission sources, it is upwind emissions that are responsible for its conversion to nitric acid. Thus, nitrogen deposition is due to local sources of nitrogen and upwind emissions of ozone precursors.

1.4 APPROACHES FOR ESTIMATING ATMOSPHERIC DEPOSITION

Both direct and indirect methods can be used to estimate deposition rates. Convergence of results of different methods provides confirmation of those results. Observation of deposition to surrogate surfaces will be continued in the form of the historical wet and dry buckets that provide the long-term record of the Tahoe Research Group, UCD. The CARB will likely have access to a water surface sampler for measuring dry deposition. The design of this sampler minimizes distortion/disturbance of the air flow as it passes over the sampling surface which is a concern with the

traditional bucket sampling method. The intent is to collocate the water surface sampler with a TRG bucket sampler for comparison of the results by the two methods given the concerns about the effect of the bucket sampler itself on air flow over it and consequently deposition from it. In addition, as resources permit, sampling and analysis of the spring snow pack will provide a direct measure of the elemental and ionic forms of phosphorus and nitrogen that accumulated via deposition during the winter season. However, the design of this sampling program (locations, frequency of samples, methods, etc.) needs careful consideration (Dawson, 1986; Berg et al., 1989).

Independent calculation of deposition rates will be made based upon ambient concentrations and deposition velocity. The deposition velocity is a transfer coefficient for the specific substance of interest. The deposition velocity is not a constant because it takes into account the current state of the atmosphere, the current state of the underlying surface, and chemical and physical properties of the species of interest. Because the state of the atmosphere varies diurnally, the deposition velocity also varies diurnally. The deposition rate (mass/length²/time) is the product of the concentration mass/length³ and the deposition velocity (length/time). The concentration and deposition velocity can each be supplied by estimation and measurement techniques. Calculation of deposition velocity requires estimation of the aerodynamic resistance or its inverse, aerodynamic conductance.

In many cases, deposition velocity estimates will be calculated based upon literature values and routine meteorological parameters. Profiles of meteorological parameters will be observed at a few sites. Eddy covariance measurements of the vertical transport of sensible heat and water vapor will be made at one or two lakeside sites including at least one site on the east shore.

The operating principle for selection of methods is that the most direct measurements are preferred for calculation of deposition at a specific location. Direct measurements are recommended when feasible and affordable. However, in many cases it will be necessary to rely on less certain methods due to lack of instrument capability and/or budget limitations.

Table 5 provides a brief and partial synopsis of the methods that can be used to quantify atmospheric deposition. The top row lists the most direct techniques and the second row describes the general estimation approach. The remainder of the table describes cascading sets of parameters needed to estimate the deposition velocity, a critical and variable (spatially and temporally) component.

Table 5. Summary and explanation of approaches for estimating deposition.

Potential Methods for Direct Observation of Deposition Rate:		Surrogate Surface	Eddy Covariance (E-C)	Relaxed Eddy Accumulation (REA)	Bowen Technique
Calculation of Deposition Rate:	As product of :	Concentration		Deposition velocity	
Deposition Velocity	Depends on:	Aerodynamic conductance	Surface conductance	Quasi-laminar-layer conductance	
Aerodynamic Conductance	Depends on:	Atmospheric turbulent transport			
Atmospheric turbulent transport and aerodynamic conductance	Estimate from micro-meteorological measurements:	Measure transport of heat or water vapor directly by E-C	Measure transport of heat or water vapor indirectly from profiles of wind speed, temperature, humidity	Measure routine meteorological parameters and use to estimate turbulent transport	
Atmospheric turbulent transport and aerodynamic conductance	Estimate by calculations:	Estimate turbulence and stability from routine met measurements	Estimate from wind speed and difference between water and air temperature	Profiles of temperature and humidity	
Surface conductance	Depends on:	Physical properties of species of interest (e.g., solubility, reactivity)		Surface properties (e.g., waves, roughness, stomatal activity)	
Lake Wave Properties	Method of definition:	Direct observation (few locations, times)		Model wave height, period from winds (all hours and locations)	

1.4.1 Direct Measurement Approaches

Direct measures of deposition are the most desirable approach for characterizing N, P, and PM deposition. The California Acid Deposition Monitoring Program (CADMP) began in 1984, was reduced in scope a couple of times, and was finally discontinued in 2000. This program began at ten sites (remote to urban) throughout the State. The data indicate a downward trend in N deposition in both urban and rural areas.

Assuming these data are also representative of the trend in the Tahoe basin, the CADMP data are consistent with the hypothesis that the water clarity of Lake Tahoe is more P dependent than N dependent because the water clarity has continued to decline despite reduction of the N deposition.

1.4.1.1 Wet and Dry Deposition Buckets

Wet and dry deposition buckets serve as a surrogate measure of the atmospheric deposition over the basin. The Tahoe Research Group of UC Davis has operated a sampling network of buckets for characterizing deposition in the Tahoe basin. Currently, the network is limited to two sites in the upper and lower reaches of Ward Creek (NW of Lake). Estimates from the bucket program, assuming the same deposition rates apply over the Lake as at the bucket sites, indicate phosphorus deposition on the order of 75 pounds/day to the Lake surface.

The CARB plan assumes continued operation of the existing wet/dry deposition samplers (two operated by TRG in Ward Creek and one operated by CARB at SLT-Sandy Way) and recommends expansion of the network to a subset of the air quality monitoring sites. Four new wet/dry samplers will be installed and operated at Lake Forest – TRG lab, Thunderbird Lodge, and Loon Lake (upwind of the Tahoe Basin on the western slope of the Sierra Nevada). Two samplers will be collocated at the Lake Forest –TRG site to allow comparison/evaluation of the TRG and CARB dry deposition methods with an aerodynamic water surface sampler being loaned to CARB. Collocation of the wet and dry buckets with measurements of concentration and meteorology is necessary for evaluation of the deposition rates reported historically.

Results of studies of deposition to surrogate surfaces are frequently reported. Because the controlling property of the uptake is determined either by the surface itself or the configuration of its exposure in the environment, the surrogate surfaces can rarely provide reliable deposition data. Surrogate surfaces can be a reasonable approach for characterization of deposition of large particles in cases where gravitational settling dominates the deposition. However, where vegetative canopies exist, impaction and interception processes are also important when determining the deposition (Wesely and Hicks, 2000). For large bodies of water, the state of the surface is important to the deposition rate. The presence of breaking waves and spray constitutes an entirely different regime for deposition in contrast to a smooth surface (Jielun Sun, 2001, personal communication).

Most direct atmospheric deposition measurements in the United States now center on “event recording” and use Aerochem Metrics dry/wet bucket system (Jassby et al., 1994; Pennsylvania Department of Environmental Protection, 1999; National Atmospheric Deposition Program, 2001). The instrument consists of a two-container system with a movable lid designed to expose the wet container and cover the dry container during periods of precipitation, and vice versa. A sensor mounted on the instrument reacts electrically to the onset of precipitation causing the lid to move thereby exposing the wet side container. Heaters mounted below the sensor serve to both melt snow and ice as well as evaporate moisture from the sensing element.

Standard recording and non-recording rain gages are also installed at each such site. Each recording rain gage would be equipped with a timer/chart recorder keyed to the sampling interval (usually weekly). The times of opening and closing of the wet/dry sampler are determined from an event recorder mounted on the recording rain gage.

The standard non-recording rain gage is used to determine the total amount of precipitation.

At the time of collection, a clean collection bucket is usually provided and placed in the sampler. The "wet" sample containers are usually shipped to the laboratory each week regardless of whether precipitation occurred. Sample buckets are removed once week at a standard time unless it rains or snows, in which case they are removed when the precipitation ceases, but in no case later than the end of the working day. Precautions are taken to preclude changes in, or contamination of, precipitation samples during collection, transport, and storage prior to analysis. Analyses are performed as soon as possible after receipt of the samples. Although it is recognized that ionic concentrations in weekly precipitation samples may be subject to change (Peden and Skowron, 1979), the feasibility of daily or event sampling was unwarranted because of the high cost involved.

Laboratory Analyses - Precipitation samples are usually analyzed for the following parameters provided a sufficient volume is present: pH (H^+), sulfate (SO_4^{2-}), nitrate (NO_3^-), ammonium (NH_4^+), chloride (Cl^-), calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^+), sodium (Na^+), and specific conductance. In the event that insufficient volume is present for complete analysis, that is noted in the record.

Sample Handling Procedures - Upon receipt from the lab, samples are assigned a number that is traceable to a specific sampling period and site. Following immediate measurement of volume, pH, and specific conductance (if sufficient volume is present), the samples are filtered. After filtration, nitrate, ammonium, sulfate, and chloride concentrations are measured within 1-3 working days; calcium, magnesium, sodium, and potassium samples are acidified and stored; analyses usually follows within 3-5 weeks. Precipitation samples that are grossly contaminated are discarded. For samples arriving with a twig, leaf, pine needle, beetle, bumblebee, etc., the contaminants are removed by filtration and the sample processed like any other precipitation sample. At the time of sample check-in, comments are noted to record the visual appearance (and presence of odor) of each sample. Quality Control and Quality Assurance-the quality control (QC) and quality assurance (QA) policies must be designed for maximum credibility of the data, including documented accuracy, precision, and completeness.

1.4.1.2 Water Surface Sampler

A relatively new sampler designed to minimize its impact on airflow and to measure the deposition of material in the gas or particle phase has been developed and successfully tested (Yi et al., 1997). The water surface sampler is an ideal instrument to evaluate the potential bias associated with the historical bucket sampler in the Tahoe Basin. If possible, a water surface sampler should be acquired and collocated with the bucket sampler at Ward Creek (CA). Ideally, the comparison study should last a full year to characterize any seasonal variations and thus permitting a more refined adjustment of the historical deposition database by the bucket should it be appropriate.

1.4.1.3 Snow Cores

Samples representing the composite load of chemical constituents from all layers of the spring snow pack have been analyzed for several ions of concern. Results for sampling at Lost Lake and Alpine Meadows suggest that winter deposition to snow of nitrogen (in the form of NH_4^+ and NO_3^-) is minimal. Quantities deposited were at most a few percent of what is reported for the annual nitrogen deposition observed with wet and dry buckets. Because these snow-sampling sites are at the upwind side of the basin, the low concentrations observed suggest that nitrogen deposition is either less than observed by the buckets or that nitrogen deposition in the basin is primarily due to local sources and is not due to upwind sources.

Because the cost is relatively low, we recommend spring snow sampling for multiple locations chosen based on elevation and proximity to sources. Spring sampling is appropriate only for higher elevations at which snowmelt is minimal. Upwind sites could potentially be located in the vicinity of Alpine Meadows, Homewood Ski Area, Sierra Ski Ranch, and or Sugar Bowl. Potential downwind sites could be near Incline Ski Area and Heavenly Valley Ski Area.

1.4.1.3.1 Snow sampling methodology from the acid deposition programs

Wet and dry atmospheric deposition of solutes was measured by sampling the aggregate of winter precipitation and dry deposition in the snow pack at maximum snow accumulation, which usually occurred during late March or early April. Samples of snow were collected from pits that were dug to the ground using plastic, aluminum or steel shovels. Once the pit was dug, a vertical wall that was not exposed to direct sunlight was created on a portion of the pit (using a plastic shovel). Samples were taken from this wall. Pit locations were chosen after extensive depth probing at each site, and the pit sites were selected at points where the snow depth was representative of the larger probed area. Pits were not dug near vegetation or exposed rocks.

Samples of the snow pack were obtained by collecting duplicate, contiguous, vertical sections about 40 cm in length using a clear PVC tube (5 cm diameter, 50 cm long, with a sharp, beveled cutting edge). Each 40-cm section was placed into a separate polyethylene bag. Personnel wore powder-free vinyl gloves during sample collection and avoided touching either the snow or the inner surfaces of the bags. Bags and sampling apparatus were soaked in deionized water for several days before use and kept clean. Snow samples were kept frozen at -20°C until they were placed into polyethylene buckets and thawed at 5°C for chemical analyses.

To estimate snow-water equivalence, snow density and snow depth were determined. Snow density was measured in vertical 10-cm intervals in the snow pit using a wedge shaped stainless steel cutter and portable electronic balance. All cutter sampled 1000 cubic centimeters of snow and were calibrated to have less than 1% error in volume. To collect a sample for weighing, the cutter was pushed into the wall of the pit until it was filled with snow. A flat metal blade was used to cut a wedge of snow from the pack. The weight of the snow was then measured on the balance (tared for the cutter weight). Because the volume of the cutter was 1 liter, the density (gm/L) of the snow sample was

its weight in grams. Two profile measurements were made through the entire depth of the snow pack. Snow depth was determined along four transects radiating out from the snow pits. Generally, snow depth was measured in duplicate every 5 to 10 meters. Sampling the snow pack using snow pits was possible in these programs because the sites were at high elevations where < 1% of the snow pack melts over the winter. At lower elevations or southern exposures where snow may melt during the winter, gauging must be employed and measurements must be taken at each snow event. Also, when snow melts ions are released in a pulse so that initial melt water has a higher concentration of solutes than later melt water.

The total winter-season nitrogen deposition (wet and dry) ranged from about 40 to 80 micrograms/m² based on the concentration observed in the snow pack and the snow water equivalent (mm). Assuming the same rate of deposition to the Lake as to the snow pack (ignoring the differences in elevation, concentrations, snow volume, and differences in deposition velocities over snow vs. water) with an area of 500 m², the amount of N entering the Lake by direct deposition would range from 0.02 to 0.04 metric tons/winter season.

This estimate is three orders of magnitude less than what has been reported for the annual deposition to the Lake as observed with wet and dry bucket measurements. This seems like a large difference although we do expect that N deposition will be greatest in summer due to production of HNO₃.

1.4.1.4 Other Direct Measurement Approaches

The Eddy Covariance (E-C) and Relaxed Eddy Accumulation (REA) approaches require measurements of:

1. concentrations with fast response instruments,
2. vertical profiles (e.g., met. tower) of temperature, wind speed, & humidity, and
3. vertical fluxes of water vapor, sensible heat, and momentum (eddy covariance).

The deposition is directly measured for the species of interest (i.e., those species with concentration data). When eddy diffusivity is measured, it can be used to calculate deposition rates for other species of interest. E-C and REA provide the most reliable estimates of deposition as long as the siting and instrumentation requirements are met. The E-C and REA approaches are probably suitable for determining deposition rates of HNO₃ and NH₃. Potentially, REA could be applied for estimating the deposition of phosphorus and PM.

1.4.2 Semi-direct Profile Approach (Bowen technique):

The Bowen technique requires measurements of:

1. concentration profiles,
2. vertical profiles (e.g., met. tower) of temperature, wind speed, & humidity, and
3. vertical fluxes of water vapor, sensible heat, and momentum (eddy covariance).

Eddy diffusivity is directly measured for water, heat, and momentum.

The deposition, resolved in time, is calculated at specific locations.

1.4.3 Profile Approach:

The Profile approach requires measurements of:

1. concentration at a single height,
2. vertical profiles of temperature, wind speed, humidity, and
3. vertical flux of water vapor, sensible heat, and momentum (eddy covariance).

The eddy diffusivity is calculated for water, heat, and momentum. The deposition velocity is calculated from observations and so the deposition, resolved in time, is calculated at specific locations. This calculated deposition rate is somewhat less reliable than with the Bowen approach, described above, due to the calculation, rather than the observation, of the eddy diffusivity.

1.4.4 Inferential Method

The Inferential approach only requires routine measurements of concentrations, wind, and temperature. The eddy diffusivity and deposition velocities are calculated from the routine meteorological observations. This approach can provide reasonable estimates of seasonal or annual deposition rates. However, this approach is not expected to provide accurate deposition estimates for a specific hour or day.

1.4.5 Data Analysis Approach

The data analysis approach relies on currently available source-profile information and concentration measurements. If the available data are limited, it is necessary to conduct source-oriented ambient monitoring to generate emission profiles from the significant sources. In addition, additional information may be needed to satisfy the data requirements for source apportionment. The eddy diffusivity and deposition velocities are estimated from literature values and so this approach provides an approximate estimate of deposition. Hourly resolution of concentration and deposition velocity data would be preferred to generate accurate daily or seasonal estimates.

1.4.6 Modeling Approach

In the modeling approach, the model, based on physical and chemical constraints, calculates estimates of ambient concentrations, eddy diffusivity, and deposition velocities. The model requires the following data for model input and model performance evaluations (MPE):

1. emission inventories,
2. wind speeds and directions,
3. temperatures, and
4. ambient concentrations.

The modeling approach potentially provides deposition estimates for all species, locations, and times. However, of the various approaches discussed, the modeling

results are the most removed from the observations. This drawback is because both concentrations and eddy diffusivity are calculated instead of measured. Thus, the model calculations and assumptions are much more difficult to review and evaluate. However, if accurate, the modeling approach provides several advantages. The various informational needs met by the modeling approach include:

- The use of actual measurements (boundary and initial conditions) can help to generate an improved conceptual model of the meteorology and air quality in the Lake Tahoe basin.
- The fine-scale modeling within the basin (i.e., 1-km grid cells) provides improved information on local transport and source-receptor relationships (relative to the information available from sparse observations).
- The use of a regional model provides improved large-scale transport information.
- The exercising of the model improves the understanding of the causal relationships (e.g., positive or negative correlation) between air quality observations at sparse sites.
- The high-resolution information (not only spatially in the horizontal and the vertical dimensions but also temporally) are not available from a sparse observational network.
- Large-scale air quality modeling can quantify the effects of upwind sources on boundary conditions in the Lake Tahoe basin.
- The effects of chemical reactions, particularly under conditions of low concentrations, are critical to properly understanding the concentrations of species affected by photochemical reactions (i.e., nitrogen species) because the responses, like the atmospheric chemistry, is non-linear.
- The modeling approach provides concentration information on directly emitted species and intermediate and end product species whereas ambient measurements can only provide information on a limited number of species.
- The modeling approach provides deposition calculations for species in addition to the measured species.
- The modeling approach can investigate the effects of changes in emissions due to population change, development, or control programs.

1.5 SOURCE IDENTIFICATION APPROACHES:

Quantification of the deposition of nitrogenous and phosphoric species is only the first step to improve the water clarity of Lake Tahoe. More important is the identification of the sources contributing the materials that contribute to the degradation of water clarity. This section presents some approaches for identifying the sources of N, P, and PM that contribute to the degradation of the water clarity in Lake Tahoe.

1.5.1 Quantitative Source Apportionment by CMB

This approach requires:

1. quantitative source profiles for all source types contributing to the presence of a particular class of compounds, and
2. speciated, size-resolved ambient measurements of that compound.

This approach quantifies source/receptor relationships (i.e., estimates the proportion of material at the receptor site that originated from a specific source type).

1.5.2 General Source Identification by Spatial and Temporal Patterns

This approach requires:

1. quantitative source profiles for suspected sources, and
2. speciated, size- and time-resolved ambient concentrations.

This approach provides inferential information regarding sources by noting what material arrived at the receptor site and the wind patterns typically associated with the temporal variation of the source activity.

1.5.3 Modeling "what if" Emission Scenarios using a Known Inventory

This approach requires:

1. meteorological inputs,
2. boundary conditions for air quality species,
3. initial conditions for aerometric (air quality and meteorological) data,
4. data for model performance evaluation, and
5. emission inventories for the air quality species.

This approach provides estimates of air quality changes when emissions change.

1.6 INTEGRATED APPROACH

ARB proposes to apply an integrated hybrid approach to studying air quality and atmospheric deposition in the Tahoe basin. This will include: 1) a field study for the direct measurement of important pollutant species, meteorological conditions, and source-specific emissions; 2) development of a mechanistic model to extrapolate those measurements into basin-wide deposition calculations; 3) construction of a basin-specific emission inventory, 4) detailed source-apportionment; and 5) data analysis.

We view the field measurements, the model, and the basin emission inventory to be complimentary. The model will permit joining the effects of long-range transport and local emissions into a single, source-aware analytical framework. The measurement program will serve both to refine model inputs (especially meteorology) and to calibrate and evaluate the model's performance (air quality and deposition). Specialized source-oriented field measurements will also be used, in conjunction with the model and source-apportionment studies, to validate and refine (or refute) the emission inventory.

Using the refined model and validated emission inventory, we will be able to project basin air quality and total deposition to the lake under a range of conditions and hypothetical emission control scenarios. Such experimentation will permit the basin's regulators (i.e., TRPA and Lahontan RWQCB) to determine what emission reductions

will be most effective and least costly or socially disruptive to reach the goal of stabilizing lake clarity, preserving forest health, and protecting air quality.

The advantages of the CARB approach is that it includes approaches that are complementary and, to a large extent, independent of each other. Ideally, these various analyses will provide consensus and confidence that the estimates reflect reality. Furthermore, modeling is the standard approach for the development of State Implementation Plans (SIPs) for particulate matter. Thus, the SIP and Lake Tahoe efforts can benefit each other. Lastly, the modeling approach for addressing air quality issues has been recommended by the National Academy of Science.

1.6.1 Major Analysis Components

The major components of CARB's analytical approach are identified and briefly described below.

1.6.1.1 Literature Review & Data Analysis

The success of the field study and the subsequent deposition characterization efforts depends on a thorough understanding of previous scientific investigations within the Tahoe basin and the adjoining portion of the Sierra Nevada. Analysis of these data is critical to the effective implementation of the atmospheric deposition program. For example, these results resulted in the development of conceptual models of the processes within the Tahoe basin. It is important that this study builds upon prior work and is designed to critically address weaknesses and uncertainties in the conceptual models. Furthermore, the review of existing data helps guide the characterization of boundary conditions for modeling applications and the choice of instrumentation with sufficiently low levels of detection when air quality is excellent (i.e., pollutant concentrations are very low).

1.6.1.2 Emission Inventory

Emission inventories are critical for the identification of major categories contributing to an air quality problem and for the proper performance of air quality models. Proper characterization of the emissions of CO, NH₃, NO_x, P, PM, SO₂, and VOCs in and around the Tahoe basin are critical to the proper performance of the Lake Tahoe air quality model and confidence in the modeling results.

1.6.1.3 Air Quality Modeling

The air quality modeling for the atmospheric deposition estimates includes two distinct efforts. The first effort builds upon existing field study data and planned modeling runs for the ozone and PM SIPs. The results of modeling runs for the Central California Ozone Study (CCOS) and California Regional Particulate Air Quality Study (CRPAQS) will provide deposition estimates for the Lake Tahoe basin. The modeling episodes will likely characterize deposition during several seasons of the year (e.g., CCOS – summer and CRPAQS – fall & winter). The results for the Lake Tahoe basin will not provide precise results because these modeling applications are based on 4-km grid cells and

validated for performance in the Central Valley of California. In addition, these modeling runs will not have an emission inventory for phosphorus (i.e., N, O₃, & PM).

The second and later modeling effort will build upon the first modeling effort and will be directed specifically at the Tahoe deposition issues. The air quality model will be updated to include 1-km grid cells in the Tahoe basin to enable better source-receptor characterization. In addition, a phosphorus emission inventory will be developed so that the estimates of P deposition can be calculated directly. Lastly, the focus of the model validation efforts will be the Tahoe basin to ensure the best modeling results and the proper assessments and conclusions. Sound results of the deposition quantification and the source characterizations are necessary to identify effective and appropriate emission reduction programs.

1.6.1.4 Deposition Calculations

The year-long measurements program beginning in the summer of 2002 will provide data from which various calculations of deposition can be made. In addition, the field study will enable the application of wind trajectories, CMB modeling, etc. to enable not only the quantification of deposition by specie but also the identification of the major categories contributing to the deposition problem.

If funding becomes available, an experiment with the controlled release of known material could be performed to provide quantification of deposition under specific conditions. Such information would be useful in evaluating deposition estimates by various methods during the study and in extrapolating those results.

1.6.1.5 Deposition Buckets

The wet and dry deposition buckets used historically by the UCD-TRG will continue to be used at the Ward Creek location with new ones located at the proposed Lake Forrest (CA) air quality monitoring site to permit comparison of the traditional deposition method (surrogate surface) with other direct measurement methods. Estimates from the deposition buckets and the CARB emission inventory differ by a factor of four. CARB still operates a wet deposition sampler at the SLT-Sandy Way site. Comparison of deposition estimates at the sites with collocated equipment (i.e., Ward Creek, Lake Forest, and SLT-Sandy Way) will provide insights into whether the limitations of the traditional surrogate surface approach are significant or whether a significant source of P is unaccounted for in the current emission inventory. Furthermore, if the relationship between the deposition estimates by the collocated buckets and aerometric measurements is consistent, it may be possible to “correct” the historical deposition records.

1.6.1.6 Ozone and Forest Health

Analysis of ozone concentrations in the Tahoe basin will document the progress in achieving one of TRPA’s air quality threshold goals and provide insight in to how continued improvement might be achieved. Furthermore, the assessment of forest health will further document the damage caused by ozone pollution and provide insight

into how the declining forest health might impact N, P, & PM deposition and uptake rates and consequent runoff into Lake Tahoe where water clarity could be negatively impacted further.

1.6.2 Elements of the Plan

The following are recommended elements that form a menu for a program of field measurements, analyses, and modeling to address air quality issues at Lake Tahoe. The primary purpose is to quantify the atmospheric deposition of phosphorus, phosphate, fine particles, and nitrogen species to the surface of Lake Tahoe and to identify the emission sources and, if possible, their relative contributions to that deposition. Because this program will be funded primarily through the ARB's BCP for Lake Tahoe, a relatively minor purpose, but one that is also specifically identified in the BCP, is the characterization of spatial patterns and trends in ozone concentration and their relationship to spatial patterns and trends in forest health.

Thus, the major elements of the plan are:

- Characterization of spatial patterns and trends in ozone and forest health
- Expanded air quality measurements at three existing sites (Echo Summit (CA), S. Lake Tahoe – Sandy Way/SOLA (CA), and Cave Rock (NV)) and at three or more new sites (an upwind transport site (CA), Lake Forest (CA), Thunderbird Lodge (NV), and, if possible, at least 2 buoys on the Lake).
- Characterization of meteorological conditions aloft (winds and temperature) in the Tahoe Basin with new remote sensing instruments (three mini-sodars and one radar wind profiler with radio acoustic sounding system)
- Source-oriented sampling for particles from wood smoke, road dust, motor vehicles
- Improvements in the inventory of emissions (e.g., activity data, source profiles)
- Snow pack sampling for assessment of average deposition during winter
- Advanced measurements of nitrogen species by laser-induced fluorescence
- Aircraft operation for observation of meteorological and air quality parameters
- Modeling of meteorological fields
- Modeling of inert and photochemical processes of ozone production, nitrogen chemistry, and aerosol formation
- Quality assurance
- Data management
- Calculation of N, P, & PM deposition by multiple methods
- Identification of N, P, & PM source categories within and outside basin
- Identification of potential control strategies.

Study elements generally support understanding of one or more aspects of deposition to the Lake as follows:

- Long-term averages of ambient concentrations and speciation of particles, including P- and N-species are useful for calculation of deposition and showing spatial patterns possibly useful for source inference.

- Short-term averages of ambient concentrations and speciation of particles, including P- and N-species, are useful for calculation of deposition and showing temporal patterns possibly useful for source inference
- ambient concentrations of gaseous N-species are useful for calculation of N-deposition
- where feasible, specialized meteorological measurements supporting estimation of aerodynamic properties of the atmosphere are useful for calculation of deposition velocities at a specific location and time.
- meteorological measurements allow detailed modeling of wind fields, which will in turn support analysis of source-receptor relationships, modeling of transport and dispersion (e.g., of P-species from local sources), and modeling and analysis of ozone and nitrogen chemistry, and prediction of wave motion on the Lake (also relevant to over-water deposition velocities).
- meteorological observations aloft are needed for defining the large-scale 3-dimensional aspects of the winds and vertical mixing. This is key to understanding and quantifying the impacts of upwind sources due to diurnal and daily variability in the interaction of winds generated on a synoptic-scale (days and 100s of kms) with terrain-induced meso-scale (hours and 10s of kilometers) winds local to the Tahoe Basin.

1.6.3 Specifics of the Monitoring Plan

The following outline explains briefly the components we selected and how we envision using their results.

1.6.3.1 Characterization of Ozone and Forest Health

This task arises from ARB's ongoing statutory obligation to protect CA resources from air pollution damage. It is also of significance in forest management for in-basin concerns such as forest health, fire, fuels, etc. Correctly explaining ozone trends and variations also helps as a crosscheck on nitrogen chemistry in the air quality model and deposition estimates.

Although the Tahoe Basin is in attainment for the California and national ozone standards, ozone concentrations at current monitoring sites occasionally approach the California standard and routinely exceed the 0.08 ppm threshold established by the Tahoe Regional Planning Agency to protect forest health. Ozone is the major air pollutant stressor of conifer forests in California. Previous surveys of pine tree damage in the Lake Tahoe Basin (late 1980s, 1992, 1997) have found increasing levels of tree injury. This task will provide an updated survey of ozone-caused tree injury in the Basin and will examine the relationship between the spatial and temporal distribution of ozone in the Basin (from a network of 32 passive ozone samplers (2-week periods) in addition to the traditional monitoring network). As part of another forest impact study of 24 tree plots in the Tahoe Basin, 2-week passive sampler measurements of nitric acid will also be available to support the atmospheric deposition study.

1.6.3.2 Improvement of Basic Monitoring

Additional aerometric (air quality and meteorological) sites are needed to provide better spatial coverage of the Basin and to gather pertinent aerometric data needed for modeling and deposition calculations. Several existing and proposed sites have been identified for measurements. Two mid-lake sites are highly desired to characterize the spatial variation in dry deposition over the Lake and, in particular, the differences between shoreline and mid-lake. A fully instrumented monitoring site on the Lake is not feasible from power and servicing perspectives. However, some passive sampling systems or battery-operated instruments are feasible. In addition, some monitoring from a boat is planned during the winter and will characterize some of the spatial variations over the Lake.

The aerometric network should also characterize the most likely transport routes for pollution from the Central Valley into the Tahoe Basin. Transport of ozone into the Basin is most likely to occur during the longer days of summer and to preferentially follow major river canyons (CARB, 1979). Because transport up the western Sierra slope is not constantly occurring, an isolated (minimal local sources of pollution) monitoring location near the crest of the Sierra west of Tahoe (e.g., Homewood Ski Resort) is highly desired to characterize regional background concentrations and document trans-Sierra transport. Furthermore, a wide distribution of monitoring sites are needed around the Lake to characterize the various air flow movements within the basin and to identify various source-receptor combinations (e.g., South Lake Tahoe area (S), Cave Rock (E), Thunderbird Lodge (NE), Incline Village (N; likely to be closed or limited to ozone), Lake Forest (NW)). In Figure 4, proposed air quality monitoring sites (other than CO only) are shaded in solid pink circles (the Incline Village site is shown as a white circle with pink border because the site will likely be shut down). Proposed meteorological sites with remote sensing for conditions aloft are shown in black circles (note: two different remote sensing instruments will be located at either Sugar Pine Point State Park or at the Tahoe Airport). The proposed collocated air quality and meteorology aloft site at Thunderbird Lodge is shown as a solid pink circle with black border. The recommended new or upgraded monitoring sites are discussed below.

1.6.3.2.1 Transport sites – Echo Summit, CA; Homewood, CA; Loon Lake, CA

The monitoring site at Echo Summit was established a couple of years ago and is the only current site fully equipped to characterize the quality of the air at the upwind edge of the Tahoe Basin. Although the data from this site are useful, they are not ideal because of the undue influence of local emissions (e.g., idling vehicles and US Highway 50).

A potential site near the top of the Homewood Ski Resort provides close to the ideal location for characterizing air quality on the western (typically upwind) boundary of the Tahoe Basin. The site is near the McKinney Creek Valley, which topographically would be one of the most likely routes for the transport of polluted air masses up the Rubicon River and into the Tahoe Basin. The proposed site's altitude is just below 8000 feet (MSL) and existing infrastructure includes power and phone lines but the lines would

need to be run some distance to be in an appropriate monitoring location (away from trees and diesel exhaust from snow grooming equipment during winter). The meteorological measurements will include wind speed, wind direction, temperature, humidity, and light scatter. Only low maintenance air quality instruments are currently proposed for Homewood – a BAM10 and, during summer, a TWS. Because the site will be inaccessible for 3-4 months during the spring and fall when the ground is too wet for vehicles and the ski lifts are not in operation, quality assurance, maintenance, and repairs would not be possible and critical data would not be collected or would be of unknown quality. To avoid not having data at the transport site during potentially critical periods, CARB is pursuing the option of having the full transport site (with remote sensing of winds to altitudes at least equal to that at the crest of the Sierra) located further west on the western slope of the Sierra Nevada near Loon Lake and having a low maintenance meteorological and air quality instrumentation at the top of Homewood for confirming any continued transport beyond Loon Lake to the Tahoe Basin. Air quality data from the Loon Lake location would provide an upper estimate of the amount and frequency of material being transported to the Tahoe Basin. Additional analyses of the ambient and modeling data would be necessary to refine the estimates of transport impact (magnitude and frequency) to ensure that potential control measures are appropriately pursued between local (in-basin) and upwind (out-of-basin) emission sources.

Air quality measurements include ozone (O_3), carbon monoxide (CO; with a high-sensitivity analyzer), total reactive oxides of nitrogen (NO_x), continuous nitrate (NO_3), two-week-sampler (TWS; PM_{2.5}, PM₁₀, TSP, speciation), and beta attenuation monitors (BAM_{2.5} and BAM₁₀). These routine measurements will supply the basic data for setting the upwind (west-side) context of the air at the boundary of the Basin and for interpreting special nitrogenous specie observations (by Laser-Induced-Florescence) that are planned for part of the year. The extreme weather conditions during winter (strong winds and deep snow) and the remote location make the set-up and operation of this site particularly difficult. These data will provide the basis for assessing the quality of the air approaching the Basin and for quantifying in-basin contributions and impacts at the sites near lake-level.

1.6.3.2.2 Cave Rock, NV

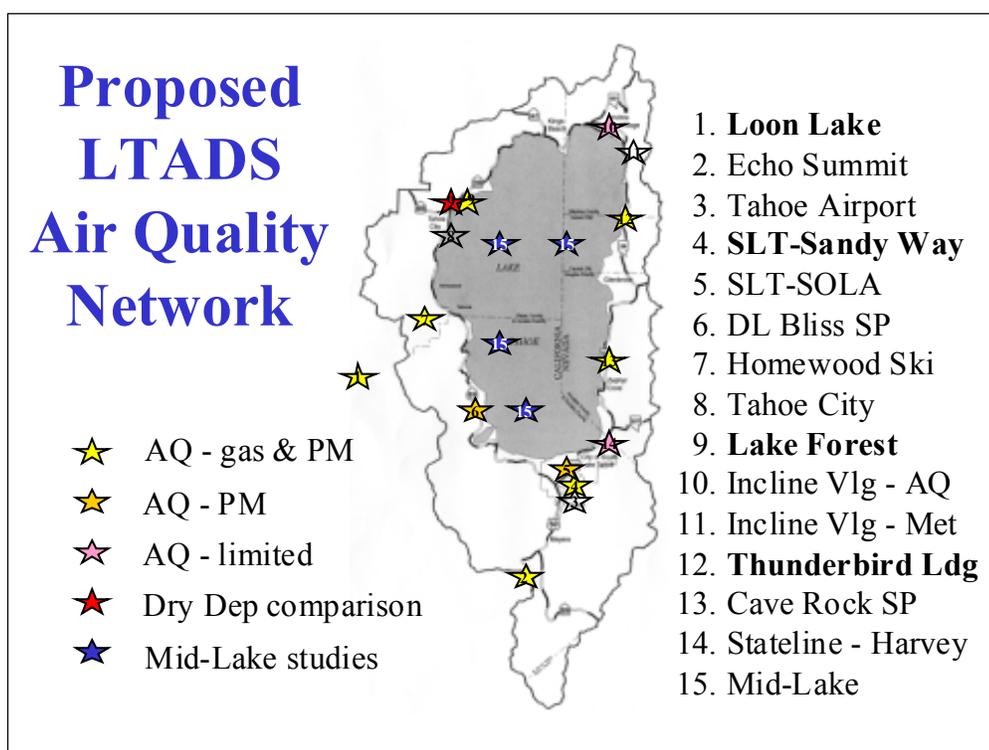
This site on the eastern shore of the Lake currently monitors only ozone. The instruments for sampling (1-in-6 day schedule) PM_{2.5} and PM₁₀ will be replaced by a quiet, continuously operating BAM for TSP. It is anticipated that this site will occasionally be impacted by emissions from the nearby highway and from the South Lake Tahoe urbanized area. Analysis of the hourly air quality and meteorological data will yield additional insights into the magnitude and frequency of in-basin impacts.

1.6.3.2.3 Lake Forest, CA (Coast Guard - meteorology, TRG lab – air quality)

This recommended new multiple location site on the northwestern side of the Lake would include the meteorological measurements from the Coast Guard dock and new instrumentation at nearby facilities. Ozone, carbon monoxide, total reactive oxides of

nitrogen, TWS, and BAM (PM2.5, PM10, and TSP) measurements would be made at the TRG building (old fish hatchery). This site will be one of the three anchor sites within the Tahoe Basin. This site should also detect any ozone transport from the Central Valley following the circuitous route up the I-80 corridor, over Donner Summit, and making a 90 degree turn south at Truckee to follow the Truckee River upstream into the Tahoe Basin.

Figure 4. Lake Tahoe map showing the approximate location of 11 air quality monitoring stations and four meteorological stations (two collocated) for remotely sensing vertical profiles of the atmosphere within the Tahoe Basin.



1.6.3.2.4 Echo Summit, CA

This existing monitoring site was established in 2000 to characterize the frequency and magnitude of pollution transport up the Sierra slope to the Tahoe Basin. Air quality measurements at this site include O₃, NO_x, CO, and filter-based PM2.5. No monitoring upgrades are proposed for this site other than raising the height of the monitoring inlet. The existing monitoring site is not ideal in that the power supply is not as stable as desired and local emissions can bias the measurements (e.g., Highway 50 and idling trucks). Even so, the current monitoring network indicates this site experiences the most frequent instances of “high” ozone concentrations (for the Tahoe Basin; still below the California ambient air quality standard). The undue local influence caused by local idling trucks will be reduced by placing the sampling inlet probe near the top of the

10-meter meteorological tower; it may even be eliminated if and when the truck operations are moved elsewhere.

1.6.3.2.5 Mid-Lake

A large buoy on the Lake would provide an ideal site for characterizing conditions and processes near the lake surface with minimal impact from local sources. However, the power requirements of various instruments cannot be met easily with batteries for an extended period of time. Furthermore, the unique environment creates additional sampling and servicing problems. Space and power are limited on existing buoys on the Lake and the preferred option of operating a TWS on a buoy is not practical. However, the small size of mini-volume samplers (mini-vol) that can be operated for 24 hours on battery power may prove a viable option. It is recommended that the 47mm filters be masked to increase the density of the sample if analysis by X-ray fluorescence (XRF) is desired. Because the number of samples on the Lake will be limited, it is important that sufficient material is collected for detection.

Six buoys are available for use on the lake (Figure 5). To characterize variations that occur over the Lake, mini-vols set up to sample TSP (or possibly PM10 as larger particles not likely to be present in significant quantities) ought to be established at various locations on the Lake (e.g., buoys TDR2, TB3, and TB1). Servicing the equipment at these buoys is difficult and 15 visits are planned. Two samplers would be attached to each buoy for collecting 24-hour samples on both teflon and quartz filters so that full compositional analyses can be performed.

A boat operating on the Lake could also provide information about spatial and temporal variations in material assuming the sampling inlets are not contaminated by emissions from the boat. The UCD aircraft group proposes to collect data on 10 days during five periods during the winter when the local (in-basin) emission sources might be expected to have their dominant impact. A particle sizing counter will be operated to provide particle count information in aerodynamic diameter sizes between 0.5 – 25 μ m over the Lake. When not on the UCD boat or airplane, the particle counter will be rotated seasonally among the sites monitoring more than one pollutant.

1.6.3.2.6 South Lake Tahoe - Sandy Way, CA

The Sandy Way site (located south of Highway 50) is CARB's main air quality monitoring site in South Lake Tahoe and the Tahoe Basin and will be one of the four anchor sites during LTADS. Air quality measurements at this site include CO, O₃, NO_x, PM_{2.5}, PM₁₀, and wet deposition. The PM_{2.5} and PM₁₀ samples are also analyzed for its compositional nature. These measurements will be enhanced with the addition of NO_y, at least on a temporary basis until any differences between the NO_x and NO_y measurements are documented and explained. This site provides the best characterization of the impacts of anthropogenic emissions in the basin. Additional new instrumentation planned for this site includes a TWS, BAM_{2.5}, BAM₁₀, and BAM_{tsp}

1.6.3.2.7 South Lake Tahoe - (SOLA), CA

This site is located near the beach on the north side of Highway 50 in SLT. The filter-based PM_{2.5} sampling and the nephelometer at this site will be supplemented with a TWS and BAMtsp. The BAM will be installed in its own environmentally controlled shelter. An evaluation of the PM impacts associated with Highway 50 will be made possible by comparing data from the BAMtsp instruments (hourly data) and the contemporary TWS data for the Sandy Way and SOLA sites. The TWS at SOLA is unique in that it will be constructed to provide day-time average and night-time average measurements of nitric acid and ammonia. This information will be used to troubleshoot any problems in validating the performance of the photochemical air quality model. This TWS will only operate every other 2-week period. During the alternate 2-week periods, the clean filters and denuders will be installed but not operated to provide field blanks for the laboratory analysis.

1.6.3.2.8 D.L. Bliss State Park, CA

This site is part of the national Interagency Monitoring of PROtected Visual Environments (IMPROVE) network. It is located near the west-southwest shore of the Lake at about 250 feet above Lake level. This site is infrequently impacted by emissions from SLT and serves as a good background site for particulate matter within the Basin. The site is somewhat difficult to access following a snowstorm.

1.6.3.2.9 Thunderbird Lodge, NV

This site will be the anchor PM monitoring site on the NE shore of the Lake. In addition to currently collected meteorological and PM_{2.5} filter data, the Lodge will also support a TWS and BAMs in the PM_{2.5}, PM₁₀, and TSP sizes.

1.6.3.3 Particle Measurements

All phosphorus and a portion of the nitrogen input to the Lake are thought to be in particle form. An important part of the nitrogen deposition is the nitrogen deposited in particle form as NH₄NO₃. Some investigators have observed more gaseous HNO₃, others have seen more NH₄NO₃.

Ideally for calculation of particulate deposition, both the concentration and size of the particles should be known hourly. Both time resolution and size resolution for PM observations are needed for the calculation of deposition. This information is needed because the deposition will be calculated as concentration times deposition velocity and the deposition velocity is very much dependent on hourly changes in meteorology as well as particle size.

Ideally for identification of sources, both time series of concentration and speciation of chemical composition should be known. Hourly changes in concentration may be related to shifts in wind direction or changes in emissions activity, such as traffic density. Thus, hourly information can help identify likely sources. Daily differences in 24-hour concentration could be related to meteorology or to emissions activity such as

weekend traffic, road sanding, or fires. Spatial differences in concentration can be related to wind direction, proximity to individual sources (e.g., roads), or general proximity to urban development. Spatial differences will be larger and somewhat more clearly interpreted from short term concentration measurements.

Figure 5. Location of buoys on Lake Tahoe available for research use.



None of the recommended measurement methods is ideal with respect to providing a complete package of time resolution, size resolution, and chemical speciation. Thus, a

combination of methods and tasks are recommended to provide temporal resolution, size resolution, and chemical composition of PM.

1.6.3.3.1 BAM2.5, BAM10, and BAMtsp

The BAM data provide hourly time resolution of PM concentrations. By operating BAMs with different sampling heads, multiple size fractions can also be known. Knowing the diurnal variation in concentration is essential for estimating deposition because the deposition velocity varies diurnally in response to changes in meteorology and particle size. The hourly time resolution provided by multiple BAMs with different size cuts supports improved temporal allocation of the specie profiles generated by size with the TWSs. Together, the size and temporal allocations will support improved deposition estimates and source identification.

1.6.3.3.2 Two-week samplers (TWS)

CARB staff will manufacture six two-week samplers for the Tahoe field study. Five of the samplers will be deployed (at Loon Lake, SLT-Sandy Way, SLT-SOLA, Lake Forest, and Thunderbird Lodge) with the sixth instrument positioned on top of the Homewood Ski Resort for several weeks during summer. At other times, the sixth sampler can be held as a back-up in case one of the other samplers should malfunction or collocated with another TWS for quality assurance (precision) purposes. To perform acceptance testing to ensure that the samplers are working properly before deployment to the field, they will be run on the roof of a CARB building in Sacramento for two weeks. Those instruments with acceptable performance will be deployed to the Tahoe study while instruments with apparent problems will be repaired and tested again.

The two-week sampler permits analysis of aerosols on multiple substrates, and the long sampling period minimizes problems of trace component detection. We propose three channels for PM_{2.5}, PM₁₀, and TSP on quartz filters and three channels for PM_{2.5}, PM₁₀, and TSP on Teflon filters. The filters will be analyzed by ion chromatography, automated wet chemistry, XRF, atomic absorption. Two channels are also needed in each observation period (with denuders) to provide HNO₃ and NH₃ measurements. To contrast the day- and night-time HNO₃ and NH₃ concentrations (i.e., at SOLA), four channels will be necessary. Thus, for the two-week period, we recommend operation of two channels during the night-time hours and another two channels during day-time hours. This new twelve-hour on/off operational feature will require some development and testing.

The PM_{2.5}, PM₁₀, and TSP filter samples and the denuder samples from the TWS network will be analyzed in the laboratory for a number of compounds. All three size fractions of the TWS will be analyzed for mass. However, only the highest 70% of the samples during each quarter will be subjected the specific analyses shown in Table 6.

Table 6. Analytical methods and analytes to be measured

Analysis Method	Analytes
Filter samples	
Gravimetric	Mass from teflon filter
XRF (analysis of PM10 & TSP fractions only)	40 elements from teflon filter (Na, Mg, Al, Si, P, S, Cl, K, Ca, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Ga, As, Se, Br, Rb, Sr, Y, Zr, Mo, Pd, Ag, Cd, In, Sn, Sb, Ba, La, Au, Hg, Tl, Pb, U)
Auto Colorimetry	NH ₄ ⁺ from quartz filter
Ion Chromatography	Cl ⁻ , NO ₂ ⁻ , NO ₃ ⁻ , PO ₄ ⁼ , SO ₄ ⁼ from quartz filter
Atomic Absorption	K ⁺ , Na ⁺ , Mg ⁺⁺ , Ca ⁺⁺ from quartz filter
Thermal Optical Reflectance	OC, EC, 7-fraction C from quartz filter
Ion Chromatography	NO ₃ ⁻ on nylon filter
Denuder samples	
Ion Chromatography	HNO ₃ from sodium carbonate coating
Auto Colorimetry	NH ₃ from citric acid coating

This data stream will provide detailed composition with some important size information for improved deposition estimates. The phosphorus measurements in two size fractions is of particular interest is to support improved calculation of P deposition rates. Filter sampling methods provide more complete composition information (by ion chromatography, XRF, atomic absorption and TOR). This additional composition information is needed to enhance source apportionment by CMB. The AA is needed for soluble potassium for identification of biomass burning. EC/OC is important for closure of the total mass. Knowledge of the difference between day- and night-time HNO₃ is needed for diagnosis of model performance for nitrogen species.

1.6.3.4 Nitrogen Species Measurements

Measurements are needed principally for boundary conditions (BC) and for model performance evaluation (MPE). Modeling is necessary for understanding the nitrogen chemistry because the chemistry is non-linear. For modeling and analysis tasks observed boundary conditions (BC) should include hourly NO_Y. HNO₃ observations are also needed, but hourly data are not feasible. One TWS in the most urbanized area of Lake Tahoe (SOLA) will be modified to enable measurements of HNO₃ and NH₃ on a 12-hour basis. This enhancement will enable better characterization and provide better data for model performance evaluation because the atmospheric chemistry and processes are so different between day and night.

Model performance evaluation (MPE) includes operational performance evaluation and diagnostic (MPE). For diagnostic MPE, hourly data is ideal. Hourly NO_Y should be collected. Though we cannot collect hourly HNO₃, some day vs. night concentration data would be valuable. For diagnostic MPE, if it were a question between sampling one-day (24-hour average) once every six days vs. an integrated two-week sample, the 1-in-6 day sample would have more value for diagnostic purposes. However, if the two-

week sample happened to initially match well with modeled concentrations, that would give some confidence in the model results. In the more likely case that the model did not initially replicate the concentration of HNO_3 from two-week sampler, the two-week samples would not be very useful for diagnostic purposes. For support of MPE, a sampling strategy should be devised that provides some observations of the difference between concentrations during the day and at night.

1.6.3.4.1 NO_Y measurements

These instruments provide hourly NO_Y for boundary conditions at Homewood and for model performance evaluation at all three sites (Loon Lake, TRG lab, Sandy Way). In addition, another NO_Y analyzer will be in operation further down the western slope of the Sierra Nevada along with a LIF instrument at Blodgett Forest.

Concentrations will be low in the Lake Tahoe area so it is important to check and quantify any baseline drift in the instruments. Furthermore, the Limits of Detection for each instrument need to be characterized well for full and reasonable application of the data.

1.6.3.4.2 Two-week samplers (TWS)

Data from the two-week sampler are needed for complete characterization of chemical species for both boundary conditions and model performance evaluation. These instruments would be established at four and one half sites to provide two-week integrated samples. If feasible, the half-time site (i.e., SOLA) sampler will be modified to provide day-time and night-time HNO_3 and NH_3 measurements to improve evaluation of photochemical model performance (different day/night chemistry). An operational issue is the programming of the sampler timer to adjust for the variable lengths of day and night during the year.

1.6.3.5 Deposition Measurements

1.6.3.5.1 Snow pack sampling with analysis for N and P

Atmospheric transport of nutrients to the lake can occur indirectly, by deposition in rain or snow falling in the basin, or by deposition into the snow pack. These indirect processes occur as long-range transport (e.g., nitric acid in "acid snow"), deposition of local primary emissions onto snow, or incorporation of soil or ash into the snow banks. While stream monitoring by the EIP already measures most of the runoff inputs to the lake, snow analysis allows distinguishing any air-deposited fraction of surface water dissolved nutrients from the naturally occurring load leached out of the basin's soils. Furthermore, snow sampling will also assist in estimating the nutrient load deposited to the lake by direct precipitation. Estimates of the total (dry and wet) deposition of nutrients that accumulated during the winter will be made by sampling the snowpack in spring (before significant melting) and chemically analyzing the samples. Samples will be collected on the upwind (west) and downwind (north & south) sides of the Basin to detect spatial differences and evaluate any in-basin influence.

1.6.3.5.2 Wet-Dry “bucket” deposition

The Tahoe Research Group (TRG) has developed a long-term record of wet- (precipitation) and dry- (air contact with a water surface) deposition in the basin. This time series is invaluable for extrapolating the findings of our single-year field program to estimate nutrient accumulation in the lake over future decades. Collecting TRG “bucket” deposition data alongside an array of air quality and meteorological monitoring equipment will facilitate understanding the depositional processes in these samplers so that these data can be quantitatively related to measured or modeled atmospheric deposition. Continuation of this sampling program is needed to better establish accuracy and potential extrapolation.

1.6.3.5.3 Eddy covariance and surface flux

This effort is not currently funded but it can be done at a later date and the results would still be applicable to this study. Deposition velocities of airborne materials to surfaces (especially wet surfaces) are modulated by micrometeorological conditions that control near-surface turbulence, mixing, particle growth, and surface conductance. Conditions on the surface of Lake Tahoe range from glassy to wind-whipped, temperature structure at the water-air interface ranges from a cold lake overlain by warm air to a warm lake overlain by cold air. Effective deposition velocities probably vary by an order of magnitude or more on temporal scales from hours to seasons. Eddy covariance measurements of wind, air temperature, water vapor and water temperature permit theoretical calculations of deposition potential to tie measured or modeled air quality to effective deposition flux.

1.6.3.6 Source-Oriented Sampling and Inventory Improvement

Emission rates and timing are not well known for several significant sources in the basin (e.g., road dust, sanding, wood smoke, prescribed fires). Failure to place emissions properly in space and time may lead to incorrect source allocation for either air quality or deposition; moreover, it may also lead to gross errors in calculating deposition due to the strong temporal variation of deposition potential at the lake surface.

1.6.3.6.1 Source sampling with mini- or medium volume samplers

Source allocation by Chemical Mass Balance methods is a proven tool for relating emissions to ambient air quality. Source specific PM samples will be collected with mini- or midi-vols, then analyzed by the same methods applied to the ambient samples in order to provide basin-specific source profiles for important sources (road dust, wood smoke, etc.). These data will permit complex multivariate analyses for source-allocation independent of a basin model or emission inventory, provide a more robust measure of nutrient content of local emissions, permit multi-species deposition calculations that are impractical to incorporate into a regional or basin model, and facilitate quality assurance checks for model performance.

1.6.3.6.2 General PM inventory improvements

Some significant in-basin emissions cannot be properly estimated from existing demographic, land use, or activity data. Three new emission inventory categories have been identified as needed:

Tahoe-specific phosphorous emissions from geologic materials

Analyze samples for chemical analysis to characterize local soil dust and road sanding material – especially size distributions of insoluble fines and total and soluble phosphorus content. Determine emission rates on various road types. Estimate timing of emissions.

A contractor (DRI) will collect source-specific profiles for wood smoke, road dust, and road sanding.

Tahoe-specific phosphorous emissions from wood smoke

Determine when, where, and how much wood is burned in the basin. Determine realistic emission rates for fireplaces, wood stoves, prescribed fires, and, if possible, uncontrolled fires. Determine demand functions for wood burning based on heating demand, day of week, holidays, etc.

A contractor (UCR/CE-CERT) will characterize the particulate matter resulting from wood burning activities in the Tahoe area, including wood burning stoves and fireplaces, prescribed burns and wildfires. The amounts of fuel used for cooking and heating in the Tahoe region will be characterized by surveying residents and small businesses at various seasons.

Tahoe-specific motor vehicle characterization

The current emission inventory for the Tahoe basin indicates that motor vehicles are the dominant source of gaseous emissions (Table 7). Because a high proportion of the vehicles operated in the Tahoe basin are not garaged there, it would be helpful to confirm the actual emissions of vehicles at high altitude and cool temperatures. Many newer models have electronically controlled combustion systems and probably do not emit pollutants significantly differently under Tahoe conditions (high altitude, low temperature) than under their typical conditions. Remote sensing measurements will be useful for confirming any differences in the emissions for vehicles when operated under Tahoe conditions. In addition, enhanced and updated traffic data (speed, volume) are needed to appropriately resolve, spatially and temporally, the unique motor vehicle emission patterns in the Tahoe Basin.

A contractor (UCR/CE-CERT) will investigate Tahoe-specific motor vehicle activity and motor vehicle age and type distributions by supplementing existing data with seasonal video images and Global Position Satellite driving patterns in the Basin.

Table 7. Y2000 emissions by source category for the Lake Tahoe Air Basin.

(tons/day)							
Source Category	TOG	ROG	CO	NO_x	SO_x	PM	PM10
Stationary	0.93	0.51	0.08	0.15	0.01	0.01	0.01
Area-Wide	4.10	2.28	13.93	0.38	0.06	7.68	4.92
On-Road Motor Vehicles	4.79	4.40	54.41	3.28	0.04	0.09	0.09
Other Mobile	3.15	2.88	19.21	2.06	0.21	0.21	0.20
Natural	0.00	0.00	0.06	0.00	0.00	0.01	0.01
Grand Total	12.98	10.08	87.69	5.87	0.33	8.01	5.23

1.6.3.7 Meteorological Measurements

In addition to existing regional meteorological data (soundings, wind speed, temperature, relative humidity, etc. from NWS sites), local data are needed to support both the long-range transport calculations for upwind source areas and the fine-scale calculations of in-basin circulation. Quality assurance efforts are needed to tie the disparate measurements from various monitoring platforms together. The following enhancements are recommended.

1.6.3.7.1 New surface meteorological sites

Because Lake Tahoe is deep and surrounded by mountains, local and meso-scale meteorological processes can exert strong influences on ambient conditions. The meteorological monitoring network must be sufficient (number of sites and locations) to adequately characterize synoptic conditions but also the dominant local and meso-scale processes within the basin. All new air quality sites and all upper air remote sensing sites will have surface meteorological stations installed.

Because of the extreme conditions that can occur, the use of sonic anemometers is recommended for the high altitude locations with heavy snowfall and potentially limited access. A sonic anemometer instantaneously determines wind speed and direction (turbulence) by measuring the change in velocity of sound waves travelling between a pair of transducers due to the effect of the wind. The sonic anemometer has no moving parts and can accurately measure slow wind speeds (i.e., has no threshold speed like standard anemometers).

1.6.3.7.2 Meso-scale meteorology aloft (mini-sodars)

Mini-sodars use sound waves to measure temperature and wind speed in three dimensions. These have a vertical range of 800 m., sufficient to document in-basin inversions (although they may not resolve very shallow surface inversions). Three sites are proposed for different regions of the basin (NW shore, NE shore, and S shore) so that horizontal and vertical gradients in winds can be measured and divergence or convergence over the Lake can be detected. The planned locations for the mini-sodars are Tahoe City (wetlands treatment center), Incline Village Waste Treatment Center,

and South Lake Tahoe Airport. If a full transport site is established at Loon Lake, another mini-sodar or radar wind profiler would be needed there to capture air flow up to the altitude of the Sierra crest.

1.6.3.7.3 Regional meteorology aloft (RWP/RASS)

Radar wind profilers are used to evaluate transport winds and vertical temperature structure through the lower troposphere. Two profilers are recommended for this study area: an existing system located at Grass Valley on the western slope of the Sierra Nevada and another near the South Lake Tahoe Airport. In addition, RWPs located at Chico and Elk Grove will provide additional information about conditions in the Central Valley and likely upwind of the study area.

1.6.3.8 Aircraft Aerometric Measurements

Measurements of pollutants (including O₃, NO_y, particle sizing counter), temperature, relative humidity, and also winds to some extent will be made above the basin floor, in vertical columns, and along specified transects by an instrumented aircraft (Cessna 182). The aircraft measurements will help link sparse meteorological networks (e.g., tracking transport up the Sierra slope) and provide valuable data to validate model performance in three dimensions. Deployment of the aircraft will be for two days per observational period, with two sampling flights per day. Five such deployments are planned during the summer and fall seasons of 2002. When appropriate, deployment will be coordinated with other researchers to provide for comprehensive data collection among all program participants. Otherwise, deployments will be distributed to collect data during a variety of meteorological conditions. To better sample the near lake surface environment in winter, when low mixing depths and meteorological conditions adverse to flight operations are likely, the UCD staff will install nearly all the same instruments on-board a research vessel (the John Le Conte) operated by the UCD Tahoe Research Group.

Previous UCD flights have indicated appreciable amounts of gaseous nitrogen as well as particulate nitrogen in the atmosphere. Overall, gaseous ammonia was the single largest component of the nitrogen budget (Table 8). Under typical conditions total nitrogen concentrations were greatest over the lower and middle elevations of the Sierra-Nevada (closest to the Central Valley) and were lowest within the Tahoe Basin. The phosphorus analyses are limited to just two samples in a fire plume. The amounts of phosphorus in the small ($\leq 3.5\mu\text{m}$) and large ($> 3.5\mu\text{m}$) particles were similar.

However, during a few flights in the Tahoe area when the air was impacted by ongoing forest fires, nitrogen levels were the highest measured during that field study, greater even than the air sampled nearest to the Central Valley. The increase in nitrogen concentration was primarily due to organic nitrogen compounds in the forest fire plumes. These organic N compounds are of interest not only because of their effect on Lake Tahoe clarity, but also because a portion of these compounds could be toxic.

While atmospheric phosphorus was occasionally found over the lower and middle elevations of the Sierras, it was more commonly present in the Tahoe Basin. Concentrations of P were highest in air impacted by forest fires; under these conditions, phosphorus was found in roughly equal amounts in both fine and coarse particles. The molar ratio of N:P in these coarse and fine particles from forest fires was approximately 10:1.

These measurements of elevated nitrogen and phosphorus levels in plumes from forest fires clearly indicate that fires can be a significant source of these pollutants to Lake Tahoe. In the absence of forest fires, the results suggest that emissions from the Central Valley could be a significant source of nitrogen to Lake Tahoe under certain meteorological conditions in the summer. Quantifying the contributions of forest fire and Central Valley pollutants to Lake Tahoe will require a great deal more study.

Table 8. Aircraft measurements of N and P species.

Location:	Sierra Foothills		Tahoe Basin		Star Fire Plume	
Variable:	n	Mean	n	Mean	n	Mean
Total Soluble N	8	536	12	129	2	578
Gases: % NH₃	8	72	12	55	2	74
%HNO ₃	8	14	12	21	2	11
% Organic N	8	14	12	22	2	14
Particles: d #3.5 : m						
Total soluble N	8	97.2	12	57.2	2	162
% Ammonium	8	44	12	39	2	13
% Nitrate	8	29	12	20	2	50
% Organic N	8	30	12	40	2	37
Total soluble P		N/A		N/A	2	12
Particles: d > 3.5 : m						
Total soluble N		N/A		N/A	2	83
% Ammonium		N/A		N/A	2	38
% Nitrate		N/A		N/A	2	22
% Organic N		N/A		N/A	2	34
Total soluble P			3	2.8	2	14

Notes: 1. Total N is listed as nmol-N / m³ and total P as nmol-P / m³;
 2. “n” = number of samples.

Additional UCD measurements by aircraft are recommended for the up-coming field study to characterize aerometric conditions aloft and to better address questions regarding the amount and sources of the N, P, & PM material in the atmosphere. The UCD aircraft will provide input and validation data for the Lake Tahoe modeling exercises by measuring vertical profiles of wind, temperature, relative humidity, aerosol counts (for diameters greater than 0.3 and 3 micrometers), and concentrations of ozone, NO, and NO_y (~1 ppbv detection limits). Gas phase ammonia and nitric acid and particulate phosphorous, nitrate, and ammonium will be collected at two altitudes per flight through an annular denuder-filter system during the spring, summer, and fall. These instruments will be flown on-board a Cessna airplane flown over and across Lake Tahoe. In winter, these instruments will be installed in a research vessel that will make dedicated cruises on the lake.

1.6.3.9 Modeling

1.6.3.9.1 CCOS/CRPAQS modeling runs

ARB has developed databases for emissions, meteorological, and air quality data and applied them in models to address regional air quality problems in the Central Valley. We will use these modeling runs planned for 2003/04 to estimate the sources of nitrogen and PM in air transported to the Tahoe basin and to approximate the total upwind contribution of N, P, PM, and ozone to the air quality in the Lake Tahoe basin. These modeling runs will be based on 4-km grid cells and the model evaluation efforts will not have focused on the performance in the Tahoe basin. Although these modeling runs will represent various seasons, they will not include any phosphorus estimates because it was not a focus of the CRPAQS and CCOS studies. Because the focus of these two studies is the development of State Implementation updates for ozone and PM, the various future year scenarios are not likely to fully address the depositional issues of concern for Lake Tahoe.

1.6.3.9.2 Extend CCOS/CRPAQS models to provide Lake Tahoe basin details

This effort will modify and extend the CCOS/CRPAQS modeling tools to include detailed treatment of Sierra west slope and Tahoe Basin. The models would be enhanced to provide 1-km grid resolution in the Tahoe basin and fine-tuned to fit with observational data collected during the 2002/03 field study. This modeling effort would also include the enhanced emission inventory (including P) for the Tahoe basin, air parcel trajectory analyses, and evaluation of various emission control scenarios.

1.6.3.9.3 Chemical Mass Balance Receptor Modeling

Receptor models use the chemical and physical characteristics of gases and particles measured at sources and receptors both to identify the sources and to quantify their contributions to the pollutants measured at the receptors. The particle characteristics must be such that: 1) they are present in different proportions in different source emissions (*i.e.*, they provide a means by which to distinguish sources); and 2) these proportions remain relatively constant for each source type. Common types of receptor

models include: chemical mass balance (CMB), principal component analysis, and multiple linear regression. The CMB is the basic receptor model, and the derivation of the other receptor models from fundamental physical principles begins with the CMB.

This application of a CMB receptor model will use updated information about Tahoe-specific emission source characteristics along with the characteristics of the pollutants at the receptor to determine the contribution of each source to the pollutant level at the receptor.

1.7 STUDY TIMELINE – PRODUCTS AND DELIVERY DATES

The key products of this study are estimates of deposition amounts for total particulate matter, ozone, particulate phase phosphorus, and gaseous and particulate phase nitrogen. Equally important is the identification of significant sources of that deposition. The study products and desired delivery dates are listed below.

- 1) Boundary concentrations of nitrogen species:
 - a) Based on existing monitoring data – June 2002
 - b) Based on upcoming runs of models for CCOS (gases, October 2003) and CRPAQS (PM, July 2004) episodes
 - c) Based on data collected during this field study – January/September 2004
- 2) Boundary concentrations of phosphorus species:
 - a) Based on existing monitoring data – June 2002
 - b) Based on data collected during this field study – January/September 2004
- 3) Quality-assured database of observed concentrations of phosphorus, nitrogen, PM, and other species of interest – January 2004
- 4) Quality-assured database of meteorological data – March 2004
- 5) Deposition estimates for N & P:
 - a) Based on observed concentrations & forms, winds, estimated deposition velocities – January/September 2004
 - b) Based on LT Basin model – December 2004
- 6) Source identification of N & P deposition – December 2003
- 7) Relative contribution of local and regional sources to N & P deposition
 - a) Based on current emissions inventory and meteorology – June 2003
 - b) Based on CCOS modeling – December 2003
 - c) Based on CMB modeling and time series analysis – January 2004
 - d) Based on CRPAQS modeling – December 2004
- 8) Modeled, validated meteorological fields (wind, temperature, etc.) for use in modeling and data analyses – September 2004
- 9) Modeled concentrations and deposition of N species based on LTAB modeling runs – October 2004
- 10) Scenario runs of LTAB model – December 2004

2 STUDY DESIGN

2.1 SCOPE

2.1.1 Forest Health and Ozone

Nitrogen oxide and ammonia deposition to the Lake Tahoe basin and more broadly throughout the Sierra Nevada may have negative consequences associated with changing the nutrient balance and acidification of lakes and streams. It may also alter ecosystem function by changing nitrogen-limited systems to ones that are saturated with available nitrogen. *Korontzi et al.* (2000) show that nitrogen deposition to the forests of the San Bernardino Mountains, west of the Los Angeles Basin, has shifted the ecology in low lying regions from nitrogen limited to nearly nitrogen saturated conditions. They also report a correlation between nitrogen deposition and increased NO_3^- in the region's watersheds. These effects no doubt have parallels in the forests and hills downwind of the Sacramento metropolitan region including the site at UC-BFRS, the American River basin and possibly Lake Tahoe. Species specific effects on California's ecology have also been the subject of discussion. For example, *Keeley et al.* (1997) argue that NO or NO_2 may be a signaling agent for seed germination in fire sensitive species. Downwind of urban areas, the implication is that many species may be perpetually germinating instead of germinating only after the clearing effects of fire. There are reports of direct uptake of artificially deposited organic nitrogen compounds (amino acids) (*Nasholm et al.*, 1998), which raise the question of whether atmospheric organic nitrates might be directly assimilated either as nutrients or with toxic consequences. Recent work at the plant and leaf scale show that the mechanisms for nitrogen oxide exchange are complex and that there may be a compensation point controlling biosphere-atmosphere fluxes of some nitrogen oxides (*Lerdau et al.*, 2000; *Sparks et al.*, 2001). A compensation point is an atmospheric concentration below which nitrogen oxides are in the net emitted and above which they are, in the net, deposited from or to an ecosystem.

Trent Procter organized and administered the pine tree assessment study known as Project FOREST (Forest Ozone REsearch STudy) that was conducted in the early 1990's. The ARB was a cooperator, and funded the Sierra Cooperative Ozone Impact Assessment Study led by John Carroll at UC Davis. Together, USDA Forest Service and USDI National Park Service staff surveyed ozone-caused pine tree damage in National Forests and Parks on the western slope of the Sierra Nevada, and UC Davis monitored ambient ozone and meteorological conditions. Various manuscripts were published in the mid-to-late 1990's (e.g., Van Ooy and Carroll (1995), Arbaugh et al. (1998)).

The project plan is to survey 24 tree plots in the Lake Tahoe Basin, supplement the active ozone monitoring already underway with a network of 32 passive ozone samplers, and to analyze the tree effects and ozone data using a GIS-based approach. The \$60,000 allocation in the Tahoe Budget Change Proposal would allow for a study to be done in summer 2002 and a follow-up study in the 2005-2007 period. Maps of the

ozone distribution in the Lake Tahoe Basin will be produced with the data supplied from the continuous monitoring network and the passive samplers.

2.1.2 Nitrogen Species Measurements

Many oxides of nitrogen play key roles in the atmospheric chemistry which results in pollutants with negative effects on health and welfare. For example, NO_x ($\text{NO} + \text{NO}_2$) is needed to produce elevated ozone levels. NO_x also, via conversion to nitrate, is a major contributor to California's fine particulate matter problem.

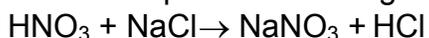
The atmospheric chemistry leading to formation of particulate nitrate is complicated. Fresh NO_x emissions, which consist primarily of nitric oxide (NO) undergo reactions with ozone (O_3) and peroxy radicals to form nitrogen dioxide (NO_2). The NO_2 can be converted to nitric acid by reaction with OH radicals during the day. At night, NO_x also is oxidized to nitric acid by a sequence of reactions initiated by O_3 , that include nitrate radicals (NO_3) and dinitrogen pentoxide (N_2O_5).

The principal chemical loss process for gas-phase nitric acid is its reaction with gaseous ammonia to form ammonium nitrate (NH_4NO_3).



This reversible reaction is believed to be the primary source of fine (<2.5 μm diameter) nitrate aerosol in California's urban air. The equilibrium constant for the reaction is both temperature- and relative humidity-dependent. High humidity and low temperature favor NH_4NO_3 formation. Aqueous NH_4NO_3 is formed at relative humidities above the relative humidity of deliquescence (62%).

Although probably not significant in the Tahoe Basin, another pathway for the formation of nitrate aerosol is a heterogeneous chemical reaction between sea-salt particles and gas-phase nitric acid, leading to thermally stable sodium nitrate production in the particle phase accompanied by liberation of gaseous hydrochloric acid (HCl) from the particles. Gard et al. (1998) focussed their study on the replacement of chloride by nitrate in sea-salt particles at Long Beach.



This reaction may be the principal source of coarse (2.5 to 10 μm) nitrate, and plays an important role in atmospheric chemistry because it is a permanent sink for gas-phase nitrogen oxide species. This reaction is one of the most extensively studied heterogeneous chemical reactions in the laboratory, and the extent to which this occurs is affected by many factors, including gas-phase and particle-phase concentrations, temperature, relative humidity, and reaction time.

Significant amounts of NO_x can be converted to organic nitrates, such as peroxyacetyl nitrate (PAN) which is the most abundant organic nitrate in urban air. The thermal decomposition of PAN is very temperature sensitive. As temperature rises, PAN decomposes back to NO_2 and peroxyacetyl. A deficit exists in observable NO_y species in ambient air, and it is thought that PAN-analog compounds could comprise a significant part of the missing nitrogen species. Nitric acid and ammonia are believed to

be deposited on surfaces very rapidly, while sulfate deposits relatively slowly. NO_x, ammonium, and nitrate aerosol deposit at rates in between these two extremes.

Until recently it was assumed that the end product of tropospheric NO_x was nitric acid. However, a recent research project (Mochida and Finlayson-Pitts 2000) has shown that nitric acid on a surface can react with NO to regenerate NO₂ which can then form ozone and particulate nitrate. Preliminary modeling studies suggest that this reaction may increase the formation of particulate nitrate and that existing models underestimate the benefit of NO_x controls for reducing PM and ozone. This finding may have very serious implications as to the effectiveness of control strategies for both ozone and PM. Additional research is continuing with a focus on providing a more complete understanding of the effect of heterogeneous nitrogen chemistry on ozone and particle formation.

Thus, the atmospheric chemistry leading to formation of particulate nitrate is complicated. The rates of transformations depend on the concentrations of many intermediate species (including ammonia and radical species) involved in reactive organic gases and NO_x photochemical system. Ambient concentrations of secondary particles are not necessarily proportional to the quantities of their precursor emissions since the rates at which they form and their gas/particle equilibria may be controlled by factors other than the concentration of the precursor gas. The rate of NO_x oxidation and the branching ratio between inorganic and organic nitrates depend on the specific environmental conditions in addition to reactant concentrations [Finlayson-Pitts and Pitts (1999), and Seinfeld and Pandis (1998)].

2.1.3 Physical and Chemical Makeup of Particles

The physical and chemical makeup of particles varies depending on the relative mix and proximity of sources, meteorological conditions, and chemical reactions. Particles can be generated directly or can form from chemical reactions of precursor gases such as volatile organic compounds and oxides of nitrogen and sulfur. The organic compounds have significant natural as well as anthropogenic sources while the oxides of nitrogen and sulfur are primarily from anthropogenic sources. The size and composition of many particles generated from gas reactions are dependent on the humidity and temperature of the atmosphere. Often water vapor and semi-volatile gases condense on particles causing them to change in size and composition. Furthermore, some sources (e.g., road sanding, wood burning) are more active in some seasons than others. Because meteorological conditions and source activities vary diurnally and seasonally, and to some extent annually, the number and size of particles also vary diurnally, seasonally, and annually. Thus, the size of a particle in the atmosphere is not constant and can also undergo transformations when it deposits on the surface of the Lake.

Furthermore, the geographic distribution of the various sources and processes creating particles causes spatial variations in the mass, composition, and size distribution of particles. In addition, large particles deposit faster than small particles and so the number and size of particles tend to decline with distance from the source. Thus, particle samples to be collected on buoys on the Lake are anticipated to have less total

mass and a higher proportion of small particles than samples from sites onshore near roadway and other sources.

The size and chemical composition of potentially significant PM sources (e.g., wood smoke, prescribed fires, road dust, road sand, motor vehicles) will be sampled to create source profiles specific to Lake Tahoe and appropriate for conducting chemical mass balance analyses.

2.1.4 Hypothesis Testing

2.1.4.1 *Testing of hypotheses regarding the magnitude of deposition:*

- 1) The magnitude of dry deposition of phosphorus is consistent with the wet and dry bucket observations.

Methods for Testing:

- Collocate dry deposition buckets for comparison of their measured deposition rates with estimated deposition rates calculated from aerometric measurements (concentration of phosphorus in PM_{2.5}, PM_{10-2.5}, TSP, and measured meteorological variables (wind speed, wind direction, temperature, humidity, turbulence).
 - Concentrations from TWS. Infer diurnal variation in concentrations from BAM sampler. Infer diurnal variation in deposition velocity over water and over snow from meteorological observations. Calculate deposition over water (and over snow) based on concentrations and literature values for deposition velocities and, where meteorological data exist, infer or preferably calculate deposition velocities from meteorological observations.
 - Collect samples of spring snow pack (at altitude) and analyze for phosphorus and phosphate. Compare and contrast with calculated deposition to the Lake surface and with observations from buckets at lake level for the same period.
- 2) The concentration of ambient particle phase phosphorus is sufficient and in size fractions capable of depositing at a rate sufficient to confirm the deposition rates observed.
 - 3) The magnitude of deposition of fine particles is sufficient to account for a significant fraction of those fine particles found in Lake Tahoe surface waters.
 - Observe hourly concentrations from the BAM_{2.5} analyzer. Estimate the deposition rates and compare with other inputs to the Lake, e.g., shoreline erosion, stream inflow, etc.

- 4) The magnitude of nitrogen deposition is consistent with the wet and dry bucket observations.
- Measure nitrogen deposition directly by eddy covariance at one site.
 - Measure profiles of nitrogen concentration to calculate deposition rate for nitrogen species at the same one site.
 - Measure concentrations of nitrogen species and estimate deposition velocity based on routine meteorological observations at all sites.
- 5) The forms of nitrogen deposited to the Lake are primarily nitric acid and ammonia
- Use measured concentrations of each species and the calculated deposition velocity to estimate deposition for each species.
 - Measure concentrations of NO_3 , NH_4^+ , and NH_3 in water samples and snow samples.

2.1.4.2 Testing of hypotheses regarding the sources of species deposited

- 1) The phosphorus and phosphate contribution is primarily from local sources.
- Geological dust is a significant source of phosphorus.
 - Spatial variability between sites.
 - Higher concentrations during windy periods.
 - Higher concentrations near exposed dirt or construction.
 - (Use mini-vols for source oriented sampling)

Develop source profile for local geological dust and other sources and test source apportionment by CMB.
 - Dust from paved roads and unpaved shoulders is a significant source of phosphorus.
 - Higher concentrations near traffic. Temporal differences seen in BAM samples correlated with time of traffic. Spatial differences between longer-term samples correlated with proximity to traffic.
 - (Use mini-vols for source oriented sampling)

Develop source profile for paved roads and unpaved shoulders (local geological dust) and other sources and test source apportionment by CMB.
 - Dust from road sanding operations is a significant source of phosphorus.
 - If higher concentrations are near traffic and timed to follow sand application and snow melt. Detect in samples at SLT.
 - (Use mini-vols for source oriented sampling)

Develop source profile for road sand types and other sources and test source apportionment by CMB.
 - Wild fires are a significant source of phosphorus or phosphate.

If high concentrations occur during fire events, phosphorus or phosphate should be correlated with chemical markers for smoke.

(Use mini-vols for source oriented sampling)

Develop source profile for wild fires and other sources and test source apportionment by CMB. Collect fly ash following fires and analyze content. Measure mass of accumulation of ash at various distances downwind of fires. Estimate possible range of emission rates, relating meteorology and size of area burned to the accumulation of ash. (Use mini-vols for source oriented sampling)

- Residential wood combustion is a significant source of phosphorus or phosphate.
 - If high concentrations occur at night and during winter holiday periods when fireplace use is obviously indicated by smell of smoke or by analysis for tracers of smoke. Use time resolution of BAMs. (Use mini-vols for source oriented sampling)
- Nitrogen deposited to Lake Tahoe originates primarily from local LTB emission sources. If any of the following are true it is likely that the hypothesis is true.
 - 1) Concentrations of nitrogen species measured at upwind boundary are clearly too low to account for the estimated nitrogen deposition rate. Measure near the upwind boundary to the Tahoe Basin.
 - 2) Upwind air masses and sources are usually decoupled from the LTB by lack of vertical mixing to lake level. Test by measuring vertical profiles of wind, temperature, humidity, and N-concentration. Predict strong vertical gradients aloft for nitrogen species concentration and meteorological parameters during some periods.
 - 3) Concentrations of nitrogen species are highly variable between sites inside the LTB. Measure in-basin N concentrations. There should be significant spatial variability in nitrogen species concentrations and this should be consistent with location of local sources and wind patterns.
- Although the nitrogen deposited to Lake Tahoe originates primarily from local LTB emission sources, it is upwind emissions that are responsible for its conversion to nitric acid. Thus, nitrogen deposition is due to local sources of nitrogen and upwind emissions of ozone precursors.

Test this hypothesis by photochemical modeling. Use existing CCOS data and modeling to estimate the boundary conditions for the LTB with respect to the air quality. Include photochemically active species, including nitrogen species, VOCs, ozone. Confirm boundary conditions with measurements. Model the boundary conditions for the LTB both with and without upwind sources. Model the LTB itself to estimate the effect of upwind emissions on concentration of nitric acid and deposition of nitric acid and other nitrogen species.

Compare modeled and locally calculated deposition rates for the same location. Calculate nitrogen deposition rate using observed in-basin N concentrations and observed meteorological variables.

2.2 DATA REQUIREMENTS FOR DATA ANALYSIS AND MODELING

An effective program to halt and reverse the degradation of water clarity in Lake Tahoe depends upon an accurate identification and quantification of the sources of nutrients to the water system. A better understanding of atmospheric deposition of nitrogen (N) and phosphorus (P) into Lake Tahoe is needed to ascertain the significance of atmospheric deposition relative to runoff and other avenues of N and P input into the Lake. One approach involves an air quality field study to collect the pertinent information necessary to apply air quality models of N & P deposition. Inert and photochemical air quality models apply scientific principles (e.g., conservation of mass) to estimate the impact of emissions on ambient conditions and deposition to the Lake. Air quality models require detailed data on the spatial and temporal variations in emissions and meteorological parameters. Air quality and meteorological data are needed to initialize the models (i.e., set initial conditions) and to validate the output/results of the models. Chemical mass balance models match chemical profiles of emission sources with ambient measurements to ascertain the relative contributions of the different sources.

Observation-based modeling empirically identifies relationships. The field study and modeling approach can be much less expensive and can produce just as accurate results as an intensive monitoring program. The main drawback of the field study and modeling approach is that the results of a limited data gathering term must be applied to other seasons or even the whole year. The various components of the field study and modeling approach are identified below; a brief description is provided of how each component contributes to the quantification of N & P deposition to the Lake.

Information Needs

Various modeling approaches with varying informational needs are possible depending on what information is currently available, what assumptions can reasonably be made, and the applicability of specific episodes to characterizing average or annual deposition. Because Lake Tahoe is a deep body of water surrounded by mountains, meso-scale meteorological processes can strongly influence deposition processes. The models used must be able to distinguish N & P deposit from local and remote sources.

Meteorological models frequently have difficulty replicating conditions in areas with complex terrain. For these reasons the model will need to be exercised to identify the most critical inputs for satisfactory replication of the meteorological processes. For example, the number of layers employed in the model depends on the complexity of the airflow over the mountains, along the mountain slopes, and through mountain passes. To accurately characterize the amount of N & P deposition to Lake Tahoe it will be necessary to quantify the nature and routes of transport into and within the basin. Background information on the diurnal and seasonal variations in meteorology and emissions will be crucial in designing the most appropriate modeling approach.

Furthermore, the transformation of N & P to different physical states and compounds must be properly accounted for. In general, the fewer assumptions that must be made, the finer the scale of the model, and the more atmospheric processes replicated, the better will be the modeling estimates of N & P deposition.

The Lake Tahoe air basin is in both the Central California Ozone Study (CCOS) and California Regional Particulate Matter Air Quality Study (CRPAQS) modeling domains. Both studies are using the MM5 and the US-EPA's MODELS3 for meteorological and air quality simulations, respectively. In the current model applications, a 4x4 km horizontal grid resolution is being used. The MM5 uses 30 and MODELS3 7 vertical layers. Simulation periods are from June 1 to September 30, 2000 for ozone and December 1, 1999 to January 31, 2001 for particulate matter studies. Emissions inventory of the modeling region is constantly improved and updated.

From the model specifications above, it will be possible to simulate the impact of local sources as well as transported pollutants to the lake. In order to further refine the effects of local sources, it is desired to use high grid resolution, e.g., 1x1 km in the Lake Tahoe Airshed. For this simulation a nested grid approach will be taken.

Observations are used for model improvements and validation. In the meteorological model, observed winds, temperature and relative humidity at the surface as well in aloft layers are used in Four Dimensional Data Assimilation to improve the simulated meteorological fields. In the air quality model, observations are used for model initialization, specification of boundary conditions as well as model validation. It is important to collect adequate spatial and temporal data for model applications. There are various techniques for judging the adequacy of observations. The most important one is the development of an observational based conceptual model.

CCOS/CRPAQS regional modeling for representative days in 2000/01 can be used to estimate ozone levels, and total N, P, and fine particle deposition to Lake Tahoe and surrounding watershed. To model P deposition, a crude P inventory will need to be developed. The models can separate long-range transport and local impacts with a simple sensitivity run to zero out in-Basin emissions. Assuming sufficient resources are provided, future year scenarios could be run to determine the impact of planned ozone and PM control programs, both in-Basin and out-of-Basin. However, these results may be limited due to uncertainties in the model calculations associated with the absence of Basin-specific meteorology aloft, of Basin emphasis in model validation, and measured Lake-specific deposition velocities. The basin-specific model (available in late 2004 or 2005 timeframe) using meteorological and air quality data collected in 2002 with measured boundary conditions of ozone, N species, P, and fine particles to quantify long-range transport could be validated based on in-Basin data collected during the field study and exercised to provide more refined scenario assessments.

2.2.1 Emissions Data

The results of modeling efforts depend heavily on accurate estimates of local and regional emissions; in this case, N, P, and fine PM. P emissions are believed to be

primarily from local sources and primarily in the coarse sizes. The bulk of the P material is thought to originate from road dust and road sanding. Thus a seasonal bias toward winter and spring might be expected. One of the significant local sources of atmospheric P, especially during winter, is thought to be smoke from wood burning stoves and fireplaces. However, this is not confirmed by current emission inventory estimates (Figure 6); more work is needed to better quantify the impact of smoke, particularly from prescribed and wild fires as the current P emission factors are very low (because of the large activity, even a small change in the P fraction could have a significant impact on the total emissions). The current emission inventory for P is dominated by geologic sources (e.g., road dust, sanding).

The emission inventory for PM10 is also dominated by geologic sources (Figure 7). Fugitive dust (e.g., road dust) and wood smoke are dominant source categories. Mobile sources account for a small fraction but emission estimates of PM from mobile sources do not include the contribution from the conversion of gaseous pollutants to PM.

Combustion processes, and mobile sources in particular, dominate local and regional sources of atmospheric N (Figure 8). Natural sources (e.g., nitrogen-fixing bacteria, lightning, fires) can be important locally. HNO₃, NH₃, and NO₂ are the primary sources of current concern. If the spatial and temporal variations in the strength of local and regional sources are characterized well, the deposition estimates of N & P will be greatly refined.

Figure 6. Emission estimates of phosphorus in the Lake Tahoe Air Basin by source category for Y2000.



Figure 7. Emission estimates of PM₁₀ in the Lake Tahoe Air Basin by source category for Y2000.

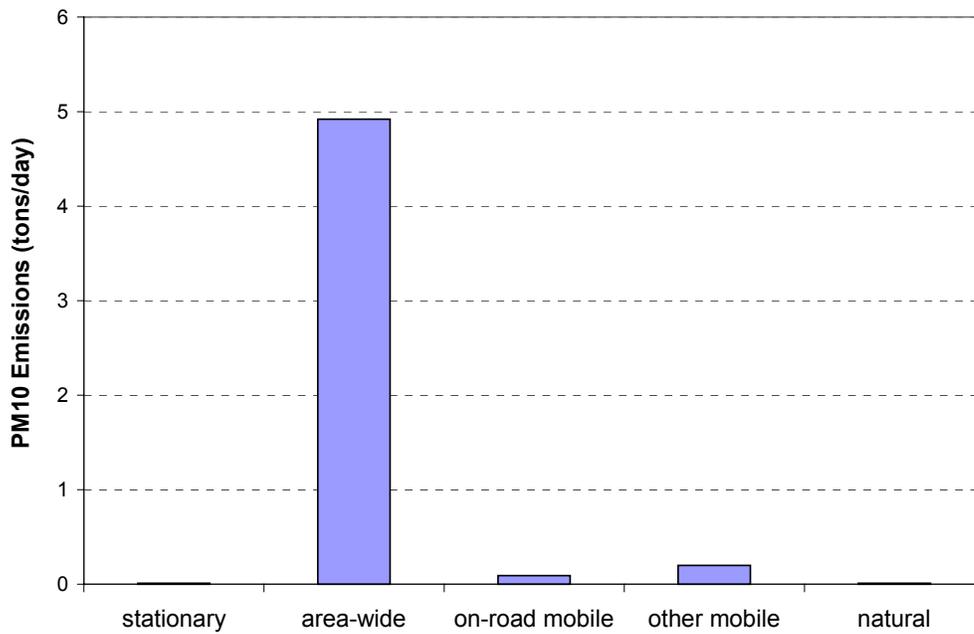
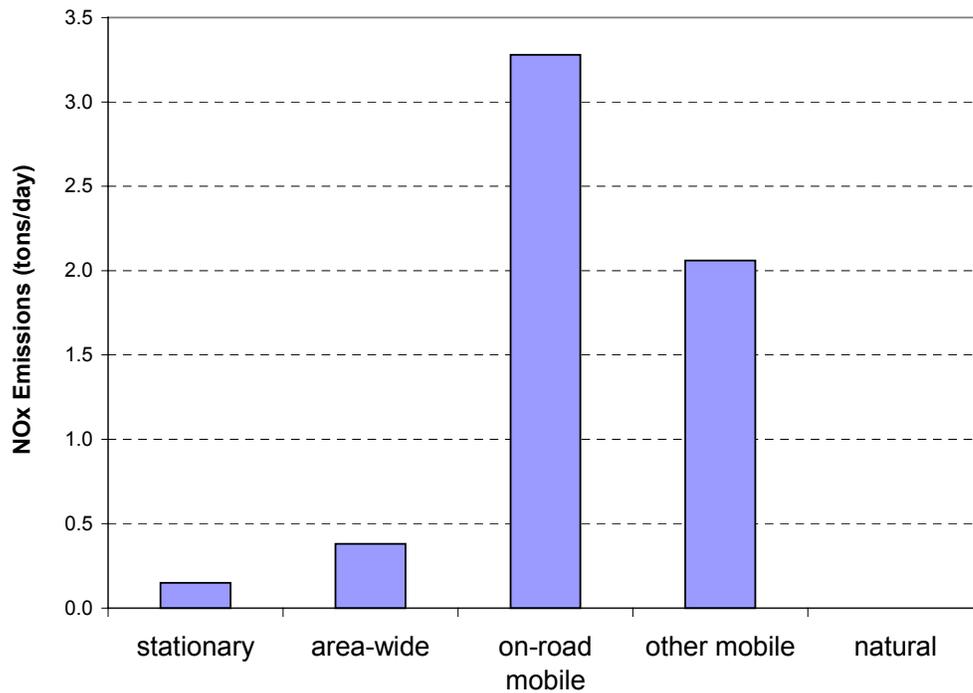


Figure 8. Emission estimates of NO_x in the Lake Tahoe Air Basin by source category for Y2000.



The physical and chemical characteristics of PM from different sources can have different “signatures” which can be used to ascertain the relative contribution of the various sources. Table 9 shows the typical characteristics of PM associated with various source categories.

Table 9. Characteristics of particles from different sources

Source	Dominant Size	Chemical Abundances in Percent Mass			
		<0.1%	0.1 to 1%	1 to 10%	>10%
Paved Road Dust	coarse	Cr, Sr, Pb, Zr	SO ₄ ⁼ , Na ⁺ , K ⁺ , P, S, Cl, Mn, Zn, Ba, Ti	EC, Al, K, Ca, Fe	OC, Si
Unpaved Road Dust	coarse	NO ₃ ⁻ , NH ₄ ⁺ , Zn, Sr, Ba	SO ₄ ⁼ , Na ⁺ , K ⁺ , P, S, Cl, Mn, Ba, Ti	OC, Al, K, Ca, Fe	Si
Construction	coarse	Cr, Mn, Zn, Sr, Ba	SO ₄ ⁼ , K ⁺ , S, Ti	OC, Al, K, Ca, Fe	Si
Agricultural Soil	coarse	NO ₃ ⁻ , NH ₄ ⁺ , Cr, Zn, Sr	SO ₄ ⁼ , Na ⁺ , K ⁺ , S, Cl, Mn, Ba, Ti	OC, Al, K, Ca, Fe	Si
Natural Soil	coarse	Cr, Mn, Sr, Zn, Ba	Cl ⁻ , Na ⁺ , EC, P, S, Cl, Ti	OC, Al, Mg, K, Ca, Fe	Si
Vegetative Burning	fine	Ca, Mn, Fe, Zn, Br, Rb, Pb	NO ₃ ⁻ , SO ₄ ⁼ , NH ₄ ⁺ , Na ⁺ , S	Cl ⁻ , K ⁺ , Cl ⁻ , K	EC, OC
Motor Vehicle	fine	Cr, Ni, Sr, Ba	S, Cl, Al, Si, P, Ca, Mn, Fe, Zn, Br, Pb	Cl ⁻ , NO ₃ ⁻ , SO ₄ ⁼ , NH ₄ ⁺ , S	EC, OC

coarse – 2.5 to 10 µm
 fine – 0 to 2.5 µm
 EC – elemental carbon
 OC – organic carbon

2.2.1.1 Emission Inventory Research

Table 10 summarizes potential research projects to better understand emissions and their subsequent environmental impacts in the Lake Tahoe Basin. This research on Tahoe-specific emissions will lay the groundwork for future data analysis and modeling to identify the primary sources and to reduce the negative affects of these emissions on visibility, water quality, vegetation, and air quality.

Table 10. Particulate matter research for improving the emissions inventory

Priority	General PM Inventory Improvements
1	Development of Refined Emission Estimates for Road Dust, Road Sanding, and Wood Burning in the Tahoe Air Basin (focus on P)
2	Motor Vehicle Emission Inventory Improvement Study for Lake Tahoe: Lake Tahoe Fleet Characterization Study
3	Development of an Ammonia Emission Inventory for the Lake Tahoe Air Basin
4	Development of Emissions Inventory for Nevada-Based Sources in the

	Tahoe Basin
5	Preparation of Spatially and Temporally Refined Emission Estimates for Wildfire and Prescribed Burning in the Tahoe Air Basin
6	Preparation of a Biogenics Emission Inventory for the Tahoe Air Basin

Evaluation of Airborne Phosphorus Sources and Emissions in the Lake Tahoe Air Basin including Materials Testing

Evidence suggests that atmospheric deposition has played a role in the ongoing eutrophication of Lake Tahoe. Phosphorus is blamed as one of the nutrients responsible in this aquatic ecosystem. Murphy and Knopp (2000) indicated that 74.8 lbs/day of total phosphorous deposition from the atmosphere to Lake Tahoe. Approximately 18 lbs/day of phosphorus emission were estimated to the atmosphere in the Lake Tahoe Basin from sources including road dust, construction, and waste burning sources. This estimation was based on the current PM emission inventory and speciation profile for Year 2000.

The difference in these estimates shows that there is a need to update the emission inventory of sources to this basin. A study done by Wittorff et al. (1996) for Reno, NV, winter 1993 reported 57% and 22% of PM contributions from road sand and motor vehicle, respectively. These sources may significantly contribute to airborne phosphorus concentrations. Unfortunately, the current inventory does not include PM emissions from road sanding and cinders. This research will estimate emission for this source, performing chemical analyses of road sanding materials, and improving emission inventory for the other sources of geologic dust.

Under this contract, sources of airborne phosphorus to Lake Tahoe Basin will be identified and quantified. This project will provide the public, districts, and scientists information necessary to develop a better management strategy.

Development of Refined Emission Estimates for Wood Stoves and Fireplaces in the Tahoe Air Basin

The smoke from woodstoves and fireplaces within the Lake Tahoe air basin contribute substantially to particulate levels during the winter months. The smoke also reduces visibility. To better understand the influence of fireplaces and wood stoves on air and water quality within the Tahoe basin, this project will work with local agencies and collect survey information regarding the number and types of residential and commercial wood burning devices within the basin. The project will also collect information about the types and quantities of wood burned within the basin and develop month-specific emission estimates for PM and other pollutants. Surveys will be conducted in the spring of 2002 and the winter of 2002/2003 on the types of stoves and frequency of usage. Information on "degree days" or a daily heating demand model is needed in addition to better data on the amount and variation in "visitor" population.

Motor Vehicle Emission Inventory Improvement Study for Lake Tahoe: Lake Tahoe Fleet Characterization Study

Currently, motor vehicle emission estimates for the Lake Tahoe region are determined using the fleet that is registered to owners that live in the Tahoe area. This data is pulled from the Department of Motor Vehicles registration database. However, we are aware that many of the vehicles operating in the Tahoe region, especially on weekends, belong to tourists visiting from other parts of California and Nevada. Therefore, we could be mis-characterizing motor vehicle emissions. Since motor vehicles make up over half the statewide NO_x emissions inventory, such errors could significantly affect the whole NO_x inventory.

By doing a visual survey of license plates in the Lake Tahoe area, we would compile data on the origin and age of the in-use vehicle fleet. We would then use this revised fleet data to revise the estimate of motor vehicle emissions in the Tahoe area. This would allow us more accurately quantify motor vehicle emissions in the Lake Tahoe area.

Development of an Ammonia Emission Inventory for the Lake Tahoe Air Basin

An ammonia emission inventory is essential to evaluate nutrient loading and visibility degradation in Lake Tahoe Basin. Tarnay (2000, 2001) found atmospheric N deposition is more important than wet deposition for forest canopies in the Lake Tahoe Basin, and at least as important as wet deposition for direct N loading to the lake, in which NH_3 is one of the two major forms. Nitric acid and NH_3 dominated N flux to Lake Tahoe surface water, delivering $27\text{-}34 \times 10^6 \text{g}$ and $2.9\text{-}22 \times 10^6 \text{g}$ during the 3-month dry season. And any NH_3 deposition in the LTB is largely localized to urban areas (i.e., South Lake Tahoe). In addition, ammonia reacts with nitrate and sulfate to produce the two fine aerosols of primary concern in Lake Tahoe Basin, ammonium sulfate and ammonium nitrate. Those fine particles are the major cause of haze, and severely degrade visibility along and into the western slope of the Sierra Nevada.

This study will construct an ammonia emission inventory in Lake Tahoe Basin, with anthropogenic sources being the major focus. Estimates of spatial and temporal emissions variations will also be developed.

Development of an Emissions Inventory for Nevada-Based Sources in the Tahoe Basin

It is not currently clear how much the emissions from Nevada contribute to air pollution within the Lake Tahoe air basin. This project will include working with the Nevada Bureau of Air Quality and the Washoe County Health District to compile an emission inventory for those sources that could negatively affect the air quality within the Lake Tahoe region.

The effects of typical meteorology will be considered in this assessment to evaluate if transport is significant.

Preparation of Spatially and Temporally Resolved Emission Estimates from Wild and Prescribed Fire in the Lake Tahoe Basin

The 2000 ARB emission inventory for the Lake Tahoe basin estimates that landscape biomass burning emits particulate matter (PM) in the range of 0.01 to 0.3 tons/day. Depending upon the chemical speciation profile, the PM emissions translate to ranges of emissions (kg/day) for ammonia (0.2-6.4), nitrate (0.1-1.6) and phosphorus (0.1), nutrients of concern to Lake Tahoe. Divergences exist between emissions and deposition estimates. For example, atmospheric loading of phosphorus to the lake is reported as 33.9 kg/day (UCD Tahoe Research Group, Annual Report) whereas the ARB's emission estimate is 7.9 kg/day (Ying, pers. comm.). Resolving the spatial distribution and timing of wild and prescribed fire, coupled with a fire emissions model, will help to reduce the uncertainty in estimating the contribution by fire to the local budget of these nutrients.

This effort will leverage ARB-sponsored work at the UC Berkeley Center for the Assessment and Monitoring of Forest and Environmental Resources (CAMFER) lab to apply a prototype GIS-based fire emission model to the Tahoe basin. Existing GIS-based fire history and vegetation fuel data layers will be utilized for this task. Emission outputs will lend themselves to assimilation by air quality models.

Preparation of a Biogenic VOC Emission Inventory for the Lake Tahoe Basin

Photochemical oxidation of biogenically emitted volatile organic compounds (BVOCs) contributes to the formation of ozone, secondary organic aerosols (SOA) and PM_{2.5}. Simulation studies suggest that biogenic aerosols may contribute up to 90% of total SOA in rural environments (CRC 2000). In turn, atmospheric deposition is an important pathway of nutrient input to Lake Tahoe (Final Report to Congress, Sierra Nevada Ecosystem Project. Addendum. 1997. UC Davis). However, BVOC emission estimates have not been developed for the Lake Tahoe basin. Coupled with investigations outside the scope of this project, a BVOC emission inventory would be an important first step toward understanding the composition and dynamics of aerosol formation in the Lake Tahoe basin.

This effort will leverage in-house resources and current ARB-sponsored work to apply ARB's Biogenic Emission Inventory Geographic Information System (BEIGIS) model to the Tahoe basin. Existing GIS-based vegetation land cover databases (California and Nevada GAP) will be utilized for this task, together with meteorological inputs. Emission outputs will lend themselves to assimilation by air quality models.

The following efforts are needed to have the necessary emissions data for modeling:

1. Develop a spatially and seasonally resolved inventory of emission estimates (traditional categories of ROG, NO_x, and CO but also compounds containing P).
2. Improve and extend the existing biogenic ROG emissions and develop estimates of NO_x emissions from fertilizer applications.

3. Develop, evaluate, and apply methods to propagate emission inventory uncertainties.
4. Project the effects of future activity and alternative controls on emission estimates.
5. Acquire, archive, and manage activity data from which emission estimates can be developed.
6. Estimate costs, schedules, and responsibilities for emission modeling activities.

2.2.2 Meteorological Data

2.2.2.1 Near-surface Meteorological Observations

Meteorological conditions will exert a strong influence on the transport, dispersion, and deposition of N & P. The potentially large temperature variations due to the cold water of the lake and the complex mountain topography can cause significant differences in meteorological conditions within short distances of each other. Furthermore, the rapid transitions between up-slope and down-slope flows strongly influence where N & P are transported and deposited. Thus, it is critical that the meteorological model accurately characterizes the meso-scale effects if N & P deposition is to be accurately characterized.

2.2.2.2 Upper Air Meteorological Observations

Modeling air quality and deposition in and around the Lake is complicated by meteorological conditions resulting from the terrain of the basin. One source of complexity is uncertainty regarding the timing, strength, and depth of flows induced by differences in air density caused by surface heating of the atmosphere. Uncertain treatment of up-slope and down-slope winds and land-water winds will add uncertainty to any analyses or modeling efforts. Defining these flows will require measurements with good vertical resolution, particularly in the first 100 meters above the surface. Slope flows and land-water flows near the surface are associated with vertical motions and compensating horizontal winds aloft. Understanding the location and timing of vertical motions requires measurements sufficient to define the convergence and divergence of the wind at the surface and aloft. Vertical structure of atmospheric temperature (and humidity) is also important. Density differences can prevent or enhance mixing between air masses transported to the LTB from upwind areas and local emissions emitted near the surface. In some cases out of basin transport may pass over well above the surface. Thus understanding the three dimensional nature of temperature, humidity and winds is necessary to understand the effects of local and upwind air emissions on concentrations and deposition.

Recommended observations:

Near surface measurements are needed of wind speed and direction, temperature, humidity and pressure. Arranging for transfer of data from existing networks having adequate siting and procedures for quality control, quality assurance, and data management should be a priority. It is likely that some additional surface meteorological observations will be desirable, but the current networks operated by other parties are not defined.

Mini-sodars are suitable for observing slope flows, land-water flows, and flows aloft. Mini-sodars can provide continuous observations of winds from 15 to 300 meters above the surface with 5-10 m vertical resolution. A minimum of three mini-sodars would be needed for calculation of convergence and divergence. Siting decisions are critical to operational constraints, data quality, and use of data.

Radar wind profiler would provide observation of winds to 2 or 3 km above the surface. Resolution can be set to 60 or 120 m with the first observation centered at about 120 m agl with the 60 m resolution. Thus the RWP is not suitable for defining slope flows and land-water flows, but it does have the range to see winds well above the range of the mini-sodar and up to or above the height of the peaks which surround the lake. RASS added to a RWP will measure the virtual temperature (i.e., the density temperature (the combined effect of temperature and humidity upon temperature). RASS range is generally about 1 km or less.

Remote sensing methods have the advantage of providing continuous observations with substantial capital and set up costs but relatively low operational costs for labor and expendables. Mini-sodars are recommended for the vertical resolution that they can provide for observing winds in the first 100 meters agl. Additional range is needed (and can be provided by a RWP) for defining flows from 100m to 2000m agl. Because RASS provides only the virtual temperature and has relatively coarse resolution, additional in-situ measurements of temperature and humidity are also recommended. Temperature and humidity observations can be provided on a short-term intensive basis with reusable instruments borne by small balloons flown and retrieved on kite lines. These provide resolution of a few meters and range could be 100s of meters. Previous operations have gone to 800 meters. A research aircraft is needed for air quality observations aloft and would also observe both meteorological parameters including wind speed, wind direction, temperature, and humidity.

2.2.3 Air Quality Data***2.2.3.1 Near-Surface Air Quality Data***

Initial and boundary conditions can exert a significant influence on modeling applications. It is important that the sampling/monitoring network properly characterize the spatial and temporal variations in not only meteorological conditions but also in concentrations of compounds containing N & P. Four sites are recommended for expanded measurements:

1. South Lake Tahoe – Sandy Way is the most developed urban area in the LTB. Measurements in SLT will represent impacts from local emission sources associated with population.
2. Homewood and Loon Lake provide upwind sites for measurement of boundary conditions and regional transport.
3. Thunderbird Lodge, NV is frequently on the downwind side of the Lake, frequently downwind of Tahoe City, and at times may be downwind of SLT.
4. Lake Forest is downwind of Ward Canyon where historical deposition measurements have been made and frequently downwind of Tahoe City. A mid-lake site is also being considered but concentrations there would likely be lower than concentrations observed near the lakeshore due to the greater distance from sources.

2.2.3.2 Upper-Air Air Quality Data

Ambient air quality measurements are typically made within 10-20 meters of ground level. However, the composition of the air above this level can be very different depending on meteorological conditions. For example, a basin such as Lake Tahoe frequently has temperature inversions near lake level as cool air drains off the mountains. In other situations, the air above the water can be much cooler than the air above it or around the perimeter of the Lake. As solar heating during the morning mixes different air masses, variations can occur in the concentrations of P, N, & PM. If transport from outside the basin were greater than local sources of P, N, & PM, then deposition would be enhanced with the increased mixing of the atmosphere. On the other hand, if local sources were dominant, then the increased mixing would tend to decrease deposition of P, N, & PM. Once again, the modeling results will depend on how well emission, transport, transformation, and mixing processes are handled.

Measurements of air quality aloft will occasionally be made by means of an instrumented aircraft owned and operated by staff of the University of California, Davis (UCD). The modified Cessna 182 will fly up to 15 two-day missions during the summer and fall of 2002. The aircraft's instrument package is described in Table 11. In addition to the aircraft's standard instrument package, ARB staff is working with the pilots on the feasibility of adding a particle-sizing counter to characterize the vertical and horizontal variations in particle sizes and counts in the study area. The preliminary flight plan is presented in Table 12. Measurements will also be made during the transit flights between Davis and the Tahoe Basin to provide an indication of air quality upwind of the Basin. The transit flights will pass over the proposed Loon Lake and Homewood sites along one of the primary transport corridors between the Central Valley and the Tahoe Basin. The preliminary flight plan will be modified slightly to accommodate staff's desire to have vertical soundings made a couple of times a day over the Loon Lake site and to have a flight leg into the Upper Truckee River Valley.

Table 11. UCD aircraft instrumentation.

VARIABLE	SENSOR	MAKER	USEFUL RANGE	ACCURACY
Pressure (Altitude)	Capacitive	AIMMS-10	- 30 to 4000 meters	± 0.3 mb ± 3 meters
Temperature	Platinum RTD	AIMMS-10	- 20 to 50 °C	± 0.5 °C
Relative Humidity	Capacitive	AIMMS-10	0 to 100%	± 3% between 20 and 85%
Air Speed	Thermal Anemometer	AIMMS-10	15 to 77 ms ⁻¹	± 0.4 ms ⁻¹
Heading	Electronic Compass	AIMMS-10	0 to 360 °	± 2 °
Wind speed Wind direction	AIMMS-10 system	Aventech Research Inc.	0 - 50 mps 0 - 360 degrees	± 1 mps ± 10 degrees
Position	Global Positioning System (GPS)	AIMMS-10	± 90 ° Latitude ± 180 ° Longitude	Position = 15 m Veloc. = 0.2 ms ⁻¹
Particle Concentration	Optical counter	Climet CI-3100-0112	d > 0.3 : m d > 3.0 : m	± 2% of count
Ozone Concentration	U. V. absorption	Dasibi 1008 AH	0 to 999 ppbv	± 3 ppbv
Nitrogen Oxides (NO, NO _y) Concentration	Gas-phase chemiluminesce	Thermo Environmental Instruments, Inc. Model 42C	0 to 200 ppbv	± 1 ppbv or 1% of reading Linearity is ± 1% of full scale.
Nitric acid Ammonia	Denuder samples and Ion Chromatography	URG Inc Dionex	> 0.05 ppbv > 0.1 ppbv with 30 min. exposure	depends on mass loading, i.e. exposure times
Phosphorous	Filter samples and Ion Chromatography	URG Inc Dionex	TBD	TBD

Table 12. Standard 2-day deployment flight plans.

Day	Flt #	Time PST	Route	Flight Hrs.	Total Hrs.
1	1	08:00	Transit from Davis	1.0	1
		09:00	Over lake sequence*	1.6	2.6
		10:36	To Truckee airport	0.3	2.9
1	2	14:00	From Truckee airport	0.4	3.3
		14:24	Over lake sequence*	1.6	4.9
		16:00	To Truckee airport	0.3	5.2
2	1	09:00	From Truckee airport	0.4	5.6
		09:00	Over lake sequence*	1.6	7.2
		10:36	To Truckee airport	0.3	7.5
2	2	14:00	From Truckee airport	0.4	7.9
		14:24	Over lake sequence*	1.6	9.5
		16:00	To Davis	1.0	10.5

*Over Lake flight sequence:

Part 1. Downward spiral 11,000' to 6700' MSL over the central part of the Lake.

Part 2. Horizontal traverses at 300' AGL - denuder 1 sampling

Part 3. Horizontal traverses at 1000' AGL - denuder 2 sampling

Part 4. Upward spiral 6700 to 11,000' MSL over central part of the lake.

2.2.3.3 Nitrogen Species Measurements

N is a very common element and can be quite reactive. The partitioning among various species is very important for accurately characterizing deposition because some N compounds are very sticky and can deposit rapidly. The ultimate fate of various N compounds depends on its environment and the transformations it undergoes. Thus, the modeling results will be dependent on how well the N compounds are apportioned.

PAN thermally decomposes back to its reactants, NO₂ and acetylperoxy radical. Thus, like HONO, PAN can serve as a nighttime reservoir for NO_X and means of transport of NO_X to downwind areas.

The reactive nitrogen compounds (NO_Y), NO, NO₂, NO₃, N₂O₅, CH₃COO NO₂ (PAN), HNO₃, HONO, and other organic nitrogen-containing species are coupled by a complex sequence of reactions in the atmosphere which generate ozone, other oxidants, organic and inorganic acids, and various hydrocarbon oxidation products. Because the amount of NO_Y in a given air mass is dependent only on the sources and sinks of its component species and not on interconversion chemistry, NO_Y is a conserved quantity. Thus, NO_Y is a measure of the amount of nitrogen containing "pollution", independent of the air mass's age. It is NO_Y rather than NO_X that is of primary interest in establishing the nitrogen budget across a transport flux plane. In addition, our understanding of the reaction pathways that involve nitrogen species can be aided by the measurement of the total abundance of atmospheric reactive compounds.

Atmospheric deposition of nitrogen species at Lake Tahoe is now considered a key pathway for altering the nitrogen balance in the Tahoe Basin ecosystem (Jassby, et al. (1994), Tarnay, et al. (2001)). The goal of the ambient air quality measurement program is to quantify contribution from in-basin generation vs. air parcel transport to the basin. This quantification and associated air quality simulations are necessary to allow decision-makers to devise rules that are technically feasible and cost effective.

2.2.3.3.1 Monitoring Assets Already Deployed & Potentially Required

Blodgett Forest records transport events from the Sacramento County, the nearest and largest urban center to Lake Tahoe. Homewood, Loon Lake, Blodgett Forest (above Georgetown), and City of Sacramento form a roughly straight line transect. To know what initial concentrations exist and what concentrations mix down into the Lake Tahoe Basin, monitoring along Blodgett-Homewood transect would probably be required (monitoring at Blodgett already funded by others). Monitoring program should reach arrangements to obtain data from Blodgett. Meteorological variability is usually a key concern of the air quality modelers (2 years of monitoring is recommended to overcome this type of variability). To cover all the ways nitrogen species are transported to or generated at the lake, substantial meteorological monitoring including assessment of slope flows as well as general daily atmospheric mixing would be required (setting up of additional meteorological only sites would be useful). Using Blodgett data plus data at Loon Lake and Homewood, we would be able to properly interpret local emissions vs. truly air pollution transport events.

2.2.3.3.2 Adding to and Complimenting Available Monitoring Assets

To understand nitric acid production vs. transport, Tarnay et al. (2001b) measured nitric acid and ammonia from five sites on the periphery of Lake Tahoe. They reasoned that if there were no differences between these sites, then the regional photochemistry and transport was at play and, if there were differences, then the likely emission sources were from the Tahoe Basin itself. They used annular denuders with a one-in-six-day and 9-hours per day sampling regime. This reasonable approach assumes that a good understanding of meteorological and air parcel transport processes within the Tahoe Basin and further that site-to-site variability in terms of meteorology and photochemistry (gases and particles) at Lake Tahoe is properly understood. These assumptions have not been verified with either substantial meteorological modeling or continuous nitrogen oxides measurements at these sites.

Another option and more established method for determining air parcel origin is through measurement of speciated hydrocarbons and carbon monoxide (CO). The mix of hydrocarbons is somewhat different for transported air parcels and the CO to total nitrogen species for aged air masses is different than for fresh emissions. Hydrocarbon measurements are not planned for the Tahoe Basin and but carbon monoxide analyzers with higher sensitivity are planned. Combined with the continuous nitrate analyzer and the Laser Induced Fluorescence instrument (LIF), the suite of measurements planned should be able to differentiate between local emissions and transported air parcels. The LIF instrument package is able to measure NO₂ specifically, nitric acid, and total organic

nitrates. A transport site is already in operation at Blodgett Forest. The gaseous measurements include ozone, CO, speciated hydrocarbons, nitrogen species using LIF, i.e., nitric acid, NO₂, and total organic nitrates (Day, et al. (2001)), as well as NO_y (chemi-luminescence), nitrate (Liu, et al. (2000)), and one Scanning Mobility Particle Sizer (SMPS).

To understand the contribution of atmospheric sources to enrichment of nitrogen in the Lake, we will measure nitric acid, nitrogen dioxide, and two separate classes of organic nitrates: total peroxy nitrates (which are usually dominated by peroxyacetyl nitrate known as PAN), and total alkyl nitrates (a class of little studied compounds that likely make up more than 20% of the atmospheric NO_y in the Tahoe Basin). The measurements will be made using new state-of-the-art thermal dissociation laser-induced fluorescence technology developed at UC Berkeley. These measurements will be co-located with ARB measurements of meteorology, O₃, and other parameters at the primary transport site (likely to be Loon Lake rather than Homewood ski resort because of logistical complexities). These measurements will be used in analyses by UCB aimed at characterizing the annual cycle of the different nitrogen oxides, quantifying the different sources of atmospheric nitrogen oxides and evaluating our uncertainty about those sources in the Tahoe basin.

UCB proposes measurements and analyses aimed at improving our understanding of: 1) the boundary conditions for nitrogen oxides in the Tahoe Basin, including the annual cycle of the chemical abundances of different classes of atmospheric nitrogen oxides 2) the factors affecting those boundary conditions, 3) the net input of atmospheric nitrogen oxides to surfaces in the Tahoe Basin and 4) factors affecting the rate of deposition. UCB will use state-of-the-art technology developed in their laboratories for sensitive, specific observations of ambient concentrations of nitric acid, two types of organic nitrates--peroxy nitrates and alkyl nitrates, and NO₂. The instrument is extremely sensitive, capable of measuring these compounds at the sub-ppbv abundances that we expect to observe in the Tahoe basin with less than 1 minute of averaging. The measurements will be made nearly continuously for one year at the transport site near the western edge of the Tahoe basin. Analyses of these measurements in combination with ARB measurements at the Homewood site and UCB measurements at both the UC Blodgett Forest Research Station 60 km to the west and at the transport site (Loon Lake) will be used to assess the contribution of different sources of nitrogen oxides to those observed in the Tahoe Basin. UCB will focus on the relative role of combustion and natural emissions, the importance of transport from Sacramento and the San Francisco Bay Area, the role of deposition and other factors that affect the abundance of atmospheric reactive nitrogen in the region and the efficiency of transfer of nitrogen oxides to the Tahoe Basin.

The correlation between ozone and HNO₃ concentrations at Blodgett Forest, as indicated by Figure 9, is weak in all seasons but having a slight improvement in late summer (i.e., September). The HNO₃ concentrations are much more strongly influenced by the available sunlight than ozone concentrations. Thus, the seasonal variations are weak but the diurnal variations are stronger. As shown in the Figure 10

for the month of August, the HNO_3 concentrations (at this location downwind of an urban area) tend to peak about solar noon while the O_3 concentrations tend to peak later in the afternoon because of transport from the Sacramento urban area.

Figure 9. Seasonal relationship between ozone and nitric acid.

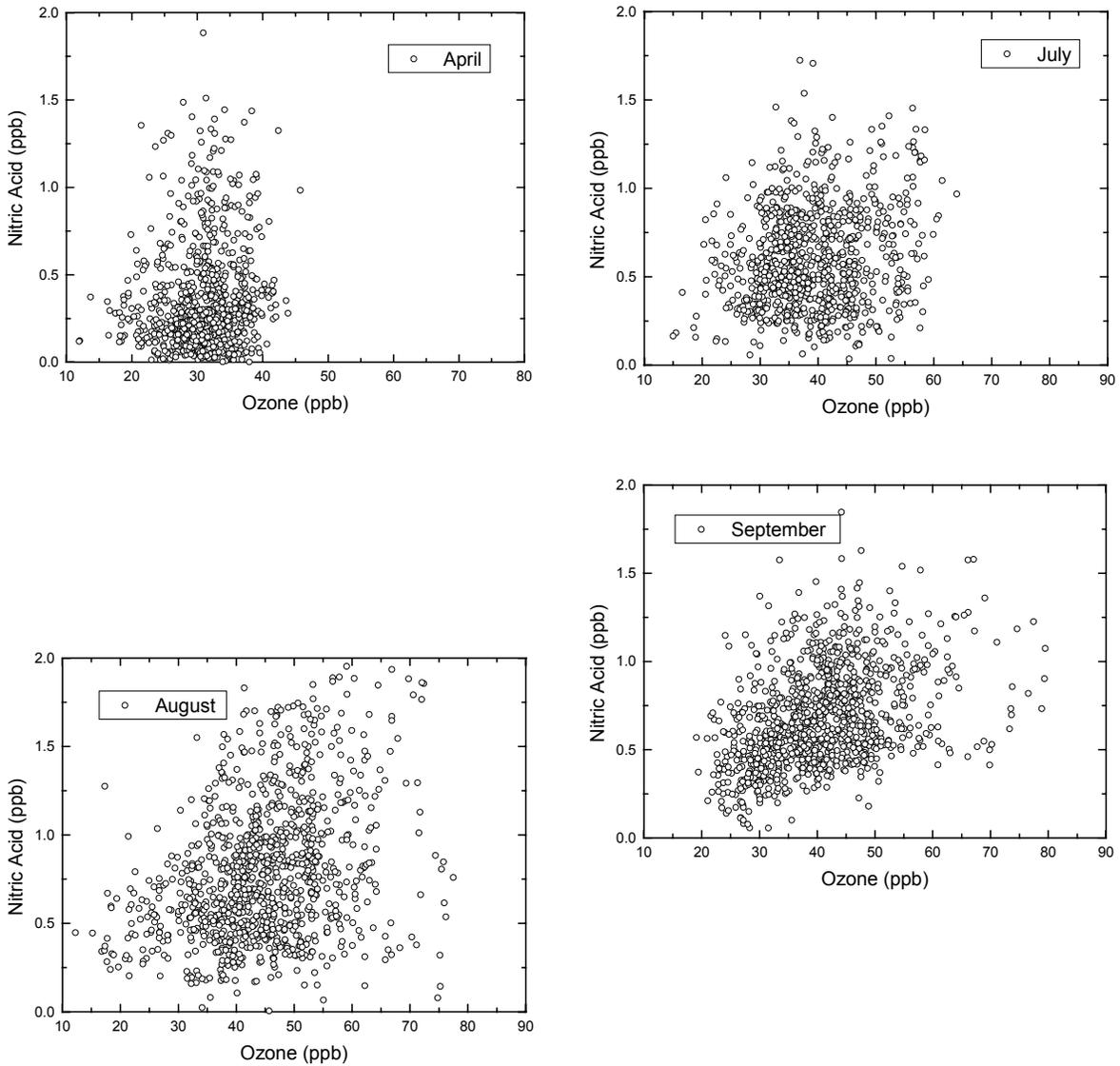
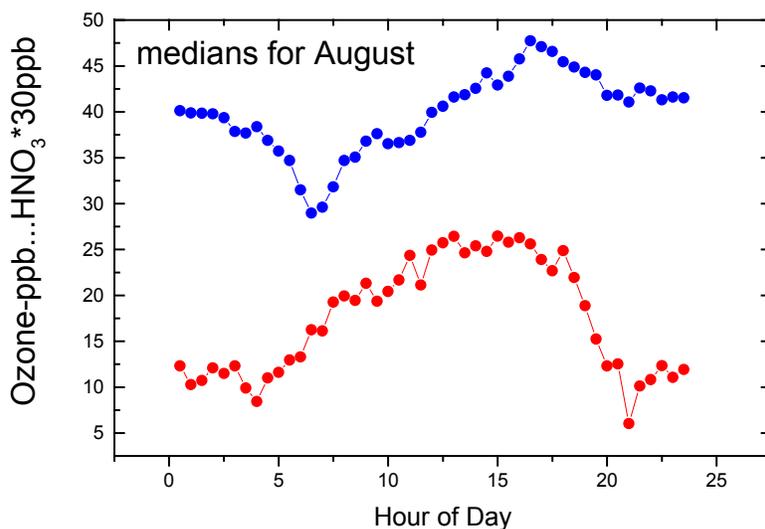


Figure 10. Diurnal relationship between ozone and nitric acid.

2.2.3.4 Physical and Chemical Makeup of Particles

Particulate matter is comprised of a wide variety of elements and compounds. The typical size distribution of particles in ambient air is determined by three different processes and is shown in Figure 11. From the perspective of water clarity, the number, size, and composition of particles can be important. Although there may be a large number of small particles, their total mass is often small compared to large particles. Thus, chemical analysis is important for gaining insights into the sources and composition of the PM. Chemical analysis is essential if the sources, amounts, and transformation of N & P compounds are to be understood and modeled properly. Furthermore, the solubility of the various N- & P-containing compounds must be known to better estimate their ultimate fate.

Various sources of PM tend to have some differences in the relative by size. Generic size distributions of various emission source categories are shown in Figure 12. Note that combustion processes tend to generate a high proportion of ultra fine particles while fugitive sources tend to be comprised of large particles.

Figure 11. Typical size distribution of ambient particulate matter.

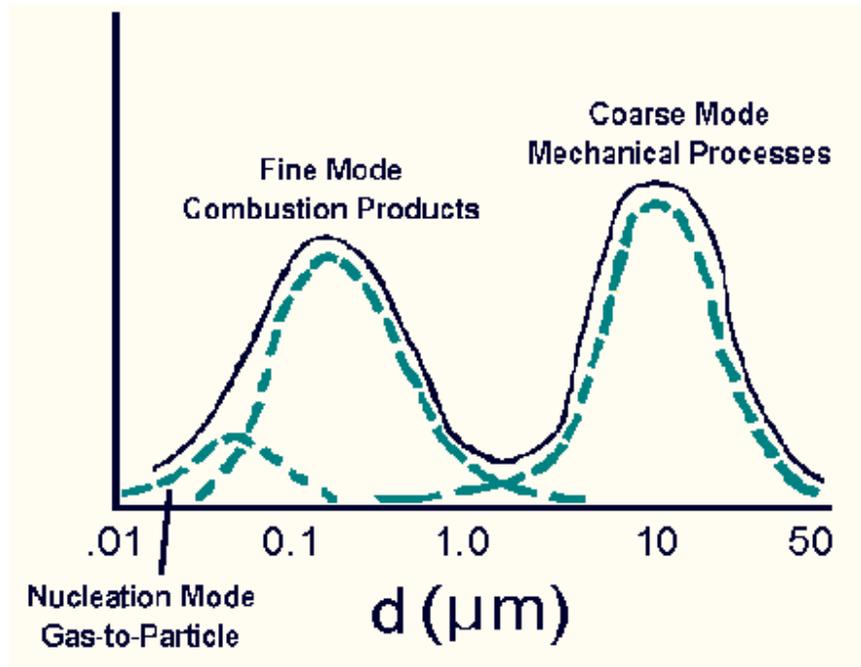
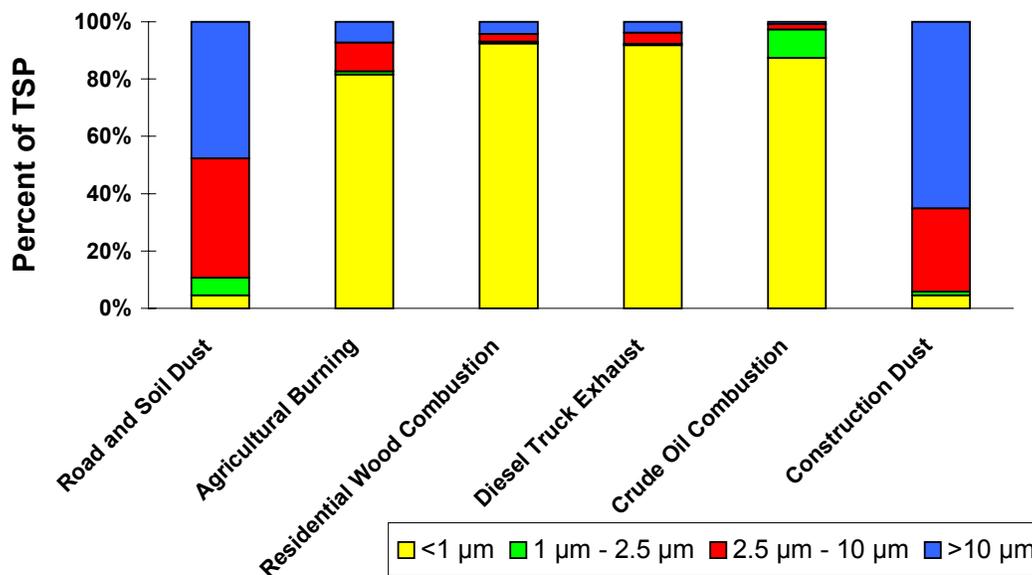


Figure 12. Size distribution of particulate matter from various sources.



2.3 MEASUREMENTS

A number of possible methods to test the various hypotheses have been suggested. These include:

1. Measure 24-hour average ambient PM_{2.5}, PM₁₀, and TSP mass, and speciate for elements and ions (e.g., phosphorus and phosphate). (To reduce cost and because the contribution of PM_{2.5} to mass concentration and deposition is small, eliminate PM_{2.5} measurement and speciation at most sites).
2. Measure continuous hourly PM_{2.5}, PM₁₀, and TSP mass (with BAMs). (Low cost for continuous mass data. No analysis cost, very limited labor.)
3. Measure and speciate bi-weekly average mass of PM_{2.5}, PM₁₀, TSP, nitric acid, ammonia, P, K, Na, EC/OC, etc. (Using the "Two-week Sampler")
4. Estimate hourly deposition velocities (Minimally based on routine measurements of meteorological parameters and preferably with eddy covariance observations of vertical fluxes of sensible and latent heat. Assume the cost is too great for eddy covariance or REA observations of the species of interest, e.g., N-species.)
5. Infer diurnal variation in PM concentrations from BAMs
6. Estimate PM deposition based on concentrations and either the observed or estimated deposition velocity
7. Infer possible key sources of phosphorus, phosphate and PM from temporal and spatial variation in concentrations
8. Model source apportionment of phosphorus and phosphate impacts by chemical mass balance using ambient concentrations and source profiles
9. Measure ambient N-species concentrations
10. Infer sources of N species from basic inventory information and refine inventory, e.g., source profile information and Tahoe survey data.
11. Measure N-species concentrations, estimate N-species deposition rates
12. Model N-species chemistry and deposition with 3-D Eulerian grid model
13. Model PM emissions, concentrations, deposition with 3-D Eulerian grid

Measurement and speciation of PM_{2.5}, PM₁₀, TSP are desirable for investigation of all hypotheses related to PM, phosphorus and phosphate, but PM_{2.5} is probably the least important to the input of phosphorus and phosphate to Lake.

Diurnal variation in both concentration and deposition velocity (V_d) will be important to the calculation of deposition rates and annual deposition. Deposition velocities will be affected by the diurnal variation in aerodynamic conductance over land and over water. The thermal mass provided by the Lake will influence atmospheric stability over the Lake, increasing night-time vertical mixing and turbulence and decreasing day-time vertical mixing and turbulence, as compared to during the same time periods over land.

Four sites are recommended for expanded measurements:

1. South Lake Tahoe is the most developed urban area in the LTB. Measurements in SLT will represent impacts from local emission sources associated with population.
2. Homewood provides an upwind site for measurement of boundary conditions.
3. Thunderbird Lodge is frequently on the downwind side of the Lake, frequently downwind of Tahoe City/Truckee, sometimes may be downwind of SLT.

4. Mid-Lake may be downwind of Ward Canyon where historical deposition measurements have been made or downwind of Tahoe City. Mid-lake concentrations may be lower than concentrations observed near the lake shore due to greater distance from sources.

Table 13 provides information about the various measurement techniques that have been suggested for the monitoring plan. The table includes a brief description of the purpose and the measurements and the suggested uses for the data.

Table 13. Purposes and uses for deployment of various measurements.

MEASUREMENT (TIME RESOLUTION)	PURPOSE	USE
Wet and dry buckets (1-week)	Bucket obs are historical deposition estimates	Needed for comparison with other measures of dep.
Sample/analyze snow pack for N, P, ions – (winter-season average)	Alternative winter measure of deposition: P, PO ₄ , N	Include for comparison with other measures of dep.
Two-week integrated sample with eight channels (2-week)	Spatial variability between sites may suggest for source id; Seasonal variations may suggest source id	Assume a diurnal variability, calculate deposition as product of concentration times Vd; Direct comparison with bucket samples
PM10 samples (24-hour, 1 day in 6)	Spatial variability between sites may suggest for source ID Day-to-day variations may suggest source id	Assume a diurnal variability, calculate deposition as product of concentration times Vd; Direct comparison with bucket samples
BAM-10 (1-hour)	Continuous hourly data: ID high concentration days and diurnal variability in PM10mass	Temporal information for clues to possible sources of importance
BAM-2.5 (1-hour)	Continuous hourly data: ID high concentration days and diurnal variability in PM2.5 mass	Temporal information for clues to possible sources of importance
BAM-TSP (1-hour)	Continuous hourly data: ID high concentration days and diurnal variability in PMtsp mass	Temporal information for clues to possible sources of importance
Basic met obs: wind speed, direction, temperature (sub-hourly)	Aerodynamic conductance for Vd	Wind fields for modeling Transport direction for analysis Source ID
Upwind N, VOC, O ₃	Bkg concs to determine relative contribution of transport	
Aircraft: vertical profiles of concentration, wind, temperature, humidity	Upwind sources may be decoupled from basin surface concentrations due to vertical temperature structure.	Needed for modeling/analysis of relative impacts from upwind/local sources
Mini-SODAR (hourly)	Continuity of winds 15-300m agl	Needed for modeling/analysis of relative impacts from upwind/local sources
Radar wind profiler (hourly)	Continuity of winds 0.1– 3km agl	Needed for modeling/analysis of relative impacts from upwind/local sources
Turbulence obs	Aerodynamic conductance for Vd	Calculate Vd

(10 hertz)		
Meteorological profiles (hourly)	Aerodynamic conductance for Vd	Calculate Vd
Profile of N-Concentration near-surface (hourly)	Calculate deposition rate	

2.3.1 Emissions Inventory

Section 3 9607(b) of the California Health and Safety Code requires the California Air Resources Board (CARB) to inventory sources of air pollution within the 14 air basins of the state and to determine the kinds and quantities of pollutants that come from those sources. The pollutants inventoried are total organic gases (TOG), reactive organic gases (ROG), carbon monoxide (CO), oxides of nitrogen (NO_x), oxides of sulfur (SO_x), and particulate matter with an aerodynamic diameter of 10 micrometers or smaller (PM₁₀). TOG consist of hydrocarbons including methane, aldehydes, ketones, organic acids, alcohol, esters, ethers, and other compounds containing hydrogen and carbon in combination with one or more other elements. ROG include all organic gases except methane and a number of organic compounds such as low molecular weight halogenated compounds that have been identified by the U.S. Environmental Protection Agency (EPA) as essentially non-reactive. For ROG and PM₁₀, the emission estimates are calculated from TOG and PM, respectively, using reactive organic fractions and particle size fractions. Emission sources are categorized as on-road mobile sources, non-road mobile sources, stationary point sources, stationary area sources, and biogenic sources.

2.3.1.1 Emission Estimation Methodology

Point source emissions occur at facilities that can be identified by name and location and emit more than the threshold value specified by the local air pollution control district (APCD). A facility may have many individual identifiable sources (points) of emissions, and a point source may correspond to one or more processes or operations. Point-source activity levels usually relate to a process rate. Emission factors are derived from tests that relate emissions to the process causing the emissions. Point source emission estimates are based primarily upon data collected by the county APCDs and air quality management districts (AQMDs). Point source emission estimates are stored and maintained in the California Emission Inventory Development and Reporting System (CEIDARS), and are also reported to the national Aerometric Information Retrieval System (AIRS) which is maintained by the U.S. Environmental Protection Agency.

Most area sources are small emitters that are not accounted for in the point source portion of the CEIDARS database. Some examples of area sources are residential space heaters, agricultural burning, pesticide applications, and consumer products. Area source emission estimates are developed by the districts and by the ARB staff.

On-road mobile sources are motor vehicles that travel on public roads. This category consists of gasoline-powered and diesel-powered passenger cars, light-duty trucks (6,000 lbs. Gross vehicle weight [GVW] or less), medium-duty trucks (6,001-8,500 lbs. GVW), heavy-duty trucks (over 8,500 lbs. GVW), urban buses, and motorcycles. Emissions from motor vehicles include exhaust, evaporative, crankcase, and tire-wear emissions. Four computer programs (CALIMFAC, WEIGHT7n, EMFAC2000, and BURDEN7n) are used to produce the motor vehicle emission inventories. These models are described in detail by the ARB (1995b). Model versions are indicated by the letter "n". Drafts of the next model version ("G") were released for public comment in December, 1995. The "CALifornia Inspection/Maintenance emission FACTor" (CALIMFAC) program computes base emission rates for each technology group with and without inspection and maintenance (I/M) benefits. The base emission rates consist of a zero mile rate and a deterioration rate for each model year for each pollutant. The "Emission FACTor" (EMFAC) model computes fleet composite emission factors by vehicle class and technology for a calendar year. The WEIGHT program provides EMFAC with activity weighting fractions for individual model years so that composite emission factors can be produced. WEIGHT also provides the accumulated mileage by model year for any particular calendar year in order to calculate the "deteriorated" emission rate for a model year. BURDEN calculates the emission estimates in tons/day by multiplying the composite emission factors from EMFAC by activity factors. Vehicle miles traveled, vehicle type distribution, and trip lengths, the input data for BURDEN are obtained from the California Department of Motor Vehicles (DMV) and the California Department of Transportation. BURDEN adjusts emission rates according to speed, ambient temperature, and heavy-duty I/M benefits.

Motor vehicle emission rates consist of running, incremental cold start, and incremental hot start exhaust emissions for TOG, CO, and NO_x, and hot soak, diurnal, running and resting evaporative emissions for TOG. Running exhaust emissions include emissions from the tailpipe or through the crankcase after the vehicle is warmed up and in a stabilized mode. Running exhaust emissions also include exhaust particulate matter and particulate matter from tire wear. Cold start emissions occur from the time the engine starts (after being off for one or more hours for a catalyst-equipped vehicle and four or more hours for a non-catalyst-equipped vehicle) until the coolant achieves its nominal operating temperature. Cold start emissions are incremental emissions that are added to the running emissions. The hot start mode occurs after a short engine-off period, less than one hour for a catalyst-equipped vehicle and less than four hours for a non-catalyst-equipped vehicle. Hot start emissions are also incremental to running emissions. Hot soak emissions result from gasoline vaporization from elevated engine and exhaust temperatures after the engine is turned off at the end of a trip. All of these emissions are assumed to be proportional to average vehicle miles traveled. The emission rates for hot soak emissions are expressed as grams of TOG per trip rather than as grams of TOG per vehicle mile traveled (VMT). Diurnal evaporative emissions result from the daily changes in the ambient temperature due to expansion of the air-fuel mixture in a partially filled fuel tank. Running evaporative losses are releases of

gasoline vapor from the fuel system during vehicle operation (included for the first time in EMFAC7E). Resting loss evaporative emissions are due to fuel line hose or fuel tank permeation (included for the first time in EMFAC7F).

Three types of inventories are available from the ARB: daily average, planning, and gridded. The average daily emissions are expressed as an emission rate in tons per average day, determined by dividing annual emissions by 365. Countywide and basin-wide totals are provided by source categories. This inventory is updated and published annually by the ARB. BURDEN can produce planning inventories that take into account the effects of diurnal and seasonal variations in temperature and activity patterns. The planning inventories provide emission estimates for six periods (0000-0600, 0600-0900, 0900-1200, 1200-1500, 1500-1800, and 1800- 2400 PST or PDT) during an average summer and winter day. The Direct Travel Impact Model (DTIM) assigns emission rates to locations and time periods to provide input to air quality models. DTIM is BURDEN's analog for gridded inventories. DTIM was developed jointly by Caltrans and the ARB. DTIM uses the temporal and spatial distributions of motor vehicle activities provided by a travel demand model, the summarized composite vehicle emission rate from EMFAC, and an input file of parameters such as hourly temperatures by grid cell to calculate and distribute emissions into the grid system defined by the user. Emission backcasts and forecasts are made by the ARB using base year emissions in conjunction with estimates of growth and emission control effectiveness. Emission growth is based upon available projections of socio-economic trends. Emission reductions are based upon adopted regulations and control measures. Backcast and forecast emissions are also available for planning inventories.

2.3.2 Monitoring Network

2.3.2.1 Surface Meteorology

The types of surface meteorological measurements needed for this study include measurements of wind speed, wind direction, and temperature. Measurements of humidity, and pressure are also available at some sites. Within the study area (modeling domain), these measurements are provided by several existing networks of sites operated by several organizations including:

- Surface Airways Observations sites from the National Weather Service (NWS), operating in conjunction with the Federal Aviation Administration
- California Irrigation Management Information System sites from the California Department of Agriculture
- Remote Automated Weather Station sites from the Bureau of Land Management, California Department of Forestry, National Park Service, and U.S. Forest Service

- APCD/AQMD Aerometric Monitoring Station sites from the El Dorado County APCD, Placer County APCD, Nevada Department of Health, and California Air Resources Board
- Private companies
- Public organizations such as universities

Table 14 provides a list of the surface meteorology sites in the study domain. A comprehensive discussion of the accuracy and methodology of surface measurements is provided in the SJVAQS/AUSPEX Meteorological Field Measurement Program report (Thuillier, 1994).

These surface sites use instruments deployed about 1.5 – 10 meters above the ground to measure surface hourly wind speed and wind direction, temperature, humidity, and pressure. Temperature is obtained by thermistor or platinum resistance elements and has a nominal accuracy of 1 °C or better. Typical sampling rates are from once per second to once per minute, with hourly averages reported. At some surface airways sites which do not utilize the newer Automated Surface Observing System (ASOS) equipment, temperature measurements are taken for a few minutes near the hour.

Wind speed and direction are usually obtained by cup or propeller anemometers, and wind vanes. Response times are on the order of a second and threshold values for an accurate response are about 0.5 meters per second (~1 mph).

Humidity measurements are taken by hygroscopic films or solutions exposed to ambient air. These sensors have a known electrical resistance that is a function of relative humidity. Reported values of relative humidity are usually ±5 percent, with better accuracy in the mid-range but lower accuracy at either extreme.

Surface sites are generally inexpensive, and can be easily outfitted for unattended operation. Thus, many sites can be deployed. However, they do not cover aloft conditions unless deployed on elevated sites like mountain tops thought to be representative of flow aloft.

Other surface sites could be used to conduct tracer tests and to deploy sonic anemometers for better boundary-layer turbulence characterization. Tracers can be released in a few selected upwind surface sites and collected by short-term (1-12 hour) samples at many surface sites downwind. Tracers specifically “tag” polluted air from upwind air basins, and multiple tracer releases can help determine the relative contributions of upwind pollutants to downwind ozone. The surface samplers can operate routinely with little operator attention. However, tracer material is expensive, and large quantities of tracer are required if long transport distances are to be studied.

Also, several days may be needed to disperse the tracer before another test can be conducted.

Sonic anemometers deployed at surface sites would provide estimates of turbulent fluxes for the modeling effort. The variations in sound propagation over a short (30 cm) path are typically sampled at 10 Hz, providing an estimate of turbulent fluctuations over that path. One-dimensional sonic anemometers measure vertical turbulent flux, while three-dimensional sonic anemometers include turbulent fluxes in the two horizontal dimensions. These data provide boundary layer characterization, representative of the type of terrain over which the measurement is taken. Urban effects could be better incorporated in the mesoscale model. The measurement could provide better dispersion estimates for models run in the data assimilation mode, and provide real-world measurements against which model estimates of turbulent flux are compared.

Table 14. Surface meteorological monitoring network.

Site	T	DP/RH	W	Prec	SR	Sponsor	Operator
California							
D.L. Bliss State Park	Y	Y	Y		Y	TRPA	ARS
Echo Summit	Y	Y	Y		Y	CARB	CARB
Homewood*	Yp	Yp	Yp			CARB	CARB
Loon Lake	Yp	Yp	Yp			CARB	CARB
Lake Forest [#]	Y	Y	Y	Y	Y	UCD	UCD
Rubicon Bay (Roy's)	Y	Y	Y	Y		UCD	UCD
SLT – Airport	Y	Y	Y			FAA	DRI
SLT – SOLA	?	?	?			TRPA	ARS
SLT - Sandy Way	Y	Y	Y		Y	CARB	CARB
Sunnyside - pier	Y	Y	Y	Y		UCD	UCD
Tahoe City - pier	Y			Y		DRI	DRI
Tahoe Vista - pier	Y	Y	Y	Y		UCD	UCD
Mid-Lake							
Buoys (6)	Y	Y	Y		Y	JPL/TRG	TRG
Nevada							
Cave Rock	Y		Y		Y	NDEP	CARB
Glenbrook Fire Station	Y			Y		DRI	DRI
Mount Rose	Y	Y				DRI	DRI

Thunderbird Lodge	Y	Y	Y			DRI/ TRPA	DRI/ARS
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* top of Homewood Ski Resort

Coast Guard pier

2.3.2.2 Upper-Air Meteorology

The types of upper-air meteorological measurements needed include wind speed, wind direction, temperature, and mixing height. Measurements of humidity are also useful where they are available at some sites. A comprehensive discussion of the accuracy and methodology of upper air measurements is provided in the SJVAQS/AUSPEX Meteorological Field Measurement Program report (Thuillier, 1994).

Radar Wind Profilers

Radar wind profilers (RWPs) provide continuous remote measurements of wind speed and direction to altitudes of ~3 km AGL. The profilers emit short pulses of generally 915 MHz electromagnetic radiation which scatter off inhomogeneities in the index of refraction of an air mass. By emitting energy directionally in three orthogonal components, the received scattered radiation provides estimates of wind speed and direction. Because of the finite length of the emitted pulse train, vertical resolution is limited to approximately 100 m. Echoes received during the detector downtime cannot be processed and this raises the threshold height to approximately 100 m above ground level. The typical five-degree beam width also limits the resolution of wind direction in a height dependent manner. There are general trade-offs between maximum range and vertical resolution and between averaging time and accuracy.

Radar wind profiler data are generally reported as 15-minute up to hourly averaged data and are representative of a three-dimensional cell. Because wind vectors may vary significantly over the course of an hour, the near-instantaneous radiosonde measurements may not compare well with radar wind profiler measurements on a case-by-case basis. However, if radiosondes and wind profilers are deployed in areas with similar winds, the statistical distribution of winds may be expected to be reasonably similar. The RWP is highly sensitive to stray electromagnetic signals and stationary or solid objects in the beam paths or their side lobes. Thus, it should be sited away from large objects such as buildings and trees and away from frequent overflights by aircraft.

Radio-Acoustic Sounding Systems (RASS)

Temperatures aloft up to 500-1000 meters can be characterized using a RASS. The RASS essentially uses collocated radio wave and acoustic sources such that radio waves are scattered off the acoustic wavefronts. The propagation velocity of the acoustic wave fronts is then measured, which can be related to the (virtual) temperature of the air. There is considerably less accuracy in the RASS temperature profiles compared to the those obtainable from tethered sonde measurements, particularly in areas of complex terrain where radar side lobes may present a problem. However, the RASS temperature data may be compared to QA radiosonde or tethered sonde temperature data

because the virtual temperature can also be calculated from the sonde measurements of ambient temperature, dew point or relative humidity, and pressure. A favorable comparison under representative conditions would increase confidence in the RASS data at these sites.

Acoustic Sounders (Sodars)

The sodar uses an observational process that is similar to the RWP except that the sodar uses pulses of acoustic instead of electromagnetic energy. The sodar then detects returned acoustic energy scattered from turbulent density fluctuation (instead of index of refraction fluctuations). It provides hourly averaged wind speed and direction in ~30 m layers up to a 500 - 600 m maximum range with a threshold height of approximately 50 - 60 m. Mini-sodars which operate more quietly than normal sodar are proposed for LTADS. Mini-sodars have a maximum range of 200 – 300 m agl and a vertical height resolution of about 10 m. Sodars can operate routinely with little or no on-site care but, compared to radiosondes, they do not measure temperature or humidity and are expensive. The sodar is highly sensitive to extraneous sources of sound. Thus, it should be sited away from substantial and continuous noise sources such as heavily traveled roads. The sodar acoustic emissions are audible and may disturb nearby residents, which can be a siting disadvantage compared with the RWP. Sodars are most appropriate in locations with lower-level structure, such as that found in marine layers, in diurnal up-slope and down-slope flows, in channeling through canyons and passes, and in nighttime radiation inversions.

Radiosondes

Radiosondes provide in situ measurements of pressure, temperature, and humidity from the ground to more than 4,500 m AGL using a manually released balloon. A radio transmitting instrument package is carried aloft by a freely ascending helium balloon. The balloon is tracked optically or electronically to provide its position relative to the release site such that estimates of the wind speed and direction can be derived. Radiosondes provide wind data that are averaged over short vertical distances and are thus nearly instantaneous measurements at a particular location. Although the radiosonde directly measures temperature and humidity during the short balloon flight, it is only a “snapshot” at each level of the atmosphere. The labor and expendable costs are significant. As the radiosonde rises, it is transported downwind, so measurements are not made above a fixed location, as with a wind profiler, for example. No radiosonde measurements are currently planned for LTADS due to funding limitations.

Existing Measurements

Upper air data routinely available near the study region consist of radiosonde data from the National Weather Service (NWS) sites at Oakland, CA and Winnemucca, Nevada. The NWS sites release sondes at the standard 0000 Z (0400 PST) and 1200 Z (1600 PST) times. Additional meteorological data aloft are currently available from two radar wind profilers operating in the general vicinity of Lake Tahoe – Grass Valley on the western slope of the Sierra Nevada and Elk Grove in the southern portion of Sacramento County. Although located a little farther north than desired, the Grass Valley site will provide connecting information between winds near the Sacramento

Delta and the western slopes of the Sierra Nevada. The data averaging time is typically hourly. Another profiler is planned for operation at the S. Lake Tahoe AP beginning in the summer of 2002. RASS is used with each of the radar wind profilers to obtain a vertical profile of virtual temperature. The planned upper-air meteorological network for LTADS is shown in Table 15.

Additional wind data are available from the WSR-88D doppler weather radars operated by the National Weather Service at Dixon, CA and other sites in the model domain.

Table 15. Upper-air meteorological monitoring network.

Site	T	DP/RH	W	vW	SR	Sponsor	Operator
RWP/RASS							
Grass Valley, CA	Y		Y	Y		NOAA	NOAA
SLT-Airport, CA	Yp		Yp	Yp		EPA	CARB
Elk Grove, CA	Y		Y	Y		SMAQMD	SMAQMD
Mini-Sodar							
Tahoe City Wetlands, CA			Yp	Yp		CARB	CARB
SLT Airport, CA			Yp	Yp		CARB	CARB
Incline Vlg Treatment, NV			Yp	Yp		CARB	CARB
Aircraft							
UCD Cessna	Y	Y	Y			CARB	UCD

2.3.2.3 Surface Air Quality

The complex geography in the Tahoe Basin causes meso-scale meteorological processes to strongly influence the air quality features. For example, the presence of a large and deep body of water ringed by mountains strongly influences up-slope and down-slope airflows. Furthermore, anthropogenic emission sources generally ring the lake with expanded areas of development where the terrain is relatively flat. Depending on the length of day and relative intensity of sunshine and synoptic meteorological conditions, emissions from within the Basin can be swept out of the Basin or can accumulate as the air diurnally “sloshes” back and forth over the local emission sources. It is for these geographical reasons that the surface (ground level) ambient air quality monitoring network (within the constraints of available facilities, power, etc.) rings the Lake in order to better characterize the spatial variability in the strength of locale emission sources but also in the meteorological processes. For example, the angle of the mountain slopes relative to the sun’s position in the sky will cause up-slope air flow to begin and end earlier on the western (California) side of the Basin than on the eastern (Nevada) side of the Basin.

In addition to accurately characterizing the impact of local emissions, the air quality monitoring network must also characterize the impact of polluted air transported into the Tahoe Basin from upwind sources. Due to the prevailing westerly airflow in the region, the quality (composition) of the air coming up the western slope of the Sierra Nevada from upwind urban areas needs to be documented to quantify the potential impacts of

transport into the Basin. Furthermore, modeling and data analysis must be conducting to quantify the actual impacts of transport. Monitoring is already occurring (Echo Summit and Truckee) or is planned (Loon Lake / Homewood Ski Resort) along the three most likely transport routes to the basin. Analyses are needed to document the frequency of transport to the upwind edge of the Basin and to determine the frequency that this polluted air at altitude actually makes it to the monitoring sites around the Lake and with what impact.

The monitoring network must characterize conditions over and on the Lake itself. This is important for understanding the mixing processes that can bring the polluted air in contact with the Lake surface. To this end, air quality (and meteorological) measurements are planned routinely on buoys on the Lake and intermittently (characterizing seasonal variations) by aircraft (during summer and fall) and by boat (during winter). Conditions at mid-lake are likely different from those near the shore as terrain effects would be less, the larger particulate matter deposits near the shore, and atmospheric circulation cells develop within the basin. The mid-lake measurements will provide critical reference points for the performance evaluation of meteorological and air quality modeling results as well as supporting conceptual frameworks for the interpretation and analysis of the data collected during the study.

Initial analysis of the IMPROVE data measured at South Lake Tahoe (SLT) and D.L. Bliss State Park indicate the following. PM (2.5, 10), nitrate, potassium, EO/OC data follow a pattern of low concentrations in the summer and high concentrations in the winter. However, arsenic, vanadium, nickel, sulfur, and phosphorous do not follow this pattern and, in fact, have their own patterns. Phosphorous concentrations in this area are about 10 ng/m^3 but have many "zero" concentrations (i.e., lower than detection limit). The phosphorous detection limit by XRF is about 2 ng/m^3 , as reported by DRI during San Joaquin Valley study. Because the P concentrations are so low and sulfur concentrations average about 200 ng/m^3 , concern exists about potential interference, by sulfur, with the phosphorus measurement. The samplers and measurement methods must be carefully selected to avoid measurements below the detection limit. The filters on the mini-vols and TWSs will be masked to 29mm to reduce the likely number of non-detects.

Accurate measurements of NO and NO₂ in the atmosphere are of considerable importance because of the role of these compounds in the production of ozone and other photochemically derived air pollutants, such as peroxyacetyl nitrate (PAN), the nitrate radical (NO₃), and nitric acid (HNO₃). Proper evaluation and exercise of photochemical models require low detection limits (<1 ppbv) and interference-free measurements of these species. Routine monitoring techniques for measurement of NO and NO₂ and other oxides of nitrogen do not meet these requirements, thus, the photochemical models are unable to reproduce the measured atmospheric concentrations of these species accurately. Recent improvements in routine monitors and the development of ultra-sensitive and specific methods for measuring the nitrogen oxide species of interest (e.g., NO, NO₂, NO_x, NO_y, HONO, HNO₃, NO₃, and PAN) provide more accurate and reliable input data for photochemical models. Most of these

methods were evaluated recently by Solomon (1995). Redundant measurements by alternative spectroscopic method such as a tunable diode laser absorption spectroscopy (TDLAS) or differential optical absorption spectroscopy (DOAS) would be desirable if sufficient funds are available.

The current limited deposition monitoring network will be expanded to provide better spatial coverage. More importantly because dry deposition measurements are notoriously difficult, a collocation experiment of three deposition monitoring techniques will be conducted at Lake Forest. Consistent results will yield confidence that the historical deposition record is accurate. Different results will force additional analysis and interpretations as to what the measurements actually represent. Of particular interest is the water surface sampler that will be deployed. This dry deposition sampler is aerodynamically designed to minimize the wake effects associated with the traditional bucket sampling system. The results are anticipated to be more representative of the dry deposition rates over the Lake.

The proposed monitoring network for LTADS is presented in Figure 13. The sites with names highlighted (bold type) will serve as the cornerstones of the monitoring network. They will include more comprehensive measurements and characterize conditions in critical regions of the LTADS domain. More detail about the actual measurements at each site is presented in Table 16.

Figure 13. Proposed LTADS air quality network.

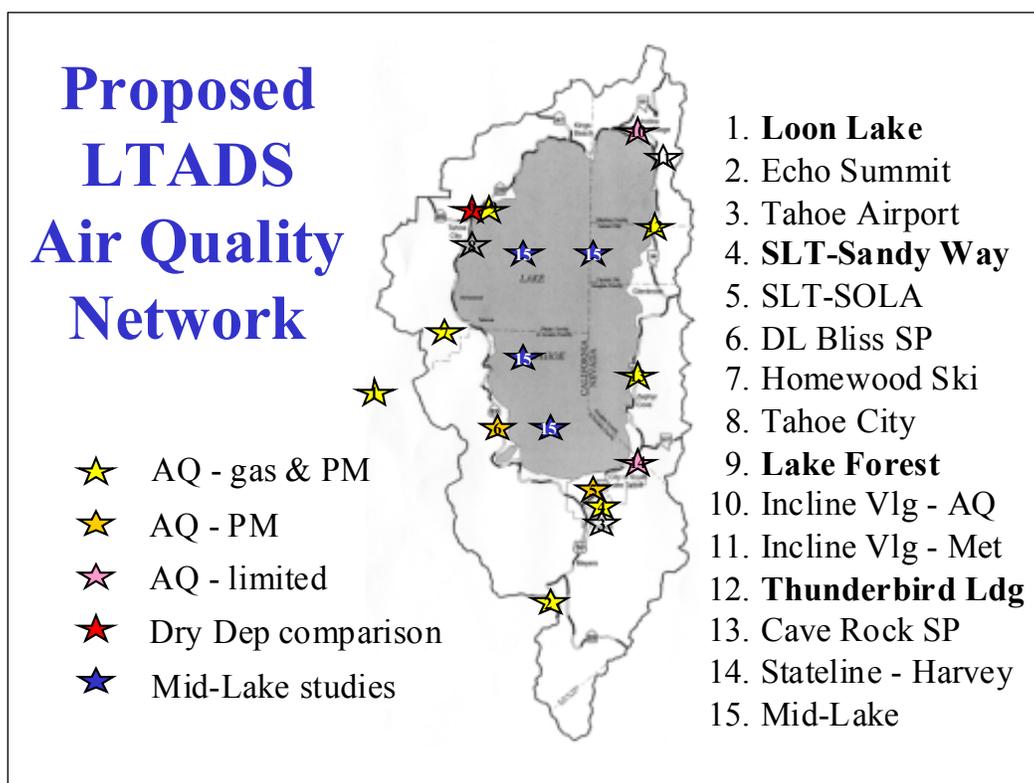


Table 16. Surface air quality monitoring network.

Site	CO	O ₃	NO _x	NO _y	TWS*	Mini-Vol	Particle Counter	PM2.5 mass	PM10 mass	BAM2.5	BAM10	BAMtsp	Neph	Bucket** Wet/dry	Sponsor	Operator
Loon Lake [#] , CA	P	P		P	P		SI			P	P			P	CARB	CARB
Echo Summit, CA	Y	Y	Y				SI		Y						CARB	CARB
Homewood [#] , CA					P [^]		I				P		P		CARB	CARB
Sandy Way, CA	Y	Y	Y	P	P		SI	Y	Y	P	P	P		Y	CARB	CARB
Stateline (Harvey's), NV	Y														NDEP	CARB
Incline Village, NV		Y													WCHD	WCHD
Cave Rock, NV		Y					SI				P				NDEP	CARB
Thunderbird Lodge, NV					P		SI	Ys	Y	P	P	P		P	TRPA	TRPA
South Lake Tahoe, CA					P		SI	Ys	Y			P	Y		TRPA	ARS
D.L. Bliss State Park, CA								Ys	Y				Y		TRPA	ARS/UCD1
Lake Forest [#] (TRG Lab), CA	P	P		P	P		SI			P	P	P		Pds	TRG/CARB	TRG/CARB
Mid-Lake buoys [#]						P [^]									CARB	TRG
TRG boat (LeConte)		Pw		Pw			Pw								CARB	TRG
Ward Creek														Y	TRG	TRG

CO – carbon monoxide; O₃ – ozone; NO_x – oxides of nitrogen (NO + NO₂ + ?NO₂); NO_y – total reactive oxides of nitrogen

TWS – two-week sampler with chemical speciation of PM2.5, PM10, and TSP

Particle Counter – size-resolved (6 bins between ~0.5 and 25 microns)

Neph – nephelometer

Bucket - historically used by UC Davis Tahoe Research Group as a surrogate surface for wet/dry deposition; Pds – water surface deposition sampler from Holsen

– new site to be established

P – planned measurement; P[^] - short-term use in 2002-03 if feasible; P⁺ - planned but need to move from upwind boundary sites or take head off another BAM and move to this site; P⁻ - planned but may move instrument to another site; Pw – planned, primarily during winter

Y – existing measurement; Ys – existing speciated measurement ala IMPROVE program

CARB – California Air Resources Board; NDEP – Nevada Dept. of Environmental Protection; TRPA – Tahoe Regional Planning Agency; WCHD – Washoe County Health Department; ARS – Atmospheric Resource Specialists

2.3.2.4 Upper-Air Air Quality

The aircraft flights will provide critical measurements of conditions aloft where carryover and transport of polluted air masses could significantly influence the performance of the model and influence pollutant concentrations at ground level. It is important that the air quality model application accurately simulate the ground level observations for the correct reasons. The air quality measurements proposed for the plane are shown in Table 17. These measurements will be supplemented, if feasible, with a particle-sizing counter.

Table 17. Upper-air air quality monitoring network.

Site	O ₃	NO	NO _Y	HNO ₃	NH ₃	#P>0.3μ	#P>3.0μ	Sponsor	Operator
Cessna	Y	Y	Y	Y	Y	Y	Y	CARB	UCD

2.3.2.5 Deposition

Both direct and indirect methods will be used to estimate deposition rates. Convergence of results of different methods provides confirmation of those results. Observation of deposition to surrogate surfaces will be continued in the form of the historical wet and dry buckets that provide the long-term record of the Tahoe Research Group, UCD. Direct observations of winter season deposition of elemental phosphorus and ions to snow can be provided by sampling and chemical analysis of the spring snow pack.

Independent calculation of deposition rates will be made based upon ambient concentrations and deposition velocity. The deposition velocity is a transfer coefficient for the specific substance of interest. The deposition velocity is not a constant because it takes into account the current state of the atmosphere, the current state of the underlying surface, and chemical and physical properties of the species of interest. Because the state of the atmosphere varies diurnally, the deposition velocity also varies diurnally. The deposition rate (mass/length²/time) is the product of the concentration mass/length³ and the deposition velocity (length/time). The concentration and deposition velocity can be either estimated or measured. Calculation of deposition velocity requires estimation of the aerodynamic resistance or its inverse, aerodynamic conductance.

Deposition rates may be directly observed or inferred from either indirect observation methods or theory. Direct observations are most reliable, but are expensive and difficult with respect to achieving appropriate siting. Generally a combination of methods is used, with direct observations at a few sites and indirect methods applied at additional sites to better represent spatial variations.

The eddy covariance method can be employed to measure the deposition rate if fast response (~10 Hz) instruments are available for the chemical species of interest. Rapid

observation of the concentrations and vertical velocity associated with turbulent eddies allows direct calculation of vertical transport. Absent other sources or sinks, absent chemical production or destruction, and absent differential advection then the vertical transport is the deposition rate. The above assumptions place stringent requirements on site selection and height of instruments.

Alternatively, direct observation is possible by eddy accumulation or profile methods if highly accurate slow response instruments are available. Sufficient instrument accuracy is required to resolve very small concentration differences (e.g., < 5% of the mean concentration). Similarly profile methods (measuring the difference in concentration at two elevations) can be employed without fast response instruments, but again the measurements must be capable of accurately characterizing very small differences in concentration. To calculate a deposition rate, measured vertical gradients of concentration must be accompanied by an estimate of eddy diffusivity (based upon measured or modeled meteorological parameters. The Bowen ratio technique, a variant of the profile method, reduces one source of uncertainty by directly observing the eddy diffusivity. The vertical flux of heat or water vapor is measured directly and measured differences in concentration, temperature, and humidity at two heights are used to calculate the flux of the species of interest.

Results of studies of deposition to surrogate surfaces are frequently reported. However, because the controlling property of the uptake is determined either by the surface itself or the configuration of its exposure in the environment, surrogate surfaces can rarely provide reliable deposition data. (Wesely and Hicks, 2000)

The use of surrogate surfaces is a reasonable approach for large particles for which gravitational settling is the principal mechanism of deposition. However, impaction and interception is important for vegetative canopies.

For large bodies of water sufficient fetch is available for the development of breaking waves and spray. This is significant, because the presence of breaking waves and spray constitutes an entirely different regime for deposition as compared to a smooth water surface. (Jielun Sun, 2001 personal communication)

Observation (measurement) of deposition requires great care in site selection and choice of instrument heights. Spatial homogeneity of the surface over sufficient upwind fetch is essential. The best opportunity for direct measurements will be over water or at the water's edge with onshore winds (airflow from the Lake toward land).

Deposition rates are highly variable between chemical species, with meteorological conditions. Thus they will be highly variable with time of day. For that reason, diurnal resolution of concentration and deposition rates is highly desirable. The Lake will provide some benefits to calculations. Presence of the Lake provides: a long upwind spatially homogeneous fetch, well defined surface temperatures for contrast with air temperatures in calculation of stability, the opportunity to utilize the Bowen technique by measurement of water vapor.

It is necessary to characterize the actual deposition (as distinct from concentration or collection on surrogate surfaces. This should include observations at a minimum of one site. Micrometeorological observations to characterize fluxes of heat and water vapor should be made at a minimum of one site on the east shore. This site should also have measurements for calculation of deposition by eddy covariance, eddy accumulation, profile, or Bowen technique. The Bowen technique is recommended for the species of interest.

2.4 MODELING

The modeling for the Tahoe Basin will be based on existing models. Initial applications will be based on modeling to be conducted for episodes during the 2000 Central California Ozone Study (CCOS) and 2000/01 California Regional Particulate Air Quality Study (CRPAQS). The CCOS modeling (gases) will be limited primarily to summer simulations while the CRPAQS modeling (gases and aerosols) will focus on the winter and fall seasons. The results of these modeling exercises pertinent to the Tahoe Basin will be evaluated and analyzed. Subsequent to these modeling efforts, the models will be adapted for a Tahoe-specific application (e.g., smaller nested grid cells within the Tahoe Basin, updated emission inventory for the Tahoe Basin, model performance validation based on LTADS data). Before the models are adapted, it will be necessary to identify performance measures and performance evaluation methods, and to specify methods by which these will be applied. Furthermore, the responsibilities for emissions, meteorological, and air quality modeling activities must be clearly delineated.

Lessons about the performance of airshed models in previous applications may be pertinent to this study:

- The airshed models used to model the 1987 Southern California Air Quality Study episodes appear to underpredict NO_x oxidation products, leading to concerns about their ability to quantify the effectiveness of NO_x controls.
- Uncertainties in the modeling results must be determined and potentially reduced. Models should not use a terrain-following coordinate system, as the observed pollutant and temperature structure aloft appears to be more horizontal in nature.
- Conditions aloft have a significant influence on surface air quality; boundary conditions also have a significant influence on modeling results. Development of reliable and cost-effective methods for measuring meteorological conditions and pollutant concentrations (aloft and in "clean" air) is needed to support modeling applications.
- The performance of photochemical models is somewhat dependent on their formulation. Improvements are needed in the meteorological and chemical formulations to improve model accuracy, precision, and validity.

2.4.1 CCOS Modeling

The field study for the Central California Ozone Study (CCOS) occurred during the summer of 2000. Modeling of these data is anticipated to be completed by the fall of 2003. The modeling domain for CCOS includes the Lake Tahoe Air Basin. Concentration and deposition estimates will be available for 4x4 km grid cells for approximately 15 days during the summer of 2000. However, the focus of the modeling efforts is the Central Valley and the model will not be adjusted for best performance in the Tahoe Basin. A couple of different meteorological models (MM5, RAMS) are being tested and their performance evaluated for future input into the air quality model. Nonetheless, an emission inventory of phosphorus does not currently exist and so the CCOS modeling will not include any estimate of P deposition.

2.4.2 CRPAQS Modeling

The field study for the California Regional Particulate Air Quality Study (CRPAQS) occurred during the fall and winter of 2000/2001. Modeling of these data is anticipated to occur by the summer of 2004. The modeling domain for CRPAQS includes the Lake Tahoe Air Basin. Once again the model performance will not be optimized for the Tahoe Basin. The phosphorus emission inventory will likely not be highly refined but will provide some crude estimates of P deposition.

Additional aerosol modeling efforts are likely for the development of the State Implementation Plan for PM_{2.5} and these results will be reviewed for pertinence to conditions and processes in the Tahoe Basin.

2.4.3 Air Parcel Trajectory Modeling

Once meteorological fields have been developed and validated for the airshed modeling, air parcel trajectory analyses can also be performed to identify likely source-receptor relationships and potential impacts. Because of the complex mountain topography, and the limited number of meteorological monitoring locations and uncertainty about the spatial representativeness of the data collected at them, individual trajectory analyses based on interpolated or diagnostic methods are likely to have significant uncertainties associated with them. Analysis of typical wind flow patterns based on multiple prognostic wind model runs with data assimilation under various synoptical meteorological scenarios will likely provide the best evidence for source/receptor relationships.

2.4.4 LTADS Modeling

Modeling based on the data collected during the LTADS field study will provide the most refined analysis of deposition of materials and their relative source strengths. Tahoe-specific emission profiles and activity factors will be used to generate an improved emission inventory of P, N, and PM in the Tahoe Basin. The nested grid scale of 1-2 km will provide improved precision compared to standard 4x4 km modeling applications. In addition, the incorporation of continuous near-surface winds will provide critical information regarding the convergence of drainage flows over the Lake. The

incorporation of winds aloft to above the Sierra Nevada crest within and outside the Tahoe Basin will provide enhanced understanding of the meteorological processes and how transported air masses are mixed with air containing local emissions within the Basin.

These enhancements in the emissions and meteorological data will enhance the performance of the air quality model within the Tahoe Basin. With an enhanced meteorological and air quality monitoring network, the performance of the model in the Tahoe Basin can be better evaluated than will be the case for the CCOS and CRPAQS modeling efforts. Unfortunately, the deposition estimates and source attribution exercises with this modeling may be too late to contribute significantly to this round of the TMDL process. The field study, emissions inventory update, meteorological modeling, and air quality modeling will need to occur without any complications to produce defensible results by the fall of 2004.

2.4.5 Chemical Mass Balance Receptor Modeling

In addition to the use of airshed and trajectory models, receptor models can provide valuable information and insights. Receptor models use the chemical and physical characteristics of gases and particles measured at sources and receptors both to identify the sources and to quantify their contributions to the pollutants measured at the receptors. The particle characteristics must be such that: 1) they are present in different proportions in different source emissions (*i.e.*, they provide a means by which to distinguish sources); and 2) these proportions remain relatively constant for each source type. Common types of receptor models include: chemical mass balance (CMB), principal component analysis, and multiple linear regression. The CMB is the basic receptor model, and the derivation of the other receptor models from fundamental physical principles begins with the CMB.

CMB receptor model uses knowledge of emission source characteristics along with the characteristics of the pollutants at the receptor to determine the contribution of each source to the pollutant level at the receptor. A CMB model assumes that the concentration of a given chemical species at a receptor is the sum of the contributions of that chemical species from each source. Mathematically this is shown below:

$$C_i = \sum f_{ij} a_{ij} S_j \quad \text{for } i = 1 \dots n \text{ and } j = 1 \dots m$$

where C_i is the concentration of chemical species i , f_{ij} is the fraction of species i from source j that has been unaltered before that species reached the receptor, a_{ij} is the fraction of species i in the emissions of source j , and S_j is the concentration of pollutants from source j at the receptor. Mathematically, to solve this series of equations $n > m$, and the a_{ij} values for each source j must be linearly independent. The a_{ij} values are termed the source profiles or source fingerprints. The fraction of species which reach the receptor site, f_{ij} cannot be measured directly, as this is a function of the chemical and physical transformations between the source and receptor site. As a practical matter, only species with low volatility and reactivity are used as tracer compounds so

that f_{ij} values are approximately equal among the tracer compounds. As mentioned above, a CMB model uses knowledge of the characteristics of the pollutants at the receptor (C_i) and characteristics of the source emissions (a_{ij}) to determine the contribution of each source (S_j) to the pollutant level at the receptor. Therefore, with measurements of C_i and a_{ij} , S_j can be calculated.

Successful application of a CMB model starts with a critical selection of chemical species. First, select chemical species for which f_{ij} can be assumed to be 1. In other words, use only chemical species which are not depleted via chemical reactions or via preferential removal mechanisms, and which are not created via atmospheric chemical reaction. Second, since the model requires that the source profiles be linearly independent, chemical species must be chosen which are unique to specific source types. The selected chemical species are often called "tracers" because they are emitted from one specific source or emitted in a unique abundance by that source. To satisfy the other mathematical requirement ($n \geq m$), the number of chemical species selected must be greater than or equal to the number of sources resolved.

The CMB modeling procedure requires: 1) identification of the contributing source types; 2) selection of chemical species to be included; 3) estimation of the fractions of each chemical species contained in each source type (i.e., the source profile); 4) estimation of the uncertainties of both ambient concentrations and source compositions; and 5) solution of the chemical mass balance equations.

The basic assumptions of the CMB model are (Watson, 1979): 1) compositions of source emissions are constant over the period of ambient and source sampling; 2) chemical species do not react with on another (i.e., they add linearly); 3) all sources which may significantly contribute to the receptor have been identified and their emissions characterized; 4) the number of source categories is less than or equal to the number of chemical species; 5) the source profiles are linearly independent (i.e., they are statistically different); and 6) measurement uncertainties are random, uncorrelated, and normally distributed.

The assumptions are fairly restrictive and will never be totally complied with in actual practice. The CMB model can tolerate deviations from these assumptions, though these deviations increase the stated uncertainties of the source contribution estimates.

Watson (1979) observed that the CMB model yields unreliable source strength estimates for sources with similar source profiles, such as different soils and road dusts. While soil and dust profiles are roughly equivalent for major chemical components such as aluminum and silicon, their composition varies substantially -- by factors of two or more (Javitz et al., 1988) -- for prominent but less plentiful elements such as iron and calcium.

2.5 DATA ANALYSIS

2.5.1 Analyses of Existing Data

Historical data collected in the Sierra Nevada and Tahoe Basin can provide valuable information for the design and refinement of new field studies. For example, historical trends of long term data, case studies of special situations, contrasting with data in other regions, assessment of observed background and basin boundary conditions to design for appropriate levels of detection, analysis of IMPROVE and aircraft data, associations between air quality and various meteorological scenarios, etc. can provide critical information for improving the design and results of the LTADS.

2.5.2 Analyses of Field Study Data

Data analysis is an essential part of the database and model development components of the Lake Tahoe study. Measurements, by themselves, say nothing about the causes of air pollution and the likely effects of emission reductions. Only when these measurements are interpreted can relationships be observed and conclusions drawn. Similarly, mathematical models cannot be expected to explain phenomena that are not conceptually defined. "Conceptual models" of pollutant emissions, transport, chemical transformation, and deposition must be formed so that the best mathematical formulations can be selected to describe them. The major goals of the Tahoe data analysis are:

- To evaluate the measurements for applicability to model input, parameterization, and verification.
- To describe the air quality and meteorology during the field study period and to determine the degree to which these measurements represent other summertime pollution levels.
- To further develop conceptual models of physical and chemical processes which affect ozone processes (including formation and transport) in the Tahoe Basin.

While these goals provide guidance, concrete actions must be taken to attain them. These actions are described in the following data analysis plan. The plan is intended to:

- Identify data analysis objectives and hypotheses to be tested by applying data analysis methods.
- Specify data analysis work elements and the data to which they will be applied so that objectives may be met and hypotheses may be tested.
- Specify methods by which the data analysis tasks can be carried out and integrated into publications and reports to meet data analysis objectives.

Data analysis activities are defined here within the following topic areas: 1) measurement evaluation; 2) spatial, temporal, and statistical descriptions; 3) qualitative transport characterization; 4) dispersion characterization; 5) emission characterization; 6) quantitative transport characterization (pollutant fluxes); 7) ozone chemistry; 8) episode characterization; and 9) refinement of conceptual models. Activities are detailed in the following sub-sections.

2.5.2.1 Accuracy, Precision, Validity, and Equivalence of Field Measurements

There has never been a field study to date that did not require substantial examination and investigation of the measurements prior to their further use in data analysis and modeling. This first topic area is essential to all subsequent data analysis efforts, and needs to be performed as data are received into the database described in Section 7. Major concerns focus on: 1) accuracy of VOC peak identification, and proper, consistent quantification of total nonmethane hydrocarbons; 2) representativeness of meteorological measurements, especially those drawn from existing networks; 3) accuracy and precision of low-concentration measurements, especially NO_x, and PAN; and 4) comparability of measurements taken from different networks with different procedures.

2.5.2.2 Evaluate the Precision, Accuracy, and Validity of Nitrogenous Species Measurements

Create scatter plots and calculate slopes, intercepts, and correlation coefficients for normal sensitivity chemiluminescent NO_x, high sensitivity chemiluminescent NO_y, measurements sites, and spectroscopic measurements (e.g., DOAS and TDLAS). Determine the equivalency of these different measurement methods by evaluating these plots and statistics. Examine differences among sites (along with calibration and performance test data) to attribute differences to instrument differences or to interferences in the sampled air streams (e.g. HNO₃ detected by chemiluminescence). Create scatter plots and statistics of collocated PAN analyzer values. Explain differences in terms of measurement methods or environmental variables (e.g., interferences). Compare differences to propagated uncertainty intervals derived from performance tests and extrapolate the collocated uncertainties to other Luminol PAN sampling sites in the network. Reconcile laboratory comparison data with field comparison data.

2.5.2.3 Evaluate the Precision, Accuracy, Validity, and Equivalence of Meteorological Data

Devise methods to compare upper air measurements of wind speed and direction from profilers, acoustic sounders, and surface wind towers and with corresponding measurements from radiosondes. Determine equivalent averaging layers and averaging times. Determine times of day (e.g., early morning, mid-day, and late-day) when these measurements are similar and when they are not. Draw conclusions regarding the equivalence of these methods. Compare surface measurements of wind

speed and direction with the lowest elevation values from collocated profile, sonde, and sounder measurements. Stratify comparisons by time of day to obtain well-mixed and layered vertical structures. Determine when surface measurements are an adequate estimate of upper air winds and when they are not, both with respect to elevation above ground level and time of day.

2.5.2.4 Describe the Spatial, Temporal, and Statistical Distributions of Air Quality Measurements

Summaries of data collected during the field study need to be created which can serve as a guide to the database and for the formulation of hypotheses to be tested by more detailed analyses. These summaries may be examples drawn from a data display package (such as that which was developed to display data in real-time during the study). The database and display software could then be used in other data interpretation projects to provide support for their findings.

2.5.2.5 Examine Average Diurnal Changes of Surface Concentration Data

Create diurnal box plots (which graphically show quartiles, median, mean, and extremes) for the entire sampling period and for each hour at each site of ozone, NO, NO₂, and PAN concentrations. Note differences in the timing and intensity of peak values as a function of sampling site, episode, and stratification. Group sites for which diurnal variations behave in a similar manner. Compare these with plots from selected sites in prior summers where ozone and NO_x data are available. Evaluate the extent to which the summer of 1997 is similar to or different from prior summers.

Create diurnal box plots for each hour at each site of ozone, NO₂, and PAN (where available) for each episode and the stratified intensive sampling days. Superimpose diurnal average total VOC, total aldehyde, nitric acid, and particulate nitrate boxes for specified sampling periods. Note differences in the timing and intensity of peak values as a function of sampling site and how these are similar to or different from those of the longer-term averages.

Create diurnal box plots of surface temperature, relative humidity, insolation, sigma theta, and scalar wind speed for each hour at each site for the entire monitoring period and for the intensive episodes. Identify similarities and differences among sites and between the intensive episodes and the entire study period.

2.5.2.6 Examine Spatial Distributions of Surface Concentration Data

Plot spatial isopleths corresponding to each intensive episode sample for total VOCs, selected VOC surrogates (selected to represent reactivity class, sources of precursors, or end products), NO_x, NO₂, PAN, NO/NO₂, VOC/NO_x, and O₃. Note similarities and differences in patterns with time of day, pollutant, and from episode to episode.

2.5.2.7 Examine Statistical Distributions and Relationships Among Surface Air Quality Measurements

Combine hourly averages of air quality measurements into sample averages corresponding to VOC and aerosol samples. For each site, calculate averages, standard deviations, first second and third maxima (with date and time of occurrence), and minima (with date and time of occurrence) concentrations for each species measured. Identify differences between morning, afternoon and nighttime, sampling locations, episodes, and chemical observable. Give special attention to differences between rural vs. urban areas, SoCAB vs. other air basins, morning vs. afternoon vs. nighttime.

Combine hourly averages of continuous measurements into sampling periods corresponding to VOC and aerosol samples. For each site, calculate the temporal correlation coefficients for all measured variables. Identify those variables which are highly correlated (negatively or positively) with each other and identify observables which might be represented by a single surrogate at each site. Combine these surrogates with meteorological variables and note positive or negative correlations among them.

Perform Principal Component Analysis (PCA) on VOC and nitrogenous species. Calculate eigenvectors of the correlation matrix and perform a varimax rotation to identify empirical factors that explain the variability in the data. Describe these factors in terms of physical phenomena, and examine factor scores to determine when each factor has much greater than or much less than average influence at each site.

Using selected species concentrations, calculate spatial correlations for the intensive episode samples. Examine correlations and identify which sites are highly correlated (positively or negatively) with each other. Calculate eigenvectors of this correlation matrix, perform a varimax rotation, and plot the empirical orthogonal functions that are deemed significant. Use these to select surrogate sites which can be used to represent neighboring sites for different observables (the surrogates and the area which they represent may not be the same for all observables).

Plot surface wind roses for all data at selected times of the day on a single map. Identify when flow reversals take place and when wind speeds increase or decrease. Note which areas have the highest frequencies of calms and when they occur. Perform these analyses for meteorologically stratified cases.

2.5.2.8 Examine Vertical Distribution of Concentrations from Airborne Measurements

Plot VOC (total and selected species, aldehydes (total and selected species), NO₂, NO, O₃, and b_{scat}) as a function of altitude for each spiral. Note similarities and differences with respect to location, time of day, and chemical species. Give special attention to VOC speciation in morning samples (i.e., local emissions) over urban (motor vehicle),

non-urban (biogenic), and industrial (oil-field) areas. Compare canister and cartridge samples of VOC and aldehydes taken in spirals with those taken in circles at the top of the spiral.

Plot spatial distributions of VOC (total and selected species, aldehydes (total and selected species), NO₂, NO, O₃, and b_{scat} along air craft traverses (within the mixed layer). Note similarities and differences with respect to location, time of day, chemical species, and the spatial distributions derived from surface-based measurements. Compare concentrations along boundaries (long-range aircraft) with those measured at locations within the study domain and note similarities and differences.

2.5.2.9 Examine the Spatial and Temporal Distribution of Solar Radiation

From the radiometer data, estimate the photosynthetically active radiation (needed for deposition and biogenic emissions), direct beam solar radiation, diffuse solar radiation, visible radiation (for light extinction), incident flux, and actinic flux (at frequencies relevant to photochemical reactions). Create spatial and temporal plots of these observables. Describe differences between sites and time-of-day in terms of measurement uncertainty, meteorological and air quality parameters. Note the effects of clouds and smoke on different types of radiation.

2.5.2.10 Characterize Meteorological Transport Phenomena

This topic addresses the major mechanisms for the movement of air into, out of, and between the different air basins in both horizontal and vertical directions. This requires an examination of conditions near sea level and also just below, within, and above the inversion layer.

2.5.2.11 Determine Horizontal Transport Patterns and Intensities Into and Within the Tahoe Air Basin

Plot 0500, 1100, 1700, and 2300 horizontal wind fields at three different heights (surface, within the mixed layer, and above the mixed layer) using continuous and radiosonde data. Examine the consistency of these flow vectors with those predicted from synoptic weather maps and pressure gradients. Note similarities and differences with respect to time of day, elevation, and episode. Associate the directions with the expected phenomena such as slope flows, convergence, and divergence. Examine aircraft data to further describe the evolution of these phenomena. Determine the time of occurrence, spatial extent, intensity, and variability of these phenomena.

Plot back-trajectories for critical air quality episodes. Identify general areas over which air masses might have passed to reach these receptors. Classify episodes into categories that are likely to be influenced by different types of source areas.

2.5.2.12 Determine Vertical Transport Patterns and Intensities within the Modeling Domain

Examine wind flow patterns to identify convergence and divergence zones. Examine acoustic sounder, profiler, and aircraft meteorological data for evidence of vertical exchanges in these regions. Determine the extent to which surface air is transported above the mixed layer, or air above is transported into the mixed layer at these locations. Verify this with vertical profiles of pollutant concentrations from onboard aircraft measurements. Examine and describe the intensity and duration of upslope flows to estimate the amount and frequency with which pollutants might be transported above the mixed layer. Verify this with onboard aircraft pollutant measurements. Plot the vertical velocity structure as a function of time. Examine sounder data and profiler data to determine the degree of layering in the atmosphere, especially during the evening and morning. Identify the locations of wind shears and their effect on layering. Note the differences in layers at different locations throughout the study area.

2.5.2.13 Characterize Meteorological Dispersion Processes

Dispersion processes address the mixing of pollutants within the mixing layer, especially elevated and ground-level emissions, dispersion within and between modeling grid cells, and transport to the surface where deposition of pollutants may occur.

2.5.2.14 Characterize the Depth, Intensity, and Temporal Changes of the Mixed Layer— Characterize Mixing of Elevated and Surface Emissions

Plot the spatial distribution of expected mixing depths derived from temperature soundings at 0500, 1100, 1700, and 2300. Examine aircraft and profiler data for evidence of other layers within the mixed layer, their time of formation and dissipation, and their typical duration and intensity. Describe the changes in layers as a function of time, especially during the morning when rapid changes are taking place with heating. Associate changes in layers with changes in surface temperature and solar radiation.

Examine vertical mixing as a function of location and time of day using aircraft data and continuous profiler and acoustic sounder measurements. Estimate the times of day when pollutants, carried over from the previous day above the mixed layer, will combine with pollutants emitted at the surface. Verify this by examining aloft and surface level concentrations that are associated with aged emissions.

2.5.2.15 Characterize Emissions

Emission data will be acquired in separate projects. If ambient measurements and emission data are correct, consistent relationships between the spatial, temporal, and meteorological variability in emissions and ambient measurements should be found. The tasks associated with this objective look for these relationships and will explain why they are observed or are not observed.

2.5.2.16 Determine the Consistency between Proportions of Species Measured in Ambient Air and those Estimated by Emission Inventories

Compare ambient ratios of pollutants with those in emission inventory grid squares in the vicinity of the sampling site and with ratios in speciated profiles. If profiles are sufficiently speciated, perform Chemical Mass Balance modeling to apportion each species to a source type (e.g., wood smoke, fires, road dust, tailpipe emissions, biogenics) and compare the ratios of source contributions to the ratios of total emissions in nearby grid squares. Note consistencies and differences between ambient ratios and emission inventories and propose hypotheses for these differences. Define further investigations needed to reconcile the discrepancies (both further work on inventories and ambient/source sampling). Compare ratios from polluted days with those on clean days and identify the presence or absence of different emissions at receptors on different types of days.

Using existing (or improved, if possible) source profiles for the study region, calculate source contributions to P at selected receptor sites using a Chemical Mass Balance (Watson et al., 1984, 1990). Compare relative source contributions with the relative emission rates from these sources in grid squares in the vicinity of the sampling sites. Examine source contributions for consistency with the emission inventory with respect to geographic location and sampling times.

2.5.2.17 Determine the Effects of Meteorological Variables on Emissions Rates

Select representative sampling sites from major source regions (e.g., town, residential, biogenic, etc.) and examine concentrations of "marker" species for sources as functions of temperature, relative humidity, wind speed, and other environmental variables which are used to adjust emission factors. If possible, draw conclusions concerning the efficacy of current emission factors to respond accurately to changes in meteorological variables. Compare source contributions when intermittent sources are known to operate and when they are known not to operate. Attempt to detect effects of different wind speeds, temperatures, solar radiation levels, and relative humidities on biogenic and anthropogenic emissions. For example, can residential wood burning be correlated to degree heating days, etc.

2.5.2.18 Determine the Detectability of Day-Specific Emissions at Receptors

Examine day-specific emissions and identify sampling locations and times that correspond to fires, pesticide applications, spills, etc. From previous measurements of emission compositions, identify chemical species that are likely to be contributed by that source. Examine transport and dispersion patterns to determine the likelihood of influence at nearby sites. Compare the ambient concentrations at likely impact sites with concentrations at that site when day-specific emissions do not exist. Examine nearby sites and draw conclusions about the region of influence of intermittent emitters.

2.5.2.19 Characterize Pollutant Fluxes

It is hypothesized that upwind sources contribute to pollutant levels measured at different receptors along the flow paths from the San Francisco Bay Area, across the Sacramento Valley, and to Lake Tahoe. A “flux plane” is a rectangular cross-section that is perpendicular to the prevailing horizontal wind direction at a location between major emission sources (e.g., between upwind sources in the SFBA & SV and local sources within the Tahoe basin). A major transport pathway that is suspected of passing through a flux plane is Highway 50.

2.5.2.20 Define the Orientations, Dimensions, and Locations of Flux Planes

Examine wind fields to identify areas in air that is transported across a boundary at vertical levels, especially at entry and exit points to the Tahoe Basin. Specify the horizontal and vertical coordinates of these flux planes. Examine the usefulness of different conceptual definitions of flux (i.e., mass/unit area/time, mass/time, upwind/downwind concentrations along a wind vector). Estimate uncertainties due to: 1) mis-specifying the portion of pollutant flux attributable to background vs. that generated in the upwind source area; 2) the effects of vertical and horizontal wind shears or reversals on the definition of the flux plane; 3) variations in wind speed and direction between measurements; 4) mis-specification of the boundary plane height; and 5) effects of wind speed and direction variability on flux estimates.

2.5.2.21 Estimate the Fluxes and Total Quantities of Selected Pollutants Transported Across Flux Planes

Using aircraft spiral and traverse data and ground-based concentration data for NO_y , HNO_3 , and O_3 coupled with average wind speeds that are perpendicular to the chosen flux planes, calculate the $\text{mg/m}^2\text{-sec}$ of each pollutant which crosses each plane as a function of time of day. Compare the fluxes for the different planes and assign downwind fluxes to a combination of fresh pollutant generation and contributions from the upwind flux plane. Examine fluxes at different layers, especially at night, if major differences are observed in vertical concentrations and wind speeds. Plot vertical cross-sections of concentrations, wind speed, and direction.

Compare the magnitudes of inflow to and outflow from regions that are bordered by flux planes. Advance explanations for major differences between inflow and outflow. Using all relevant field study data, test the hypotheses that: 1) there is significant local generation of pollutants; 2) there is significant venting through the mixed layer; and 3) there is substantial reverse or lateral transport owing to eddies, nocturnal jets, and upslope/downslope flows.

2.5.2.22 Characterize Chemical and Physical Interactions

Ozone, several nitrogenous species, and significant portions of the VOCs found in the study domain are not emitted directly from sources, but form from precursors.

2.5.2.22.1 Nitrogen and Carbon Budgets

Plot pie charts of the gaseous and particulate nitrogen (NO , NO_2 , HNO_3 , PAN, HONO, and NO_3^-), and carbon (elemental and organic aerosol carbon) as a function of location. Make the radius of each pie proportional to the total number of N, S, or C atoms, and make each wedge proportional to the number of N, S, or C atoms contributed by each species. Examine the distributions of these species among gaseous and particulate phases as a function of time and location.

2.5.2.22.2 Characterize Seasonal Episodes of Elevated Concentrations

Each of the seasonal episodes of two- to four-week duration has similarities and differences with respect to emissions, meteorology, transformation, deposition, and air quality levels. These episodes may be high for similar or for different reasons. Information derived from the preceding activities is synthesized to provide an anatomy of each episode. Conclusions are drawn with respect to which episodes are, for all practical purposes, the same, and which ones are substantially different.

2.5.2.23 Describe Each Selected Seasonal Episode in Terms of Emissions, Meteorology, and Air Quality

Prepare written overviews of each selected seasonal study period. Describe the synoptic meteorology leading up to the episode. Illustrate, with plots generated in other work elements, the general wind flows for the duration of the period and any deviations from these generalizations. Identify major emissions events, identified as significant in other work elements, which affected pollutant concentrations. Summarize the key pollutant concentrations at key times and key locations in the study domain. Summarize the completeness and validity of the data set from each episode with respect to modeling of ozone and PM. Identify the transport and transformation mechanisms that are likely to be dominant in each episode. Evaluate each episode for its potential use in model testing and control strategy evaluation.

2.5.2.24 Determine the Degree to which Each Selected Seasonal Episode is a Valid Representation of Commonly Occurring Conditions and its Suitability for Development of Annual Average Bounds

Examine continuous meteorological and air quality data acquired for the entire study period, and determine the frequency of occurrence of days which have transport and transformation potential similar to those of the intensive study periods. Generalize this frequency to previous years, using existing information for those years.

2.5.2.25 Reformulate the Conceptual Model

The conceptual models of N, P, & PM deposition must be revisited and refined using the results yielded by the foregoing data analyses. New phenomena, if they are observed,

must be conceptualized so that a mathematical model to describe them may be formulated and tested. The formulation, assumptions, and parameters in mathematical modules that will be included in the integrated air quality model must be examined with respect to their consistency with reality.

2.5.2.26 Refine Conceptual Models of Pollutant Emissions

Specify the various emission model equations, assumptions, input data, and uncertainties. Reconcile the ambient species ratios found in ambient data with ratios determined from emissions models in terms of model or measurement biases. By stratifying samples, estimate the effects of different meteorological variables on emission rates. Recommend improvements to emission models based on these observations.

Specify biogenic emission model assumptions, input data, and uncertainties. Reconcile ambient ratios at sites located in agricultural and forested areas with those determined from emission models in terms of model or measurement biases. By stratifying samples, estimate the effects of different meteorological variables, especially wind speed, on emission rates. Examine chemical speciation as a function of vegetation type. Examine total ammonia concentrations as a function of nearby soil types and fertilizer applications. Recommend improvements to emission models based on these observations.

Intermittent events include fires, entertainment, and sporting events. Specify the models that treat intermittent events, their assumptions, and input data. Examine the magnitude of emissions from intermittent events with respect to other emissions to determine whether or not these emissions are significant. Recommend improvements to emission models based on these observations.

Examine the variability in emissions for intensive analysis days. Compare this variability to that assumed by point source models. Recommend improvements in emission models based on these observations.

2.5.2.27 Refine Models of Pollutant Transport and Dispersion

Specify meteorological model assumptions and input data relevant to calculating the vertical profile of the potential transport pathways. For unidirectional flows, the mathematical formulation should show a minimum in turbulence or laminar flow occurring at the height of the wind maximum, and the width of the jet should be adequately estimated. The model formulation should allow this region of minimal turbulence to intensify the nighttime inversion in the vicinity of the flow and to inhibit vertical transport. Reconcile the model formulation with the location, dimensions, intensity, duration, and frequency of the transport. Quantify and compare measurement and model uncertainties.

Upslope flows in the Sierra Nevada result from heating of the mountain sidewalls during the day. Upslope flows will begin earlier on the west side of the basin and be stronger during the afternoon on the east side of the basin. The downslope flows commence as the sun sets and the slopes cool. When the intensity of these up-slope winds is large, pollutants are vented from the Tahoe Basin into the air above the mixed layer. Examine the assumptions and input data of the meteorological model which relate to slope flows. Determine whether or not the intensity and timing of these flows corresponds to those observed in other data analysis work elements. Identify those cases in which upslope flows vent pollutants above the mixed layer or over the summit, and determine the extent to which the mathematical formulation can represent these cases. Identify areas of uncertainty in the modeling and measurement processes and attempt to quantify these uncertainties.

Identify the occurrence and thickness of different atmospheric layers from other data analysis work elements. Determine the modeled layer structure. Examine the extent to which layers can be assumed to be uniform, or must vary in depth as a function of location and time. Evaluate the uncertainty introduced to the modeling process by anticipated deviations from layering assumptions.

2.5.2.28 Evaluate Boundary Conditions for Models

List assumptions and input data requirements for boundary conditions, and estimate the effects of uncertainties caused by insufficient data on the ability of the model to represent reality. Ozone, nitrogenous species, and PM boundary concentrations need to be identified, particularly at the western boundary and at the top of the study domain. Plot airborne measurements of O_3 , NO , NO_Y , HNO_3 , and NH_3 along boundaries and above the mixed layer, then examine the magnitude and constancy of their concentrations in space and time.

2.5.2.29 Evaluate Initial Conditions for Models

Each grid square and each layer in the modeling domain starts with a concentration for each chemical species. These must be estimated from a sparse network of ambient measurements. Examine the different methods by which initial conditions are estimated from surface and airborne measurements. State the equations, assumptions, inputs, and uncertainties for these methods. Determine which methods are most applicable to the single point and aircraft measurements. Determine which methods are most useful for approximating initial conditions for integrated air quality modeling.

2.5.2.30 Evaluate Pollutant Deposition Models

Specify the equations, assumptions, input data, and uncertainties for the deposition model. From the examination of micro-meteorological data and vertical flux measurements, determine the extent to which these equations represent reality, and the degree to which assumptions are complied with. Evaluate the effects of input data uncertainties on deposition estimates.

3 OPERATIONS PLAN

3.1 COORDINATION MEETINGS

Routine meetings are necessary to promote coordination among the many parties involved in conducting the various components of the LTADS. The study planners need to be familiar with the needs of the data users and the data users need to be aware of financial limitations and practical limitations to the collection of new data. The design of a study plan evolves as the participants define the study needs and reconcile ideal approaches with the study resources and physical limitations (e.g., facilities, power, access rights).

To facilitate coordination among all the parties involved in achieving the goals of the LTADS, CARB staff are participating in weekly meetings. At these meetings, the staff updates each other on the latest developments and share concerns and ideas on how to make the best possible measurements, within the constraints of fiscal and personnel resources, to achieve the objectives of the study. The air quality point person from TRPA also participates to provide guidance and insight regarding local history, issues, and contacts.

To facilitate coordination of the LTADS with the goals and objectives of the TMDL setting process, CARB staff will participate in coordination meetings, attend training classes to become familiar with the water and Basin issues, and provide reports on the progress and findings of LTADS every six months.

3.2 FIELD OPERATIONS

Existing efforts to characterize emissions, meteorology, and air quality will be supplemented during the year-long field study to provide additional spatial, temporal, and compositional information. These data are needed to support the analysis and modeling that will address the informational needs of the planners for meeting various environmental goals. To do this efficiently and in a timely manner, coordination among the various participants (monitoring technicians, laboratory technicians, auditors, data managers, data analysts, modelers) is critical. Procedures will be developed in consultation between the field study participants to ensure the smooth exchange of materials and information. In addition to the exchange/delivery of data, the quality control procedures and the formats of the data supplied must be clearly identified and agreed upon. The Contact information will be generated and distributed to facilitate the exchange of information and the resolution of problems.

3.3 CONTINGENCY FUND

Monies (e.g., 5-10% of the data collection budget) should be set aside for unexpected expenses or to take advantage of unanticipated measurement or analytical opportunities.

4. DATA QUALITY ASSURANCE PLAN

4.1 QUALITY ASSURANCE OBJECTIVES FOR MEASUREMENT DATA

The objective of a quality assurance program is to provide a quantitative estimate of the uncertainty of the measurements that will be made. Modeling and data analysis are only as good as the data upon which they are based. The information and results available for decision-makers must be sufficiently accurate and precise to support the decisions that need to be made. Measurement methods must be sufficiently precise to accurately detect compounds at the lowest ambient concentrations. If a significant number of measurements were to be below the limit of detection (LOD) for a particular instrument or analysis method, assumptions will need to be made that could bias estimates of annual mean concentrations and deposition. Furthermore, different methods of measuring the same parameter are often available. If different methods or platforms are used in a field study, it is imperative that the data are compared in a controlled setting to identify any biases that could lead to erroneous conclusions. Standard operating procedures must be developed and followed to assure the quality of the data collected. Part of a good quality assurance program is to ensure the establishment of a monitoring network that accurately represents the spatial and temporal variations in meteorology and air quality that occur around the Lake. Another aspect of a good QA program is to perform audits of the data collection system before the field study begins. In this way, problems can be identified and corrected before data are collected and their quality possibly compromised.

The purpose of quality assurance is to provide a quantitative estimate of the uncertainty of the measurements through estimates of the precision, accuracy (or bias), and validity. In addition, QA ensures that the procedures and sampling methods used in the study are well documented and are capable of producing the data that meet the specifications of the study. The QA auditing program consists of two components: system audits and performance audits. System audits include review of operational and quality control procedures to assess whether they are adequate to assure valid data that meet the specified levels of accuracy and precision. After reviewing the procedures, the auditor examines all phases of the measurement or data processing activity to determine whether the procedures are being followed and the operating personnel are properly trained. Performance audits establish whether the predetermined specifications for accuracy are being achieved in practice. For measurements, the performance audit involves challenging the measurement/analysis system with a known standard sample that is traceable to a primary standard. Measurements that can be subject to sampling artifacts, such as carbonyl compounds, hydrocarbon speciation, and NO_y , preclude simple performance audits. Intercomparison studies are often used in these cases to assess the representativeness, accuracy, and precision of these measurements.

The QA manager bears overall responsibility for ensuring that the quality auditing tasks are performed by members. The major tasks are summarized below.

Overall:

- Manage the overall QA activities. Interact with the field manager and the principal investigator and provide feedback to them concerning the status of unresolved QA problems and the potential for their resolution.

Before field operations begin:

- Work with investigators to determine whether each measurement method is likely to meet its specifications for accuracy (or bias) and precision.
- Review the SOPs for each measurement and verify the assumptions on which they are based.
- Prepare systems audit procedures.
- Perform preliminary systems audits at investigators' analytical laboratories, paying particular attention to calibration methods.
- Develop performance audit procedures for measurements for either accuracy (i.e., compared to established standards) or, where that is not possible, for bias (i.e., compared to another co-equal laboratory's measurements).
- Arrange for investigators' calibration standards to be checked against USEPA, CARB or other standards.
- Audit transfer standards.
- If not all field sites are to be audited, develop a priority system indicating which field sites and which laboratories should be audited during or just prior to field measurements.
- Immediately prior to field operations, carry out performance audits of the continuous gas analyzers and flow measuring instruments at the chosen field sites.

During field operations:

- Perform system audits on field and laboratory measurements, and data processing procedures. Field air quality measurement sites, sampling aircraft, upper air sites, and meteorology sites should be audited.

- Perform systems audits of the data processing and data management operations of the measurement and data management contractors.
- Coordinate performance audits on routine measurements. Arrange for or perform those audits not done by the sponsoring organizations.

After field operations:

- Prepare reports of the audits.
- Work interactively with the data management contractor in the on-going Level 1 and Level 2 validation of the data.
- Work with investigators to determine the accuracy (or bias) and precision for each measurement value and prepare a report summarizing the uncertainties in the study data.

This QA plan describes the procedures that will enable the QA manager to verify that planned quality control procedures are being followed and the measured data are meeting specified tolerances. The plan identifies the work elements to be performed, the technical approach for implementing each element, and the schedule for performing the work. It specifies the measured quantities to be challenged during the audits, criteria for evaluation of audit findings, estimated precision and accuracy of audit standards, certification of audit standards, and approaches to problem resolution and verification of corrections. Data quality objectives are specified prior to the study to ensure that all measured data meet the end-use requirements for air quality and meteorological model input and evaluation, data analyses, and monitoring the success of meeting data quality objectives. Precision and accuracy goals are identified for measurement variables. Many methods and procedures employed in this field study are routinely measured variables for which expected precision and accuracy are known.

Data quality objectives should be specified prior to the study to ensure that all measured data meet the end-use requirements for air quality and meteorological model input and evaluation, data analyses, and monitoring the success of meeting data quality objectives. Precision and accuracy goals are identified for measurement variables. Many methods and procedures employed in this field study are routinely measured variables for which expected precision and accuracy are known. Other measurements are experimental and target objectives can only be estimated.

In evaluating precision and accuracy objectives, it is important to consider the methods used to determine the values. For example, a greater deviation may occur between replicates with real samples with complex matrices than with replicates of standards in simple matrices. Synthetic mixtures of hydrocarbons that are used in the Photochemical Assessment Monitoring Station Program is an example. An ambient

sample yields a more complex chromatogram and greater potential for inconsistent identification. Analysis of a standard mixture of hydrazones does not address potential sampling artifacts that may be associated with carbonyl compound measurements using the DNPH derivitization method.

Precision and accuracy targets are commonly based on relative percent differences. Precision is either based on a relative percent difference between replicates (analytical precision) or duplicate samples (method precision) as follows:

$$100 \cdot (\text{rep 1} - \text{rep2}) / (\text{rep 1} + \text{rep2}) / 2$$

The standard deviation of the average of a group of replicate (or duplicate) pairs represents the precision for a measurement parameter. For accuracy, percent difference is determined relative to a known or target value and is as follows:

$$100 \cdot (\text{observed} - \text{target}) / \text{target}$$

The objective may be a standard of known concentration or an audit value independently obtained or prepared by the QA team. For some parameters, standards of known concentration are not easily obtained or cannot be accurately prepared for use in the field, and accuracy can only be checked against an independent method that is believed to be either without bias, has a known bias that can be accounted for, or a method that has been used historically. Accuracy determined in this manner is considered a test of equivalency and not true accuracy.

After an audit, data flags are reported immediately to the field operations manager and to the appropriate contractor to ensure rapid implementation of corrective action by the measurement group.

Quality assurance (QA) for a program consists of two parts: one is an independent assessment of the effectiveness of the measurement program to meet its goals (often denoted as QA audits), and the other is the operational procedures or quality control (QC) necessary to evaluate ability of the measurement process to yield valid data. The Quality Assurance Project Plan defines data quality goals for the project and QC activities necessary to obtain them. These goals are stated in terms of precision, accuracy, completeness, comparability, and representativeness of the data as defined in the following:

- Accuracy is the degree of correctness with which a measurement system yields the true value or bias of an observable (Watson et al., 1989). For the field project, accuracy is quantified comparing the responses of instruments to independent standards or collocated measurements.
- Precision is a measure of agreement among individual measurements of the same observable or repeatability of the measurement. For the field project,

precision is quantified by periodically challenging a measurement device with known, identical input conditions.

- Completeness is the measure of the quantity of data collected by a measurement system compared to the total possible amount of data.
- Comparability is a measure of the traceability of the same type of data collected from several different organizations. Comparability can be qualitatively assessed by comparing procedures, QA/QC results, and traceability of standards.
- Representativeness is a qualitative measure of the ability of the collected data to meet the criteria necessary to model ozone formation and transport in the area of interest. Some sites may be source-oriented while others are regional in nature.

QA objectives in terms of accuracy and precision, and completeness of data collected during the field project are presented in the following tables grouped by type of measurement. This information will be updated and expanded in the course of the quality assurance program to include each of the core measurements of the field study. Data quality objectives for surface monitoring sites are presented in Table 18 for gaseous pollutants and in Table 19 for meteorological variables. Quality assurance objectives for upper-air meteorological data are presented in Table 20.

Table 18. Data Quality Objectives - Gases - Surface Sites

	Measurement	Precision	Accuracy	Precision	Accuracy	
3.1.1.1.1.1	<i>Observable Completeness</i>	<i>Method</i>	<i>Check</i>	<i>Check</i>	<i>Target</i>	<i>Target</i>
Ozone	UV absorption	Weekly precision check	UV photometer	±15%	±15%	80%
NO/NO _y	Chemiluminescence with external converter	Weekly precision check	NO gas standard/ Dilution system	±15%	±15%	80%
NO/NO _x	Chemiluminescence with nylon inlet filter	Weekly precision check	NO gas standard/ Dilution system	±15%	±15%	80%

Table 19. Data Quality Objectives - Meteorological Data -Surface Sites

Observable	Measurement Method	Precision Check	Accuracy Check	Precision Target	Accuracy Target	Completeness
Wind Speed	Anemometer propeller or cups	None	Constant RPM motor	None	±0.25 m/s for WS<5m/s ±5% for WS>5m/s	90%
		Starting Threshold Torque wheel			< 0.3 g-cm	
Wind Direction	Vane	None	Alignment with true North	None	±5°	90%
Ambient Temperature	Thermal Resistance	None	Collocated Thermistor	None	±0.5 °C	90%
Relative Humidity	Capacitive or resistive	None	Collocated Capacitive	None	±10%	90%
Dew Point	Computed or dew cell	None	Collocated Ca Capacitive RH	None	±1.5 °C	90%
Solar Radiation	Pyranometer	None	Precision Spectral Pyranometer	None	±25 w/m ²	90%

Table 20. Quality Assurance Objectives for upper-air meteorological data.

Measurement Method	Variables Measured	Systematic Difference (Bias)	Comparability (RMS difference)	Data Recovery % of Observations to Given Height
RASS	T_v	$\pm 1\text{ }^\circ\text{C}$	$1.5\text{ }^\circ\text{C}$	50%, 1000 m
RWP	WS, WD	WS: $\pm 1\text{ ms}^{-1}$ WD: $\pm 10^\circ$	WS: 2 ms^{-1} WD: 20°	50%, 3000 m
Sodar	WS, WD	WS: $\pm 1\text{ ms}^{-1}$ WD: $\pm 10^\circ$	WS: 2 ms^{-1} WD: 20°	50%, 500 m
Rawinsonde	WS, WD, T, T_d , RH, p	WS: $\pm 1\text{ ms}^{-1}$ WD: $\pm 10^\circ$ T: $\pm 1\text{ }^\circ\text{C}$ Td: $\pm 2\text{ }^\circ\text{C}$ RH: $\pm 0\%$ P: $\pm 1\text{ mb}$	WS: 2 ms^{-1} WD: 20° T: $1.5\text{ }^\circ\text{C}$ Td: $3\text{ }^\circ\text{C}$ RH: 10% P: 2 mb	90%, 5000 m

4.2 SURFACE MEASUREMENTS

Most of the field monitoring during the study will include continuous measurements for a year to capture the range of conditions that occur normally. Limited measurements of air quality aloft with an instrumented aircraft will be performed on a forecast basis during selected periods of interest during the spring, summer, and fall to characterize the spatial and temporal variations in air quality aloft. During the winter when aircraft flights are more difficult and greater impacts from smoke, CO, and road sanding are most likely to occur, the instruments will be located on a boat for sampling variations in air quality near the Lake surface. The continuous, routine measurements will enable researchers to assess the representativeness of the air quality aloft study days, to provide information on the meteorology and air quality conditions on days leading up to the air quality aloft study days, and to assess the meteorological regimes and transport patterns associated with the study days of conditions aloft. The air quality aloft study components are designed to provide a detailed aerometric database which, along with the emission estimates and continuous monitoring data, can be used to improve our understanding of the causes of pollutant episodes in the study region and to provide data for input to the models and for model evaluation.

This section describes the existing routine air quality and meteorological monitoring network in the Lake Tahoe air basin. Three types of surface air quality monitoring stations are operated by the air pollution control districts. The National Air Monitoring Stations (NAMS) were established to ensure a long term national network for urban area-oriented ambient monitoring and to provide a systematic, consistent database for air quality comparisons and trend analysis. The State and Local Air Monitoring Stations (SLAMS) allow state and local governments to develop networks tailored to their immediate monitoring needs. Special purpose monitors (SPM) fulfill very specific or short-term monitoring goals. SPMs are typically used as source-oriented monitors rather than monitors which reflect the overall urban air quality. Data from all three types are submitted by state and local agencies to USEPA's Aerometric Information Retrieval System (AIRS), which serves as the national repository for air quality, meteorological and emissions data.

The operators of these routine measurement networks have in place or are developing quality assurance plans specific to their network or are using the operating procedures developed by the CARB. In all cases, the operating plans are reviewed and approved by the CARB. The CARB also provides regularly scheduled air quality audits of field sites and equipment.

4.2.1 Sampling Site Selection Criteria

There are seven active monitoring stations in the greater Lake Tahoe Basin. These sites have been installed at their locations to meet the needs of the local agencies. The criteria for site selection will not be discussed here.

The general locations for the supplemental monitoring sites have been chosen because they are in key locations for assessing the complex meteorology and potential precursor transport from the San Francisco Bay Area, urbanized areas of the Central Valley (e.g.,

Sacramento and Stockton), and the developing foothills of the Sierra Nevada (e.g., El Dorado and Placer Counties). Measurements at the sites will include concentrations of ozone and NO/NO_x and meteorological observations.

The following site selection criteria will be used for the sites:

- Exposure to regional air transport
- Absence of local sources or sinks of measured species
- Adequacy to meet USEPA-PSD siting criteria for air pollutant and meteorological measurements
- Availability of power and telephone
- Cost for site preparation
- Ease of access
- Security

4.2.2 Installation

At the supplemental sites, equipment will be installed in either available buildings at the site or in temporary shelters installed specifically for the purpose. In any event, the air quality instruments will be placed inside temperature-controlled environments with sample inlet systems and manifolds, air conditioning, instrument racks, and power distribution. Meteorological equipment will be installed on 10-meter towers at all sites. Telephone lines will be connected to the sites for regular data access and instrument checks.

4.2.3 Sampling Procedures

Sampling methods are summarized in this section. Actual operational procedures are contained in Standard Operating Procedures (SOP) of the various agencies and in the instrument manufacturers' manuals.

All the air pollution control districts measure ozone and NO/NO_x with continuous analyzers. At present, most of the NO/NO_x analyzers are operated with an inline filter made of Teflon to remove particulate matter from the ambient air before the measurement is made. Teflon filters will be replaced by nylon filters that will remove particles and nitrogen species such as nitric acid so that only NO_x is measured.

4.2.3.1 Ozone

Ambient ozone concentrations in the Tahoe Basin are currently monitored with Advanced Pollution Instrumentation, Inc., model 400 instruments. This analyzer employs the UV photometric technique to determine ozone concentration. This analyzer has been

designated as a USEPA Equivalent Method. The analyzer consists of a sample chamber illuminated with a continuous ultraviolet (UV) lamp with frequency at 394 nm. The air sample is first introduced to the chamber after passing through a molybdenum oxide scrubber to catalytically convert ozone to oxygen. A sensing system measures the amount of radiation that passes through the chamber without ozone in it. Then the sample is introduced to the chamber with ambient ozone in it. The difference between the UV light passing through the chamber without ozone and with ozone is proportional to the amount of ambient ozone. The analyzer also contains sensors to measure temperature and pressure in the sample chamber so that ozone readings can be referenced to ambient conditions.

4.2.3.2 Oxides of Nitrogen

Concentrations of nitric oxide (NO) and total oxides of nitrogen (NO_x) in the Basin are measured by a chemiluminescence method with a Thermo Environmental Inc., model 42 instrument. Nitrogen dioxide (NO₂) is estimated by difference between NO_x and NO. This analyzer has been designated as an USEPA Reference Method. When NO and ozone are mixed, a gas-phase reaction occurs that produces a characteristic luminescence with an intensity that is linearly proportional to the concentration of NO. A photomultiplier tube senses the luminescence generated by the reaction. Other oxides of nitrogen can also be measured by first reducing them to NO with a molybdenum converter heated to 325 °C and then measuring the result by chemiluminescence as NO_x. The analyzer switches between measuring NO and NO_x and electronically computes difference between NO_x and NO. The difference can in some cases be attributed to NO₂ as the other major constituent of NO_x. The instruments converter can also convert other nitrogenous species, such as nitric acid and PAN, to NO. Nitric acid and nitrate particles can be removed from the sample by installing a nylon filter on the sample inlet.

Total reactive oxides of nitrogen (NO_y) will also be monitored at some locations with a Thermo Environmental Inc., model 42CY instrument that has the converter mounted at the air inlet (to minimize deposition of PAN and HNO₃ in the sampling line).

4.2.3.3 Wind Speed Sensor

Wind speed is measured by cup or propeller anemometers of several manufacturers and models. As the cup or propeller turns a pulse is generated by a magnetic or optical switch or a direct voltage is generated by a small electrical generator. The frequency of the pulses or the generated voltage is proportional to the wind speed. The manufacturers supply relations between wind speed and rotation rate for their sensors. The sensors using a propeller are generally combined with a moveable vane to align with the wind. The cups rotate about a vertical shaft have an omnidirectional response to the wind. Met One sensors, model 010 and 014, is used by the CARB in the Tahoe Basin but other sensors such as Climatronics, model F460; R.M. Young, model Wind Monitor-AQ, Wind Monitor-RE; and Bendix Aerovane may be used by other groups.

4.2.3.4 Wind Direction Sensors

Wind direction is measured with a vane that aligns itself along the direction of the wind. The orientation of the vane relative to a fixed direction, generally true north, is measured by the voltage across a potentiometer and is proportional to the angle of the vane. Met One sensors, model 020 and 024, is used by the CARB in the Tahoe Basin but other sensors such as Climatronics, model F460; R.M. Young, model Wind Monitor-AQ, Wind Monitor-RE; and Bendix Aerovane may be used by other groups.

4.2.3.5 Temperature Sensor

Temperature at the sampling sites is measured with a thermistor, a platinum resistance thermometer, or a thermocouple. The thermistor and RTD are both resistance devices that respond proportionally to temperature with a voltage output that is proportional to temperature. The thermocouple develops a voltage proportional to temperature because of the proximity of dissimilar metals. A data acquisition system linearizes the voltage output for these sensors. The sensors are installed in radiation shields to reduce the effect of direct solar radiation. The shields are either mechanically aspirated with a small blower or naturally aspirated by air movement around the sensor.

4.2.3.6 Relative Humidity/Dew Point Sensor

The relative humidity or dew point is measured at some sites. Relative humidity is measured with capacitance or resistive devices having thin polymer films that change characteristics as water is absorbed. Dew point is measured with a chilled mirror sensor or LiCl dew cell with a heated wire-wound bobbin that absorbs water vapor and releases water vapor in proportion to the dew point.

4.2.3.7 Solar Radiation Sensor

Solar radiation at most sampling sites is measured with LiCor model LI-200SZ pyranometers. This sensor consists of a silicon photodiode that responds to light over the range that includes visible spectrum. When calibrated and orientated properly, the sensor has an output that is proportional to the incoming solar radiation, both direct and diffuse. Some sites use Epply thermopile sensors that generate a voltage by differential heating of white and black materials.

4.2.4 Calibration Procedures and Frequency

Calibration procedures are described in the following section. Specific instructions are contained in available QA Plans in the form of standard operating procedures and in the manufacturers' manuals.

The air pollution control districts have routine calibration procedures that include multi-point calibrations of the ozone and NO/NO_x analyzers when instruments are installed or repaired.

In addition to calibrations, routine site visits are made to each site by field technicians on a regular schedule at least once a week but usually daily. The technicians have been trained to follow established monitoring and maintenance procedures. Automated zero/span checks are performed every night at most sites. Manual precision checks are made once a week at many sites.

Site visits are used to ensure that all of the equipment is operating properly, to identify instrument problems and to give warning of developing problems.

Station checks are performed each site visit following the steps prescribed on station check forms.

Each site visit, the site technician visually inspects the meteorological sensors, the ambient air sampling probe and inlet system, and the air sampling systems.

All visits are documented. Copies of recorded data and documentation are returned at specified intervals, generally once a month, to the agency office for processing.

Quality control checks consist of periodic zero/span checks and precision checks. In both cases, test atmospheres are introduced to the analyzer operating in its normal sampling mode through a solenoid valve controlled by the site DAS. Test gases pass through all filters, scrubbers, conditioners, and other components used during normal sampling.

At many sites, each air quality analyzer is subjected to an automated zero/span check once a night. Test gases at zero and one span concentration are introduced to each analyzer. The span gas concentration is about 80% of the analyzer's nominal operating range. Zero/span data are used to determine if an analyzer needs adjustment and to evaluate validity of data. Zero/span data are accessed by telephone along with the ambient data and are reviewed daily. The following criteria are used in evaluating the data:

- Zero checks: Daily check should be within $\pm 2\%$ of full scale from the zero value established during calibration. If two consecutive zeros exceed $\pm 2\%$, the instrument is removed from service, the problem corrected, and the instrument recalibrated and returned to operation. If the check exceeds $\pm 3\%$, the instrument is immediately taken off line, given a "before" calibration, fixed, and given an "after" calibration. If the check exceeds $\pm 5\%$, the instrument has serious problems and data is invalidated. The same action as the 3% criteria is done.
- Span checks: Daily check (about 80% of full scale) should be within $\pm 10\%$ of span value established during calibration. If two consecutive spans exceed $\pm 10\%$, the instrument is removed from service, the problem corrected, and the instrument recalibrated and returned to operation. If the check exceeds $\pm 15\%$, the instrument is immediately taken off line, given a "before" calibration, fixed, and given an "after" calibration. If the check

exceeds $\pm 25\%$, the instrument has serious problems and data is invalidated. The same action as the 15% criteria is done.

At some sites, the technician performs a manual precision check once a week. For this, gas with concentration between 80 and 100 ppb is introduced to the analyzer. The response of the analyzer is entered on the log sheet. Precision checks are made before any instrument adjustments or re-calibrations are done. Procedures for calibration, zero/span, and precision checks are summarized in the following sections.

4.2.6.1 Ozone

The ozone transfer standard and clean air system are taken to the monitoring site. Ozone-free air is generated by passing ambient air through a desiccant and activated charcoal and a desiccant. The ozone transfer standard has an internal ozone generator that supplies ozone to the instrument to be calibrated and its own measurement chamber. First, ozone-free air from the dilution system is introduced to the instrument to obtain the zero level. Then, up to five concentrations of ozone are supplied to the analyzer ranging from 10% to 90% of the analyzer range with one near the span point of 450 ppb and one near the precision point of 100 ppb. The test gases are delivered to the analyzer's sample inlet via a Teflon tube to reduce losses of ozone. This tube contains a Teflon vent to allow excess flow escape and maintain the inlet at atmospheric pressure. Test gas passes through as much sample tubing as possible including any filter normally associated with the sampling process.

Readings from the calibrator display and primary site DAS are recorded on a calibration form and a least-squares linear regression between DAS and calibrator readings is computed. The regression for a valid calibration has a slope of 1.000 ± 0.01 , an intercept of 0.0 ± 0.01 , a regression coefficient of at least 0.999. Instruments exceeding these tolerances require further checking and possibly repair or replacement.

The ozone transfer standards are calibrated approximately once a quarter with a laboratory transfer standard. The laboratory standard verified annually with the long-path UV Photometer at the California Air Resources Board in Sacramento, CA.

4.2.6.2 Oxides of Nitrogen

The calibration standards consists of a dilution flow metering system, NO/NO_x-free dilution air (zero air) system, and a cylinder of compressed gas containing a known amount of NO. The manually operated dilution system contains one flow controller (mass or volumetric) to meter accurate amounts span gas, a second flow controller (mass or volumetric) to meter accurate amounts of dilution air, and a Teflon-lined or glass mixing chamber. The dilution air is generated by forcing ambient air through desiccant, Purafil, and activated charcoal. Purafil (potassium permanganate) oxidizes NO to NO₂ which is then removed by the charcoal. A cylinder of compressed gas provides a source of approximately 50 ppm NO in a balance of nitrogen. The dilution system also has a section that produces a known concentration of NO₂ by performing a gas phase titration (GPT) in which O₃ is mixed with NO to generate NO₂.

Zero and up to five upscale concentrations of NO are introduced to the instrument. The concentrations of NO range from 10% to 90% of the analyzer range with one near the span point of 450 ppb and one near the precision point of 100 ppb. Delivery to the analyzer is through as much sample line as possible including the switching solenoid valve and any inline filters.

Readings from the analyzer display and primary DAS for NO and NO_x are recorded and linear regressions of sampler versus calibrator NO and NO_x are computed. For linear operation of the analyzer, the computed regression coefficient should be at least 0.999.

The NO₂ channel response and the efficiency of the NO_x to NO converter are tested with NO₂ generated in the GPT section of the dilution system. These tests are done at 3 different NO₂ and NO_x concentrations while the NO concentration remains between 80 to 100 ppb. NO gas with concentrations for the three points are near 450, 300, and 150 ppb. The responses of the NO and NO_x channels to this NO are recorded and adjusted by the linear regression equations relating instrument response to calibration concentration. Ozone is mixed with the NO to generate NO₂ concentrations near 350, 200, and 50 ppb which are introduced to the instrument. The responses of NO and NO_x are recorded and corrected for the calibration results.

For each test, the response of the NO₂ channel is compared to the NO₂ concentration generated by the GPT as determined from

$$\text{GPT NO}_2 = \text{Orig NO} - \text{Rem NO}$$

where: Orig NO is adjusted response of NO channel before O₃ is mixed and Rem NO is adjusted response of NO channel after O₃ is mixed.

The converter efficiency, Conv Eff, is determined in the following steps:

$$_NO_x = \text{Orig NO}_x - \text{Rem NO}_x$$

$$\text{Conv NO}_2 = \text{GPT NO}_2 - _NO_x$$

$$\text{Conv Eff} = 100 \times (\text{conv NO}_2) / (\text{GPT NO}_2)$$

where: Orig NO_x is adjusted response of NO_x channel before ozone is mixed and Rem NO_x is adjusted response of NO_x channel after ozone is mixed.

An overall converter efficiency is calculated by averaging the efficiencies at the three levels. A converter efficiency less than 96% indicates that the converter material should be replaced.

4.2.6.3 Wind Speed

The wind speed sensors are calibrated one to two times a year when routine maintenance is done on the sensors, such as replacement of bearing. Known rotation rates are applied to the sensors while monitoring the DAS reading. Variable or fixed rate motors are attached to the anemometer in place of propeller or cups and the sensor shaft is turned at known angular speeds. DAS wind speeds are compared to the values supplied by the manufacturer of the sensor for known rotation rates.

Bearings are checked before calibration to determine if they affected the wind speed data before replacement. Rotation of shaft is checked for smoothness of operation and starting torque is measured with a torque wheel. For the RM Young Wind Monitors, bearings are replaced if a sensor fails to respond to a 0.3 g-cm torque.

4.2.6.4 Wind Direction

The wind direction sensors are calibrated one to two times a year using an angle calibrator. With the sensor in place on the calibrator and connected to the DAS, the vane is moved around the 360° circle in 10° increments. The DAS readings are compared to the calibrator angles. Sensors that have readings within $\pm 2^\circ$ of calibrator are used without correction. Sensors outside that limit are inspected for problems or used with an correction developed from the calibration.

4.2.6.5 Temperature

Temperature sensors that can be immersed in water are calibrated one to two times a year using water baths over the range of the sensor. Low temperature is obtained with an ice bath. Higher temperatures are reached by heating the bath with an immersion heater. A calibration thermometer with NIST-traceability should be used to measure the bath temperature. The error associated with this method is less than $\pm 0.5^\circ\text{C}$.

For temperature sensor than cannot be immersed in water, the calibration can be checked by placing an aspirated, NIST-traceable thermometer near the sensor and comparing the site sensor reading to the calibration thermometer. The side-by-side calibration check can have an error of about $\pm 1^\circ\text{C}$ when done outdoors because of the effect of solar radiation.

4.2.6.6 Relative Humidity/Dew Point

The calibration of the relative humidity/dew point sensor is checked by placing the sensor in chambers containing different saturated salt solutions. These solutions give relative humidities that depend on the salt and the temperature. The range of relative humidity for typical salts is about 12% for LiCl to 97% for K_2SO_4 . This calibration is best done in controlled environment and not outdoors.

The calibration can be checked in the field by placing a separate relative humidity sensor or an aspirated, psychrometer with NIST-traceable thermometers near the sensor. As with the temperature check, the psychrometer should be shaded from direct solar radiation while being exposed to the free-air. Simultaneous readings from the sensor and the wet-

and dry-bulb thermometers of the psychrometer are recorded. The relative humidity is determined from psychrometric tables or a psychrometric slide rule.

4.2.6.7 Solar Radiation

The calibration of the solar radiation sensors is best done by returning the sensor to the manufacturer on a routine schedule. A secondary check of the sensor can be made with a side-by-side comparison between the site pyranometer and a similar pyranometer that is only used for comparison. This comparison sensor is placed as near to and with similar exposure as the site pyranometer for a several hour period. A comparison of the readings of the two pyranometers gives an indication of the operating characteristics of the site sensor.

4.2.5 Systems Audits

Formal, in-depth systems audits will not be conducted for the air quality and meteorological sites. Personnel from Quality Assurance Section (QAS) of the CARB will complete Comprehensive Site Surveys during site visits. The Site Survey is a qualitative evaluation of the sampling site and its operation.

Each Site Survey will be conducted by completing a standard form specific, which will consist of the following tasks:

- Document site location, measurements at site including instrument type, sampling purpose, and applicable measurement scale.
- Describe vicinity of site within 100 m radius including heights of sensors, length of probes, and towers.
- Describe obstacles near site including direction, distance, height, distance to tree dripline, distance to walls, and arc for free air flow.
- Describe nearby sources including distance and direction for flues, non-vehicular local sources, and traffic. Give dominant influence category.
- Describe the ambient air delivery system to analyzers including inlet probe, sample manifold, and tubing to instruments. Include composition, inside diameters, lengths, and flow rates. Determine probe and total residence times.
- Determine if an approved QA Plan is used, schedule for cleaning, auto-calibration type and schedule, use of in-line filter, control and recording of station temperature.

Prior to the start of the field study, the auditing team obtains pertinent forms and documents, their latest revisions, and information needed to perform the audits. These forms and documents include SOPs, instrument manuals, logbooks, chain-of-custody records, data sheets, control charts, and maintenance records. The auditor verifies that

each of these forms and documents is available at the field site. If out-of-date documents are identified at the field site, recommendations for replacement are made in the systems audit report. Calibration records, performance test tracking charts, and maintenance records are examined to determine that the tasks were being performed on the schedules specified in the SOP. Contents of logbooks and checklists are examined to determine that the field documentation procedures were being followed. The auditor examines the site description, field documentation, SOPs, spare parts, and supplies, and performs a general instrument inspection. The QA manager coordinates review of the latest revision of field SOPs and ensures that each auditor has the most recent version prior to systems audits. The auditor independently evaluates the siting of measurement platforms to document relevant characteristics that might affect the measurement at a particular location. An inspection of measurement devices and evaluation of their condition with respect to obtaining a quantitative measurement is also part of each system audit. The audit examines the relationship among different instruments and their conformity with requirements at each site. The instrument serial numbers and model numbers are compared with those recorded in the project records as being present at each site. Sample lines are examined for dirt or obstruction. Leads from each instrument to data acquisition system are examined to ensure that they are connected to the proper channels. Inconsistencies with project records are reported, and recommendations for site modification are made by the QA manager.

4.2.6 Field Performance Audits

Performance audits will be conducted by personnel from Quality Assurance Section (QAS) of the CARB. Performance audits are quantitative assessments of instrument operation that are accomplished by challenging site instruments with known audit standards. This section provides an overview of the key procedures that will be used. All audit procedures are described in detail in several appendices of CARB's "Audit Procedures Manual" (CARB, 1990, 1993a, 1993b, 1994a, 1994b, 1995a, 1995b, 1995c, 1995d, 1996a, 1996b). The procedures are also consistent with USEPA guidelines for audits of gaseous and particulate samplers (40 CFR 58, App A, B, and E; USEPA, 1984; USEPA, 1986; USEPA, 1987) and for meteorological instruments (USEPA, 1989).

All audit results will be entered on QA Audit Station Data Worksheet forms and into an audit computer. Calculations are done by the computer and by hand for verification. Preliminary results will be summarized in reports for each measurement issued to the site operator at the conclusion of the audit. For gas analyzers, the reports will present the audit concentrations, the instrument responses, and the percent differences. Instrument performance will be assessed by comparing the percent differences to USEPA criteria as shown in Table 21. For meteorological equipment, the reports will present the expected instrument responses, the actual instrument responses, and their differences. Instrument performance will be assessed by comparing the differences to the USEPA criteria as shown in Table 22. For those instruments that exceed the criteria, the auditor will issue an Air Quality Data Action (AQDA). The site operator will be required to respond to the AQDA by detailing the actions done to correct instrumental problems found during the audit.

Table 21. Audit Criteria - continuous gas analyzers

Quantity	Measure	Excellent	Satisfactory	Unsatisfactory
Difference	Percent	0 - ± 5	$\pm(5 - 15)$	<-15, >15

Table 22. Audit Criteria - meteorological sensors

Sensor	Satisfactory Limits
Wind Speed	± 0.25 m/s for $WS \leq 5.00$ m/s $\pm 5\%$ value for $WS > 5.00$ m/s not to exceed 2.5 m/s
Wind Speed (starting threshold)	< 0.5 m/s
Wind Direction	± 5 degrees relative to True North
Wind Direction (starting threshold)	< 0.5 m/s
Temperature	± 0.5 °C
Dew Point	± 1.5 °C
Dew Point (in fog)	± 0.5 °C
Solar Radiation	greater of $\pm 5\%$ or ± 25 w/m ²
Pressure	± 10 mb (± 7.5 mmHg)

4.2.6.1 Surface Monitors

Quantitative transfer standards are used during field performance audits to determine the percent difference between the field measurements and the standard (i.e., to estimate the accuracy of the measurement). The difference should meet the acceptance criteria defined by the quality assurance objectives. Otherwise, reasons for exceeding acceptable levels are sought, and recommendations are made for eliminating the problem and adjusting or flagging data as necessary.

Ozone. A calibrated transfer standard with an internal ozone generator is used to generate five standard ozone concentrations and one zero level concentration to audit the instruments. Corresponding concentrations are recorded from each instrument and compared. A linear regression of measured versus audit results is calculated to determine baseline offsets and linearity of response. The in-station performance test gases are verified against the certified NIST standards. The audit includes a comparison of values taken from the instrument display, the strip chart recorder, and the data acquisition system.

Performance audits of ozone analyzers will be conducted with one of two methods depending on the accessibility of the analyzers. In the first method, a Dasibi 1009 CP gas calibrator will be used as an ozone source and transfer standard. This instrument is contained in QAS's audit van. The Dasibi 1009 CP will generate known concentrations of

ozone that will be supplied to the site analyzer through a 150-foot gas presentation line connected to the site inlet probe. The generated ozone will be measured by the Dasibi 1009 CP itself or by a separate API 400 Ozone analyzer. In the second method, a Dasibi 1008 PC portable ozone transfer standard will be transported to air monitoring site. The Dasibi 1008 PC will generate and measure concentrations of ozone to be introduced at the rear of the site analyzer.

The Dasibi 1009 CP and Dasibi 1008 PC instruments will generate ozone with an adjustable UV lamp. The concentration of the generated ozone will be measured with a UV photometer, either within the instrument or contained in a separate analyzer. For the van system, ozone-free air will be produced by an Aadco 737R pure air system in the audit van and a compressor capable of producing a constant 20 lpm supply of air at the end of the gas presentation tube. For the portable ozone standard, ozone-free air will be produced by passing ambient air through a cartridge of activated charcoal connected zero-air inlet of the instrument. Ozone concentrations measured by the transfer standards will be corrected to account for calibration factors for the standards, for the altitude correction factor if standard does have temperature/pressure correction, and for line loss in the gas presentation line.

Before starting the audit, the standard will be warmed up for at least one hour. It will be verified that all connections are made according to standard procedures. Instrument checks will be made and recorded.

The first audit point will be the response to ozone-free air. Three upscale ozone concentrations will be generated and delivered to the site analyzer and audit standard. The ranges of the concentrations will be 0.35 to 0.45 ppm, 0.15 to 0.20 ppm, and 0.03 to 0.08 ppm. A final response to zero air will be done after the 3 upscale points. For each concentration, the instruments will equilibrate for 30 minutes. Then ten consecutive readings of the ozone transfer standard will be recorded followed by ten consecutive readings from the data collection device site for the site analyzer. The average responses, differences, and percent differences will be calculated for each audit point. The overall percent difference will be calculated for comparison to the audit criteria.

The ozone transfer standards are submitted to CARB's Standards Laboratory on a quarterly basis for recertification against the USEPA-verified Primary Ozone Photometer. For a valid certification, it is required that the standard differ by less than $\pm 1.5\%$ from past certification values and the slope and intercept fall within one standard deviation of the last six certification equations.

Standard and High-sensitivity NO/NO_x. A calibrated audit system used to challenge the standard sensitivity instruments consists of zero air, NIST-traceable NO gas in a cylinder, and an ozone generator. At least three NO concentrations and a zero are introduced to the instrument, and the response of the data acquisition system and the instrument are recorded. Audit NO₂ is produced by gas-phase titration and introduced to the analyzer for at least five different concentrations. Audit versus site differences are determined, and a linear regression of site versus audit results is calculated to

determine baseline offsets and linearity of response. In addition, site test gases are verified against the audit standard.

Performance audits of NO/NO_x analyzers will be conducted using the Thru-the-Probe method as generated by instrumentation contained in QAS's audit van. Known quantities of National Institute of Standards and Technology (NIST) traceable gases will be diluted with 20 lpm of pure air will be introduced to the site analyzer through a 150 foot gas presentation line connected to the site inlet probe. NO will be supplied from a cylinder of compressed air. NO₂ will be generated by the gas phase titration (GPT) of NO with ozone.

The audit standard will consist of a Dasibi 1009 CP dilution flow metering system, an Aadco 737R pure air system to generate NO-free dilution air (zero air) and compressor capable of supplying 20 lpm system, a superblend cylinder of compressed gas containing a mixture of NO and CO (along with other gases) in NIST-traceable concentrations, a Thermoenvironmental (TEI) Carbon Monoxide analyzer, model 48, two cylinders of compressed gas with known amounts of CO, and one cylinder of compressed ultrapure air.

The Dasibi 1009 CP system also contains an ozone generator and second mixing chamber for the generation of NO₂. When ozone is mixed with NO, a GPT results which oxidizes some NO to NO₂. The generated NO₂ is calculated from the change in NO. The analyzer NO₂ readings and the converter efficiency are determined from the GPT.

Before starting the audit, the TEI 48 and dilution system will be warmed up for at least one hour. The CO analyzer will first be calibrated using the zero air cylinder and two CO cylinders. The CO concentration of the gas mixture generated by the Dasibi 1009 CP using the Aadco pure air and gas from the mixed gas cylinder will then be measured with the TEI 48. The dilution ratio of the generated audit sample will be calculated. The generated NO concentration will be calculated using the dilution ratio and the cylinder concentration.

The first audit point will introduce zero air to the site analyzer. The next steps will consist of introducing NO to the analyzer for the response of the NO and NO_x channels followed by the generation of NO₂ by GPT. A total of three NO₂ concentrations will be generated. A final low NO concentration will be generated. The ranges of concentration for NO, NO₂, and NO_x delivered to the site analyzer will be 0.35 to 0.45 ppm, 0.15 to 0.20 ppm, and 0.03 to 0.08 ppm. A final response to zero air will be done at the end of the audit.

Readings will be recorded from the primary data acquisition system. Sufficient time is allowed for the response to stabilize before recording any information. The measured values from the display, analog output, and data logger are compared to the audit concentration.

The dilution ratio will be calculated according to the equation:

$$\text{DILUTION RATIO} = \frac{\text{True CO Response (ppm)}}{\text{Superblend Cylinder CO Concentration (ppm)}}$$

The true concentration in ppm will be calculated from

$$\text{TRUE CONCENTRATION} = \text{Superblend Concentration} \times \text{Dilution Ratio}$$

The NO₂ channel response and the efficiency of the NO_x to NO converter will be tested with NO₂ generated in the GPT section of the dilution system. These tests are done at 3 different NO₂ and NO_x concentrations while the NO concentration remains between 80 to 100 ppb. NO gas with concentrations for the three points are near 450, 300, and 150 ppb. The responses of the NO and NO_x channels to this NO are recorded and adjusted by the linear regression equations relating instrument response to calibration concentration. Ozone is mixed with the NO to generate NO₂ concentrations near 350, 200, and 50 ppb which are introduced to the instrument. The responses of NO and NO_x are recorded and corrected for the calibration results.

The converter efficiency, Conv Eff, will be determined in the following steps:

$$\text{Conv Eff} = 100 \left(\frac{\Delta \text{NO} - \Delta \text{NO}_x}{\Delta \text{NO}} \right)$$

$$\Delta \text{NO} = (\text{Orig NO} - \text{Rem NO}) / \text{Slope NO}$$

$$\Delta \text{NO}_x = (\text{Orig NO}_x - \text{Rem NO}_x) / \text{Slope NO}_x$$

where: Orig NO is adjusted response of NO channel before ozone is mixed,
 Rem NO is adjusted response of NO channel after ozone is mixed,
 Orig NO_x is adjusted response of NO_x channel before ozone is mixed and
 Rem NO_x is adjusted response of NO_x channel after ozone is mixed.

An overall converter efficiency will be calculated by averaging the efficiencies at the three levels. A converter efficiency less than 96% will require an AQDA.

High-sensitivity NO₂. This audit involves the use of a calibrated audit system consisting of zero air and a NIST-traceable low concentration NO₂ gas cylinder. These standards can be unstable with time, and precautions need to be taken into account for any degradation that occurs during the audit process. At least three NO₂ concentrations and a zero are introduced to the instrument, and the response of the data acquisition system and the instrument is recorded. Audit versus site differences are determined, and a linear regression of site versus audit results is calculated to determine baseline offsets and linearity of response. In addition, site test gases are verified against the audit standard.

PAN. Since NIST transfer standards do not exist for PAN, collocated measurements using a gas chromatograph with electron capture detection (GC/ECD) may be used for comparison. PAN is thermally unstable, even at room temperature, and thus difficult to calibrate. This difficulty can lead to discrepancies between field measurements that are difficult to resolve without further laboratory studies. One advantage of the LPA-4 PAN analyzer is that the instrument can be calibrated in the field with NO₂ rather than the thermally unstable. Level 2 validation of the PAN data includes correlation and time series of PAN values compared to NO_y, NO_z, and NO/NO₂ ratios.

4.2.6.2 Surface Meteorological Monitors

This audit includes the variables of wind direction, wind speed, temperature, relative humidity, and solar radiation. These procedures generally are performed by both the auditor and site operator because several of these procedures require readings to be made in the instrument shelter while someone is on the meteorological tower. Safety considerations also require the presence of an additional person whenever someone ascends the tower. Audit values are compared with instrument displays (when available), stripchart output, and data acquisition system output. In this way, the entire measurement system is audited, and the causes of exceedances of the acceptance criteria can be isolated. The following paragraphs summarize the audit procedures.

Wind Direction. Distance sighting targets are determined for each site. Where possible, these targets are measured with a stable sighting compass on a nonmagnetic tripod and corrected for declination. The operator ascends or cranks down the tower and aligns the point and tail of the wind vane toward these targets while the auditor records the output in the shelter. Differences between true and measured direction are recorded. Vane starting thresholds are checked using a starting torque watch.

The wind direction sensor audits will consist of an evaluation of the threshold, orientation of cross arm, and instrument responses to known positions. If possible, the sensor will be audited in place on the tower. The auditor will not climb the tower. The site operator will handle the sensor. The only sensors that have been calibrated recently will be audited. There will be some limitations on the audits because sensor accessibility and sensor type.

The auditor will check the starting threshold qualitatively in the same manner as for the wind speed sensor by feeling for drag and grinding. A quantitative measurement of starting threshold with a torque gauge can only be done under conditions of no air motion. With the sensor in a sheltered location, a gram gauge will be used to measure the starting threshold, which should be less than 0.5 mps at a deflection of 10°.

Sensor orientation can be determined in several ways depending on the accessibility and type of sensor. In general, the audit will consist of holding the vane at several known positions covering the 360° circle and comparing the sensor reading to the position relative to true north. Angular bearings will be measured with measured with a Brunton Pocket Transit on a tripod or Site Path Transit. Magnetic bearings from these transits will be

converted to bearings relative to true North using current magnetic declination for the location obtained from the USGS GEOMAP program. The crossarm or sensor orientation will be measured. The vane orientation will be compared to known landmarks, the crossarm, or a degree orientation fixture such as the R.M. Young model 18212 or Met One models 040/044. The vane will be held in at least 4 different directions that are separated by approximately 90°. The output of the DAS for the 4 directions will be compared to the angle computed from bearing relative to true North. Differences between site and audit wind directions will be computed and compared to audit criteria.

Wind Speed. The anemometer cups are temporarily replaced by synchronous motors, and the equivalent wind speed displayed by the anemometer is compared with the speed corresponding to the rotation rate as supplied by the manufacturer. Anemometer starting thresholds are checked from a torque measurement using a gram scale applied at a measured distance from the axis of rotation.

The wind speed sensor audit will consist of an evaluation of the starting threshold of each sensor and a comparison of sensor response to fixed inputs with a variable speed motor at several constant rotation rates (EPA, 1989d). If possible, sensors will be audited in place with tower standing or tilted down but with cups or propellers removed. The auditor will not climb the tower. The site operator will handle the sensor. The only sensors that have been calibrated recently will be audited. There will be some limitations on the audits because sensor accessibility and sensor type.

The condition of bearings and any dirt/materials in the anemometer shaft affects the starting threshold. The auditor will qualitatively evaluate these by rotating the sensor shaft by hand and feeling for drag and grinding. The starting threshold will be measured with a torque watch or torque disk to determine if the starting threshold is 0.5 mps or less.

Accuracy of the wind speed output of the system will be determined by replacing the anemometer or propeller a variable speed anemometer drive (R.M. Young) to turn the shaft at rotation rates of 0, 60, 300, 600, and 1800 RPM. Instrument responses as registered by the DAS are compared to the manufacturer's speeds for these rotation rates. Differences between site and audit wind speeds is computed and compared to audit criteria.

Temperature. An aspirated thermometer traceable to standards from the NIST is placed adjacent to each temperature-sensing device, and the two readings are compared. The resistance of temperature-sensing units is compared to the NIST-traceable thermometer. When feasible, two sets of readings are taken to cover a wide range of readings.

The accuracy of the temperature sensor will be evaluated one of two methods. If the sensor can be immersed in water, it will be removed from its shield and placed in water baths of three temperatures. The bath temperature will be measured with a calibrated audit thermocouple. The audit sensor will be a Digi-Sense J,K,T Thermocouple thermometer with a T-type thermocouple. Different bath temperatures will be obtained

with ice, an immersion heater, and near ambient water. The audit comparison will consist of the difference between readings of the audit thermometer and the site sensor.

If the site sensor cannot be immersed in water, a side-by-side comparison will be made between the sensor and the audit thermocouple for a total of three readings. The sensors will be shaded to minimize the effect of solar radiation.

The audit thermometer and thermocouple are certified annually by a certification laboratory.

Relative Humidity. An aspirated psychrometer using NIST-traceable thermometers is operated at the level of the relative humidity sensor. Relative humidity based on the psychrometer readings is determined and compared to the instrument value.

Accuracy of relative humidity/dew point sensor will be determined by placing the audit relative humidity sensor near the site sensor and obtaining 3 readings. The primary relative humidity probe will be a Rotronic Hygroskop GT-L relative humidity/temperature probe. This sensor will measure relative humidity directly. A secondary audit instrument will be an Environmental Tectonics Psychro-Dyne dry bulb/wet bulb psychrometer. The psychrometer measures wet- and dry-bulb temperature from which relative humidity and dew point can be calculated.

Since USEPA's acceptance criteria for relative humidity is in terms of dew point temperature. The audit and site relative humidity will be converted to dew point using an expression for vapor pressure versus temperature for the Rotronic instrument or the psychrometric tables and/or psychrometric equation for the psychrometer. The difference between site and audit dew point will be computed and compared to the audit criteria.

The Rotronic probe is calibrated quarterly using salt solutions in a calibration device. Readings at 35, 50 and 80% relative humidity are obtained. The probe is returned to the manufacturer annually recertification of the temperature sensor and a 35 and 80% relative humidity comparison.

Solar Radiation. An audit pyranometer is zeroed and readings are taken with the audit instrument placed next to the station pyranometer. A comparison is made between the hourly average readings of the two instruments.

Accuracy of solar radiation sensor will be determined by installing an audit pyranometer near the site sensor and obtaining several readings. The audit probe will be an Eppley model PSP precision spectral pyranometer with a LI-1000 data logger. The data logger will collect a series of 10-minute readings or readings integrated over a longer time period. The audit sensor will be placed as near the site sensor with the same exposure as possible. The difference between site and audit solar radiation will be computed and compared to audit criteria. The solar radiation audit will not be done if it is raining. The audit should be done near noontime if possible.

The audit pyranometer is returned annually to Eppley for recalibration against the company's standards.

4.2.6.3 Corrective Action

Corrective action will be initiated when a problem is identified. Problems may be identified during operations and/or during performance audits. The goal of corrective action is to remedy any problem before the affected quantity drops below the desired accuracy, precision, or completeness.

Problems found during the audits will be documented with the Air Quality Data Action (AQDA) mechanism. The site operator will be notified of problems during the audit. A response to the AQDA that covers the resolution of the problem will be required. The audits will be somewhat limited in determining operational problems since they will occur only once during the study.

During routine operations of the air quality and meteorological sites, data from the field sites will be reviewed on a daily schedule. This daily review will provide the primary initiation for corrective action when problems with the data are identified. The site operators will be secondary in identifying most problems except those by visual inspection.

Once a problem has been identified, it will be evaluated for most efficient way to fix that may involve the combined efforts of the data analyst, an instrument technician, and the site operator. The local supervisors, the study QA officer, and the study project manager will be informed of the problem, and later its resolution, through verbal and written notification. This will documents the problem, its resolution, and the effect on the particular quantity and the project in general.

4.2.6.4 Data Acquisition and Processing

The individual agencies and other participants in the field project are responsible for acquiring and processing data from their networks. In general, all procedures meet the requirements and guidelines of USEPA (40 CFR 58, Appendices A and B; Quality Assurance Handbook for Air Pollution Measurement Systems, Volume I, II, and IV). The objective of the data reduction and validation effort is a quality assured data base monitoring data in a consistent format.

Continuous data are collected by data acquisition systems (DAS) in the field at the agency sites and at the supplemental sites. The DAS samples the outputs from the instruments serially at fixed intervals and converts analog voltage signals to digital numbers for processing. Each hour, it computes hourly averaged data as scalar averages. Day and time of sample are collected also. Meteorological data may also include hourly and 15-minute averages are computed with temperature and relative humidity as scalar averages and winds as average scalar wind speed and unit vector wind direction. The standard deviation of the wind direction may be computed using the Yamartino method over 15-minute segments with an hourly averaged sigma theta computed as the root-mean-square value of the four 15-minute averages. Each record stored by the DAS is identified with a

date and time. The time collected by most data loggers is time at the end of the sample period. The time associated with specific data records, beginning or ending, needs to be specified in the final data product.

At many sites, the DAS commands the site calibration system to perform daily automated zero/span checks of the instruments.

At many sites, averaged air quality and meteorological data and automated calibration data are retrieved automatically from the field each night by telephone and modem. At some agencies and for supplemental sites, these data are automatically screened for anomalies that are flagged for further investigation. The screening routines check for outliers, instrument problems, and data system problems. They can test for data that exceed set minima, maxima, and rate-of-change values. For the supplemental sites, reports from the screening programs will be available for review the next day. Data are entered into a raw database as they are received. This database is saved in its original form and noted as such to assure that it could be obtained again if necessary. Subsequent databases are updated as processing proceeds.

All site documentation are sent from the field to the operations office at least once a month. This includes site logs, checklist logs, zero/span checks, and multi-point calibration results. The ancillary site data are logged in and made available for use during data processing and validation.

4.2.6.5 Data Validation

All data are reviewed before use, starting with observations and reports from the site operators and continuing with the review of logs, checklists, and data. All flagged or anomalous data are investigated. All data are retained unless substantial evidence is available for their deletion.

For air quality data, zero and span check data are reviewed as an integral part of the process. Data for which the span response deviates by more than 25% or the zero by more than 25 ppb from expected values are invalidated. Data for which the span response deviates by 15 to 25% are adjusted using correction factors obtained for zero/span and calibration data.

All changes resulting from reviewing documentation are made directly on the raw data report and comments added as required. Raw data reports are reviewed to see that outliers have been corrected, replaced by missing data code if deleted, or checked as valid. When raw data are completely checked, corrected, and approved, changes are made to the data base and any necessary correction factors applied.

For supplemental sites, a data report will be generated that describes the data collected including units and lists missing data.

4.2.6.6 Data Archival

Data from the air pollution control districts are archived in AIRS format and are submitted to CARB and USEPA. Data from the supplemental sites will also be archived in AIRS format and submitted to CARB.

4.3 UPPER-AIR MEASUREMENTS

4.3.1 Aircraft Measurements

3.1.1.2 Aloft air quality measurements during LTADS only include an instrumented aircraft. The systems audit of the aircraft will be done at the level of the Comprehensive Site Survey by personnel from the Quality Assurance Section (QAS) of CARB at the time the performance audits are done. The sampling procedures will be reviewed including operating procedures, calibration equipment and standards, and instrumentation.

4.3.1.1 Navigational Instruments

Position of the airborne platform in space and time is extremely important for the use and intercomparison of all other measured quantities. The Global Positioning System (GPS), a satellite system operated by the U.S. Department of Defense (DOD) provides radio signals from which GPS receivers can calculate 3-dimensional position and time at several different accuracy levels.

Civilian users worldwide use the Standard Positioning System (SPS) without charge or restrictions. Most receivers are capable of receiving and using the SPS signal. The SPS accuracy is intentionally degraded by the DOD by the use of Selective Availability (SA). The SPS predictable accuracies are: 100 m horizontal accuracy, 156 m vertical accuracy, and 340 ns time accuracy. These GPS accuracy figures are from the 1994 Federal Radionavigation Plan. The figures are 95% accuracies, and express the value of two standard deviations of radial error from the actual antenna position to an ensemble of position estimates made under specified satellite elevation angle (five degrees) and Position Dilution of Precision PDOP (less than six) conditions. For horizontal accuracy figures 95% is the equivalent of 2drms (two-distance root-mean-squared), or twice the radial error standard deviation. For vertical and time errors 95% is the value of two-standard deviations of vertical error or time error. Receiver manufacturers may use other accuracy measures. Root-mean-square (RMS) error is the value of one standard deviation (68%) of the error in one, two or three dimensions. Circular Error Probable (CEP) is the value of the radius of a circle, centered at the actual position that contains 50% of the position estimates. Spherical Error Probable (SEP) is the spherical equivalent of CEP, that is the radius of a sphere, centered at the actual position, that contains 50% of the three dimension position estimates. As opposed to 2drms, drms, or RMS figures, CEP and SEP are not affected by large blunder errors making them an overly optimistic accuracy measure. Some receiver specification sheets list horizontal accuracy in RMS or CEP and without Selective

Availability, making those receivers appear more accurate than those specified by more responsible vendors using more conservative error measures.

Authorized users with cryptographic equipment and keys and specially equipped receivers use the Precise Positioning System (PPS). U.S. and Allied military, certain U.S. Government agencies, and selected civilian users specifically approved by the U. S. Government, can use the PPS. The PPS predictable accuracies are: 22 m horizontal accuracy, 27.7 m vertical accuracy, and 100 ns time accuracy.

Differential GPS (DGPS) techniques improve the accuracy of GPS by correcting bias errors at one location with measured bias errors at a known position. A reference receiver, or base station, computes corrections for each satellite signal. Because individual pseudo-ranges must be corrected prior to the formation of a navigation solution, DGPS implementations require software in the reference receiver that can track all satellites in view and form individual pseudo-range corrections for each satellite. These corrections are passed to the remote, or rover receiver that must be capable of applying these individual pseudo-range corrections to each satellite used in the navigation solution. Applying a simple position correction from the reference receiver to the remote receiver has limited effect at useful ranges because both receivers would have to be using the same set of satellites in their navigation solutions and have identical Geometric Dilution of Precision (GDOP) terms (not possible at different locations) to be identically affected by bias errors. Differential corrections may be used in real-time or later, with post-processing techniques. Real-time corrections can be transmitted by radio link. The U. S. Coast Guard maintains a network of differential monitors and transmits DGPS corrections over radio beacons covering much of the U. S. coastline. DGPS corrections are often transmitted in a standard format specified by the Radio Technical Commission Marine (RTCM). Corrections can be recorded for post processing. Many public and private agencies record DGPS corrections for distribution by electronic means. Private DGPS services use leased FM sub-carrier broadcasts, satellite links, or private radio-beacons for real-time applications. To remove Selective Availability (and other bias errors), differential corrections should be computed at the reference station and applied at the remote receiver at an update rate that is less than the correlation time of SA. Suggested DGPS update rates are usually less than twenty seconds. DGPS removes common-mode errors, those errors common to both the reference and remote receivers (not multipath or receiver noise). Errors are more often common-mode when receivers are close together (less than 100 km). Differential position accuracies of 1-10 meters are possible with DGPS.

An extensive overview of the GPS system and further references have been given by Dr. Peter H. Dana of the University of Texas at Austin and can be found on his web site at <http://www.utexas.edu/depts/grg/gcraft/notes/gps/gps.html>.

The vertical accuracy of standard GPS (156 m for SPS) is marginal for lower tropospheric studies. Therefore, vertical position, i.e., altitude is often derived from pressure measurements. If the pressure-derived altitude measurement is corrected for

atmospheric pressure changes before take-off and/or after landing an accuracy of ± 3 m can be obtained.

4.3.1.2 Field Performance Audits for Aircraft Platforms

Quantitative transfer standards, similar to those used for the performance audits of the surface-based monitors, are used to challenge each measurement system aboard the aircraft platform. Results of each audit are compared to acceptance criteria and values that exceed the criteria are flagged. Immediately following the audit, the auditors provide a verbal report of the audit to the appropriate aircraft supervisor. During the verbal report, values and equipment problems are discussed in terms of possible reasons for the discrepancies and corrective action to be taken. If corrective action is implemented, the audit is repeated.

Aloft performance audits for aircraft and balloon-based instrumentation complement ground based performance audits. They take place in the same setting as the actual measurements and are able to identify some problems that are not noticed in ground based audits, such as problems related to air speed, altitude, and vibrations. For ozone lidar systems, aloft performance audits constitute the only meaningful kind of performance audit, making them a necessity.

The aloft performance audits are not true performance audits as no primary standard is being used but take the form of intercomparison studies.

Performance audits of instruments installed on the aircraft will be conducted by personnel from Quality Assurance (QAS) of the CARB. Each measurement method will be audited on the project. The CE-CERT ozonesonde will also be audited.

As with the surface monitoring stations, performance audits are quantitative assessments of instrument operation that are accomplished by challenging site instruments with known audit standards. The procedures described for instruments at the surface sites will be followed for the aircraft equipment in as far as they are applicable. Some modifications may have to be made. The delivery of the audit gases may have to be changed to match the instrument sample inlets. The higher ranges of audit concentrations likely exceed the operating range of the aircraft instruments. At the low concentration end, the lowest audit concentrations should be as low as possible.

Meteorological instrumentation on the aircraft will also be audited. The audit criteria will have to be relaxed for those instruments that require airflow past them at speeds attained by the aircraft. The measurements of temperature and relative humidity are particularly affected by the moving and static air streams. For instruments that depend on orientation during flight, such as a solar radiation sensor, the audit sensor will have to be positioned in approximately the same orientation as the aircraft sensor which may not be horizontal when the aircraft is on the ground.

4.3.2 Field Systems Audits for Upper-Air Measurements

Aircraft systems audits are similar to surface systems audits. A systems audit questionnaire is completed by the auditor for each aircraft. The auditor reviews the type of measurements that are actually being performed relative to those specified in the most recent work plan. The level of documentation of quality control checks, instrument logs, etc. is examined. Results of calibration records and performance tests are evaluated. The auditor records pertinent information relative to the sampling system to form an independent documentation of conditions as they existed during the audit.

4.3.2.1 Temperature Measurement

Temperature can be measured via a diverse array of sensors. All of them infer temperature by sensing some change in a physical characteristic. Resistive temperature devices (RTDs and thermistors) are commonly used to measure air temperature in conjunction with a data acquisition system.

Resistive temperature devices capitalize on the fact that the electrical resistance of a material changes as its temperature changes. Two key types are the metallic devices (commonly referred to as RTDs), and thermistors. As their name indicates, RTDs rely on resistance change in a metal, with the resistance rising more or less linearly with temperature. Thermistors are based on resistance change in a ceramic semiconductor; the resistance drops nonlinearly with temperature rise.

A typical RTD consists of a fine platinum wire wrapped around a mandrel and covered with a protective coating. Usually, the mandrel and coating are glass or ceramic. The mean slope of the resistance versus temperature plot for the RTD is often referred to as the alpha value, alpha standing for the temperature coefficient. The slope of the curve for a given sensor depends somewhat on purity of the platinum in it. The most commonly used standard slope, pertaining to platinum of a particular purity and composition, has a value of 0.00385 (assuming that the resistance is measured in ohms and the temperature in degrees Celsius). A resistance versus temperature curve drawn with this slope is a so-called European curve, because RTDs of this composition were first used extensively on that continent. Complicating the picture, there is also another standard slope, pertaining to a slightly different platinum composition. Having a slightly higher alpha value of 0.00392, it follows what is known as the American curve. If the alpha value for a given RTD is not specified, it is usually 0.00385. However, it is prudent to make sure of this, especially if the temperatures to be measured are high.

The resistance-temperature relationship of a thermistor is negative and highly nonlinear. This poses a serious problem for engineers who must design their own circuitry. However, the difficulty can be eased by using thermistors in matched pairs, in such a way that the nonlinearities offset each other. Furthermore, vendors offer panel meters and controllers that compensate internally for thermistors' lack of linearity. Thermistors are usually designated in accordance with their resistance at 25°C. The most common

of these ratings is 2252 Ω ; among the others are 5,000 Ω and 10,000 Ω . If not specified to the contrary, most instruments will accept the 2252 Ω type of thermistor.

4.3.2.2 Humidity Measurement

The humidity of air can be expressed as absolute humidity (either dew point or water concentration) or relative humidity. These quantities can easily be converted from one to the other if the atmospheric temperature is known. Two common methods of measuring atmospheric humidity are described in the following.

The dewpoint monitor determines absolute humidity from a fundamental measurement and therefore does not depend on empirical calibration factors. This instrument cools a small mirror to the point at which moisture condenses on the mirror surface and optically detects the first sign of condensation. The mirror temperature is measured accurately, often with an RTD resulting in a measurement of the dewpoint which is directly related to the absolute humidity.

The capacitive humidity sensor measures relative humidity via the change in capacity of a thin film polymer capacitor. The thin polymer film either absorbs or exudes water vapor as the relative humidity of the ambient air rises or drops. The dielectric properties of the polymer film depend on the amount of water contained in it: as the relative humidity changes, the dielectric properties of the film change and so the capacitance of the sensor changes. The electronics of the instrument measure the capacitance of the sensor and converts it into a humidity reading.

4.3.2.3 Upper-Air Remotely Sensed Meteorological Measurements

The upper air data are intended to allow for the generation of gridded 3-dimensional wind and temperature fields sufficient for use to understand complex meteorology and source-receptor relationships in the Lake Tahoe basin.

System audits are used to evaluate whether a system is set-up correctly and that standard operating procedures are being followed. System audits should be conducted at all upper air monitoring sites shortly after start-up of the field work and again shortly before ending the field work component of the study. The list of system audit checks for rawinsondes, sodars, and RWP/RASS from the STI (1995) draft report should be used and appears below.

3.1.1.2.1 Remote Profiler Instrumentation (Sodar, Radar Wind Profiler/RASS)

A routine check of the monitoring station should be performed to ensure that the local technician is following all the standard operating procedures. In addition, the following items should be checked:

- The antenna and controller interface cables should be inspected for proper connection. If multi-axis antennas are used, this will include checking for the proper direction of the interface connections.

- Orientation checks should be performed on the individual antennas, or phased-array antenna. The checks should be verified using solar sitings when possible. The measured orientation of the antennas should be compared with the system software settings of the system. The antenna alignment should be maintained within $\pm 2^\circ$, which is consistent with wind direction vane alignment criteria specified by the USEPA (1995b).
- For multi-axis antennas, the inclination angle, or zenith angle from the vertical, should be verified against the software settings and the manufacturer's recommendations. The measured zenith angle should be within $\pm 0.5^\circ$ of the software settings in the data system.
- For phased-array antennas, and for the vertical antenna in a multi-axis system, the level of the antenna should be within $\pm 0.5^\circ$ of the vertical.
- For multi-axis sodar systems, a separate distinct pulse, or pulse train in the case of frequency coded pulse systems, should be heard from each of the antennas. In a frequency-coded pulse system, there may be a sound pattern that can be verified. The instrument manual should be checked to see if there is such a pattern.
- For sodar systems, general noise levels should be measured, in dBA, to assess ambient conditions and their potential influence on the altitude capabilities of the sodar. In general, levels below 50 dBA indicate a quiet site, while levels above 60 dBA are quite noisy. The altitude coverage of the sodar will be directly related to the ambient noise at the site.
- A tabular vista diagram should be prepared documenting the surroundings of the site in 30° to 45° increments. The diagram should identify any potential sources clutter and reflective and active noise sources in each of the directions, as well as the approximate distance to the objects and their elevation angle above the horizon. This information is useful in assessing the effects of the environment on the data collected. As part of this documentation, photographs in various directions may be helpful for interpreting information in the tabular diagram. If this documentation exists in the monitoring plan for the site, it should be reviewed for accuracy.
- The controller and data collection devices should be checked to ensure the instruments are operating in the proper mode and that the data being collected are those specified by the SOP's.
- Station logbooks, checklists, and calibration forms should be reviewed for completeness and content to assure the entries are commensurate with the expectations in the procedures for the site.

- The site operator should be interviewed to determine his/her knowledge of system operation, maintenance, and proficiency in the performance of QC checks.
- The antenna enclosures should be inspected for structural integrity that may cause failures as well as any sign of debris or animal or insect nests that may cause drainage problems in the event of rain or snow.
- Preventative maintenance procedures should be reviewed for adequacy and implementation.
- The time clocks on the data acquisition systems should be checked and compared to a standard of ± 2 minutes.
- The data processing procedures and the methods for processing the data from sub-hourly to hourly intervals should be reviewed for appropriateness.
- Data collected over a several-day period should be reviewed for reasonableness and consistency. The review should include vertical consistency within given profiles and temporal consistency from period to period. For radar wind profilers and sodars, special attention should be given to the possibility of ground clutter (i.e., fixed echoes) and/or active noise source contamination in the data.

This quality assurance plan is based principally upon guidelines from the report "Draft Guidelines for the Quality Assurance and Management of PAMS Upper-Air Meteorological Data (STI, 1995). Quality assurance for upper air monitoring has the following components: 1) siting and installation (includes testing); 2) periodic review of data (frequent inspection of collected data and evaluation of it's reasonableness); 3) system audits and performance audits; 4) a plan for quickly correcting problems; 5) data acquisition and processing; and 6) data validation and archival.

4.3.2.3.1 Sampling Site Selection Criteria

Detailed criteria for precisely locating sites are given in this section.

Site needs include:

- A flat location, clear of obstacles, and with good drainage
- Sufficient electrical power
- An environmentally controlled instrument shelter
- A fence around the equipment and shelter, or other sufficient security measures

- A remote communications link

Sodar and RWP/RASS sites have additional needs:

- Locate sodars and RASS away from areas that would result in annoyances due to the sound waves emitted from these instruments. Thus, before locating instruments, evaluate the expected effects (intensity, exposed population, time of day) of the instruments upon sensitive receptors.
- Avoid noise sources (roads, industrial processes, air conditioners, etc.) that may interfere with sodars and RASS. Provide sufficient acoustic shielding to minimize the effects of noise. Measure noise levels at the potential site during the expected highest noise period of the day, if possible. Noise levels should be below 60 dBA; below 50 dBA is preferable.
- Building, trees, power lines, etc. may reflect sodar and radar pulses and contaminates the data. Sites should be chosen that minimize obstructions taller than 15 degrees above the horizon. If objects extend above 15 degrees elevation, the beams should be located away from these objects.

4.3.2.3.2

Installation

- Sodar, RWP, and radio theodolite system antennas should be aligned to true north using the solar siting technique (USEPA, 1989).
- Determine the latitude, longitude, and elevation of the site using detailed maps or a Global Positioning System (GPS) instrument.
- Site documentation: Take photographs in each of four cardinal directions, and of all shelter, instruments, and other equipment. Videotape the site, including a 360-degree view of the surrounding area. Produce a detailed site layout plan documenting location of the instruments, shelter, and other equipment. Produce a diagram that describes all objects and topographic features around the site in 30 to 45 degree increments. Include potential sources of clutter and noise sources, and distance to and elevation angle of objects.
- After installation, perform acceptance testing of the instrument following the manufacturer's procedures.
- When system becomes operational, check data for reasonableness. This is best done using collocated meteorological data from surface or upper air meteorological data. If collocated data is not available, nearby upper air data and the judgement of a person familiar with expected conditions at the site can be used.

4.3.2.3.3

Sampling Procedures

3.1.1.2.2 Sodars

The optimum type of sodar and sampling procedure depends upon the intended use of the data. If high vertical resolution is needed over a relatively shallow layer, high frequency mini-sodars are appropriate. Mini-sodars give vertical resolution on the order of 5-20 m up to about 300 m or less AGL. If a greater depth is needed, with less resolution required, standard sodars with vertical resolution of 20-50 m and coverage typically to about 1000 m, are appropriate. For sodars located without collocated RWP, higher vertical range is usually needed. The flows of interest near the surface of Lake Tahoe necessitate the use of mini-sodars.

3.1.1.2.3 Radar Wind Profilers/RASS

RWP/RASS are typically operated in the RASS mode for the first 5-10 minutes of the hour, then in the RWP mode for the remaining 50-55 minutes. At the end of each hour, hourly consensus wind and temperature profiles are computed, although they are not true hourly averages. The data can then be reviewed on a near real-time basis for forecasting purposes and quality assurance. For more reliable wind and temperature data, and a closer representation of a true hourly average, continuous, interleaved sampling of wind and RASS derived temperature may be done. In this mode, the oblique beams are sampled for 20-30 seconds, then the vertical beam with RASS is sampled for 20-30 seconds; this creates a profile for each 20-30 second sampling period. Post-processing must then be performed to obtain hourly averaged data.

Due to the higher quality and better representativeness of the continuous, interleaved data, this is the preferred method. However, if continuous, interleaved hourly averaged data cannot be provided within a few hours of collection, the standard method of 5-10 minutes RASS, followed by 50-55 minutes of wind data should be used.

4.3.3 Performance Audits

A performance audit is intended to provide a measure of the performance of a measurement system. With upper air measurements, the concept of performance audits is somewhat altered, because there is not typically a known reference value for each measurements. Sodars and radar wind profilers measure winds over varying spatial and temporal (typically 1-hour) domains. Rawinsondes measure winds that are closer to instantaneous in time and spatially averaged over a small, nearly vertical path. Thus, direct comparisons are not possible. However, comparisons among the different measurement types (RWP, sodar and rawinsonde winds; RASS and rawinsonde derived virtual temperature) can give an overall indication of instrument performance and can be useful in data validation for periods with collocated data.

Field audits for upper-air meteorological measurements from surface-based platforms are particularly challenging, and special techniques are needed. For systems, ground-truthing of set-up conditions (surface wind, pressure, and temperature) is performed similar to the standard surface meteorology audit procedures described above. In

addition, for Doppler acoustic sounders and radar profilers, performance audits are accomplished using collocated audit tethersondes, radiosondes, and/or instrumented aircraft (flying nearby spirals).

3.1.1.2.4

4.3.3.1 Periodic Review of Data

Upper air data should be evaluated daily for operational status and reasonableness. Each day (at least Monday through Friday) a meteorologist or other person knowledgeable about upper air meteorological patterns in the Tahoe basin should examine the data for each site for the past 24 hours for reasonableness. Time-height cross-sections plots provide for an efficient way of inspecting data at one site. Spatial patterns at a few selected heights would also be helpful for noting suspicious data. If data are not being received, or appear to be invalid during part or all of the 24-hour period, the organization responsible for collecting the data should be contacted immediately. The responsible organization should promptly evaluate whether a problem does exist, and remedy any problems as soon as possible.

A routine check of the monitoring station should be performed to ensure that the local technician is following all the standard operating procedures. In addition, the following items should be checked:

- The antenna and controller interface cables should be inspected for proper connection. If multi-axis antennas are used, this will include checking for the proper direction of the interface connections.
- Orientation checks should be performed on the individual antennas, or phased-array antenna. The checks should be verified using solar sitings when possible. The measured orientation of the antennas should be compared with the system software settings of the system. The antenna alignment should be maintained within $\pm 2^\circ$, which is consistent with wind direction vane alignment criteria specified by the USEPA (1995b).
- For multi-axis antennas, the inclination angle, or zenith angle from the vertical, should be verified against the software settings and the manufacturer's recommendations. The measured zenith angle should be within $\pm 0.5^\circ$ of the software settings in the data system.
- For phased-array antennas, and for the vertical antenna in a multi-axis system, the level of the antenna should be within $\pm 0.5^\circ$ of the vertical.
- For multi-axis sodar systems, a separate distinct pulse, or pulse train in the case of frequency coded pulse systems, should be heard from each of the antennas. In a frequency-coded pulse system, there may be a sound pattern that can be verified. The instrument manual should be checked to see if there is such a pattern.

- For sodar systems, general noise levels should be measured, in dBa, to assess ambient conditions and their potential influence on the altitude capabilities of the sodar. In general, levels below 50 dBA indicate a quiet site, while levels above 60 dBA are quite noisy. The altitude coverage of the sodar will be directly related to the ambient noise at the site.
- A tabular vista diagram should be prepared documenting the surroundings of the site in 30° to 45° increments. The diagram should identify any potential sources clutter and reflective and active noise sources in each of the directions, as well as the approximate distance to the objects and their elevation angle above the horizon. This information is useful in assessing the effects of the environment on the data collected. As part of this documentation, photographs in various directions may be helpful for interpreting information in the tabular diagram. If this documentation exists in the monitoring plan for the site, it should be reviewed for accuracy.
- The controller and data collection devices should be checked to ensure the instruments are operating in the proper mode and that the data being collected are those specified by the SOP's.
- Station logbooks, checklists, and calibration forms should be reviewed for completeness and content to assure the entries are commensurate with the expectations in the procedures for the site.
- The site operator should be interviewed to determine his/her knowledge of system operation, maintenance, and proficiency in the performance of QC checks.
- The antenna enclosures should be inspected for structural integrity that may cause failures as well as any sign of debris or animal or insect nests that may cause drainage problems in the event of rain or snow.
- Preventative maintenance procedures should be reviewed for adequacy and implementation.
- The time clocks on the data acquisition systems should be checked and compared to a standard of ± 2 minutes.
- The data processing procedures and the methods for processing the data from sub-hourly to hourly intervals should be reviewed for appropriateness.
- Data collected over a several-day period should be reviewed for reasonableness and consistency. The review should include vertical consistency within given profiles and temporal consistency from period to period. For radar wind profilers and sodars, special attention should be given to the possibility of ground clutter (i.e., fixed echoes) and/or active noise source contamination in the data.

4.3.3.2 Sodars

An acoustic pulse transponder (APT) shall be used in sodar performance audits to test the ability of the instrument to correctly interpret test signals representing known wind speeds. Audit results should be within $\pm 0.2 \text{ ms}^{-1}$ on a component basis. Audits using an APT should be conducted over at least three averaging intervals and over a range of wind speeds corresponding to those normally observed. These audits should be conducted near the beginning of the field study at each sodar site, simultaneously with the first system audit.

4.3.3.3 Radar Wind Profilers

Collocated sodars and rawinsondes at several sites can be used for performance audits. If additional performance audits are needed, sodars and/or rawinsondes may be used. If rawinsondes are used, at least 3 soundings covering the diurnal cycle should be taken. If sodars are used, the sodars should be configured to match the RWP data in temporal and spatial averaging as much as possible. The sodars should be run for at least 24 hours, and data compared to the RWP data while on-site. Comparisons between sodars and rawinsondes and RWP should be done when winds are at least 2 ms^{-1} .

4.3.3.4 RASS

RASS performance audits shall be done using collocated rawinsondes to provide virtual temperature. The radar wind profiler performance audits use sodars to check the lower gates of the RWP and rawinsondes to check the full RWP range. Sodars are performance audited by using collocated rawinsonde data and with acoustic pulse transponders (APT). The APT produces a simulated wind profile made up of sounds with known frequencies that are timed to simulate the doppler shifted echoes scattered by the atmosphere from various altitudes. The RASS performance audit will use collocated rawinsonde data to compute virtual temperature for comparison to the RASS derived virtual temperature.

4.3.4 Corrective Actions

All audit results will be entered on QA Audit Station Data Worksheet forms and into an audit computer. Calculations are done by the computer and by hand for verification. Preliminary results will be summarized in reports for each measurement issued to the site operator at the conclusion of the audit. For gas analyzers, the reports will present the audit concentrations, the instrument responses, and the percent differences. Instrument performance will be assessed by comparing the percent differences to USEPA criteria as shown in Table 21. For meteorological equipment, the reports will present the expected instrument responses, the actual instrument responses, and their differences. Instrument performance will be assessed by comparing the differences to the USEPA criteria as shown in Table 22, although possible modified as indicated above. For those instruments that exceed the criteria, the auditor will issue an Air Quality Data Action (AQDA). The site

operator will be required to respond to the AQDA by detailing the actions done to correct instrumental problems found during the audit.

If problems are identified through system or performance audits, inspection of the data, or by other methods, a plan of action is needed to quickly correct such problems and avoid any further loss or corruption of data. Each contractor or agency responsible for collecting upper-air meteorological data shall submit a plan for identification and remediation of problems. Any problems noted by the audit contractor during system and performance audits shall be reported to the station operator before leaving the site. For sites without station operators on site, the contractor (principal investigator) responsible for the site will be contacted while at the site. For problems not corrected immediately, the auditor will also notify the Quality Assurance Manager. If the audit results suggest that previously or currently collected data are suspect, the auditor shall notify the principal investigator and Upper-air Quality Assurance Manager and supply copies of audit reports as soon as practical.

4.3.5 Data Acquisition and Processing

A summary of the upper-air data acquisition and processing procedures are presented here. All data used for determining vertical temperature and wind profiles shall be stored, including complete spectral moment data.

4.3.6 Data Validation

Level-1 validation should be performed automatically shortly after the data is received using time/height consistency checks for the RWP/RASS and sodar, and height consistency checks for the rawinsondes. Level-2 validation includes comparing collocated measurements in time and height and network-wide consistency in time, and space. After completion of the field study, all data products will be reviewed by trained personnel familiar with the study area. Additional data validation will occur during data analysis activities, when data may appear inconsistent with other analysis and modeling results.

4.3.7 Data Archival

Upper air data archival format and location should be specified by the Data Manager in consultation with the Quality Assurance Manager. STI (1995) identified the following desired features of upper-air data:

- Ability to use the data across a range of computer systems.
- The format should be independent of the instruments used to collect the data.
- Ability to store quality control information. Data validation level should be identified and stored with the data.
- Ability to store the data in ASCII and/or binary formats.

- Ability to include self-documentation that describes the content of the data sets.
- Ability to use commercial off-the-shelf software to read, sort, and manipulate the data.

4.4 LABORATORY AUDITS

4.4.1 Laboratory Systems Audits

Laboratory analysis and data processing activities are audited in this procedure. The laboratory systems audit examines the procurement and acceptance testing of sampling substrates, laboratory documentation, SOPs, laboratory instrumentation, spare parts, and supplies. A traceability audit randomly selects a single data value for each observable from a recent data report and tracks the documentation and traceability to standards associated with that value. This traceability audit determines how well each of the individual procedures was integrated to produce valid data values.

4.4.2 Laboratory Performance Audit

The performance audit will consist of the submission of samples for analysis among different laboratories.

5. DATA MANAGEMENT PLAN

Data from an air quality study come from a variety of sources – emissions, meteorology, and air quality and data providers. If remote sensing is used to collect continuous data, the size of the data files can become large very quickly. Often data providers provide data in different formats suited for particular experiences and needs. It is imperative that the various amounts and types of data are anticipated in the design of the data base and data management procedures. A well-designed data base(s) will facilitate the accessibility, the quality control, and the analysis of the data. Chain of custody records are very useful for documenting what actually happened and when. Original data records are kept permanently and subsequent modifications are documented. A good data management system will enable future analysts to trace the history of the data that they are working.

The Data Manager is responsible for developing the data management plan in conjunction with the field managers and field contractors. The data manager works with the field manager, measurement contractors, modelers, and analysts to develop standard data formats for use in the study. The data manager is responsible for obtaining project data and supplemental data, integrating the data into a common database, performing Level 1 screening of the data, providing the data to the QA, analysis, and modeling contractors, and documenting and maintaining the data archive.

The data management process is the beginning of the data analysis and modeling of the data set by the community of scientists.

Data used for data analysis and modeling derive from measurements made as part of the study as well as from other sources. The execution of the technical study plan will involve several investigators at different locations, each providing validated measurements that are integrated with those from the others. Measurements from other databases will be requested, received, transformed into common units, and reformatted for compatibility with data acquired during the field study. Common communications, data management, and validation conventions are needed to allow this information to be gathered and disseminated in an efficient manner. These conventions are described in this section.

5.1 DATA DIRECTORY STRUCTURE

Data and communications files will be organized into several sub-directories within the data server. Each of these contains additional sub-directories to further organize the information. All directories, with exception of the TEMP directory, have read-only privileges for most users to avoid the inadvertent erasure of information. Files may be uploaded to the TEMP directory for later placement in the appropriate read-only directory by the data manager. These directories are:

- TEMP: This is a temporary location where files are uploaded by project participants prior to their transfer to their designated parent directory. An e-mail message should be sent to the data manager indicating the uploaded file name and its desired directory location. The TEMP directory is also used to allow the transfer of non-archived scratch files among project participants.
- REPORTS: This directory contains files related to project reports, memoranda, and minutes. Sub-directories are:
 - PROGPLN for the latest draft of the program and management plans
 - MEMO for project memoranda
 - MINUTES for minutes of discussions
 - PRGREP for progress reports
 - RFP for final versions of requests for proposals
- DATA: This directory contains data files in the form they are received from the data source. These files are in several different formats, cover different time periods, and do not necessarily conform to the standard units and variable naming conventions. To conserve disk space, these files are usually backed up onto storage media after they have been processed; they can be re-loaded upon request to the data manager. They are located in directories specific to each data supplier, as specified in the next section.

- DBASE: This directory contains validated ambient measurement data in xBase (*.DBF) formats that have been converted to common units and variable names. These conventions are described below. These files are organized according to their source:
 - MISC for database documentation files described below
 - AT for data from the AIRS database
 - AR for data from the Air Resources Board
 - BL for data from the Bureau of Land Management
 - FS for data from the U.S. Forest Service
 - NO for data from the National Oceanic and Atmospheric Administration
 - NW for data from the National Weather Service
 - RA for data the Remote Automated Weather Station (RAWS) network
 - MM for data from the Minerals Management Service
- QA: This directory contains quality assurance results from audits, performance tests, and collocated measurements.
- TABLES: This directory contains tables of processed results, including statistical summaries of data, frequency distributions, and data capture rates.
- FIGURES: This directory contains figures of processed results, including time series, spatial isopleth plots, cumulative frequency plots, and scatter plot comparisons.
- MAPS: This directory contains base maps of terrain, highways, population centers, political boundaries, land use, and surface characteristics in formats that are deemed useful for different analyses.
- UTILITIES: This directory contains software created for the project, software available for distribution for which licenses have been obtained, and commonly used shareware. These include data conversion, format conversion, file compression, and data display programs.

Other directories and sub-directories are created as needed to organize the information produced by the study. The database is organized by network with sub-directories for each source. Files within these sub-directories are further organized by the type of measurement. For example, surface meteorological data are contained in one file, while surface light scattering data are contained in another file. One file contains data of the specified type for the entire measurement period and all sites in the specified network. The records in each file are ordered by site (alphabetically), date, and time. For contiguous data, records are maintained for intervening periods even if no valid data were acquired for that period to facilitate time-series analysis.

5.2 DATABASE DOCUMENTATION

Informational files as shown in Table 23 will document the numerical database.

Table 23. Filename extensions and definitions

- LTFLDNAM.DBF: This file contains variable names, units, field lengths, and decimal positions (precision) for each variable in every other file. All variables of a given type have been converted to common units, regardless of their original units, and these units are specified in this file. For example, National Weather Service wind speeds included in the database are in meters/second, even though they were obtained from NWS in knots.
- LTSITE.DBF: This file contains monitoring site codes, site names, coordinates (in latitude and longitude and UTM Zone 10), elevations in meters above mean sea level, and the types of measurements acquired at each site. A data quality designation is provided for sites that are operated by other agencies, such as the Remote Automated Weather Station (PAWS) monitoring network. This designation is drawn from each agency's data documentation to facilitate the selection of sites for use in data analysis and modeling. Subsequent fields identify the types of measurements available at each sampling site; these are defined in SCFLDNAM.DBF.
- LTFJLES.DBF: This file lists file names, their location (i.e. directory path), and date of latest update. This file should be consulted to determine where data are located and to ascertain that the most recent data sets are being used.
 - LTEXT.DBF: As noted above, this file contains software extensions, their definitions, and the types of software that creates them. This file should be consulted to determine how a binary file might be used.
- LTFLAGS.DBF: This file maps the common measurement flagging system used in the MZVS to specific flags associated with measurements from an individual measurement device and from individual networks. The common flags are defined in Table 24 and are intended to guide the data user to seek greater detail in the individual network flags. The network flags are also included, where available, in the data files, but they are not generally carried when data from different networks are integrated for data analysis and modeling.
- LTCONVRT.DBF: This file documents the conversions made in integrating data into the database. If, for example, wind speed units are changed from miles per hour to meters per second, then the change is documented in the file.

Table 24. Common data flags.

- 0 Valid data
- 1 Estimated value
- 2 Calibration or instrument check
- 3 Instrument failure
- 4 Off-scale reading
- 5 Interpolated
- 6 Below detection limit
- 7 Suspect
- 8 Invalid
- 9 Missing
- a Hourly average, $45 \text{ min} \geq \text{avg period} \leq 60 \text{ min}$
- b Hourly average, $\text{avg period} < 45 \text{ min}$
- d Averaged data
- e Zero mode
- f Blank sample

5.3 DATA PROCESSING AND TRANSFER

For measurements acquired as part of this study, data are submitted by each investigator using the variable naming conventions and units described in LTFLDNAM.DBF. All values are to be at Level 1A when submitted. These are passed through the Level 1B tests described above, and discrepancies are resolved with the measurement investigator and corrected prior to designation as Level 1B. Data are added to the master data files as they are received.

Measurements from other networks, such as RAWs and the National Weather Service, are acquired in formats and units specific to those networks. Data processing functions are specific to these networks. First, these files are manually edited, when needed, because they sometimes contain minor variations in format that confound the data conversion programs. After editing, a network-specific data conversion program reads the data and converts it to an xBase file format with a single record for each measurement. Variable names in these intermediate files differ from those in the official files by designating the unit used for each measurement in the specified network. For example, field name "TA F" indicates ambient temperature in degrees Fahrenheit as found in the NWS database rather than the "TA" field name for ambient temperature in degrees Celsius that is used in the study data files.

The next step converts measurement units to the study's common units specified in LTFLDNAM.DBF. Conversion factors are accessed from a file that maps one unit into another based on the specification of the input and output variable names. In addition to changing units, the conversion program maps times, dates, missing values, and validation flags into the study conventions described above. Conversions are documented by writing two records to a file entitled LTCONVRT.DBF. The first record gives the input file name and input file field names and the following record gives the

output file name and output file field names, thereby documenting the conversions performed.

A data validation log is kept to document all changes made to the data files, including changes in the data validation level. This includes a record of the data changed, the reason for the change, and the date of the change. All data as originally submitted to the database are retained so that changes can be traced back to the original data.

5.4 DATA FILE NAMING CONVENTIONS

Several data files are binary and can be accessed only by specific software packages. The type of file is specified by its three-character extension.

Data file names are coded to indicate the type of data, the network from which they were derived, the measurement period covered, and the averaging time for each measurement. File names follow the pattern "SSDDVPXY", where SS is the network/investigator (data source) code, DD is the data type code, V is the averaging interval code, P is the data collection time period code, and X and Y allow further differentiation by the analyst. For example, ARSMHP.DBF, is the file name for hourly (H) surface meteorological (SM) data taken by Air Resource Specialists, Inc. (AR) for the entire study period (P). Table 25 defines the codes used in this structure, and the full definitions of filenames are contained in the MZFILES.DBF file.

Table 25. Database file naming conventions

Data Source Codes:

AT	AIRS database.
AR	Air Resources Board.
BL	Bureau of Land Management
CI	California Irrigation Management Information Ssystem
FS	US Forest Service.
NO	National Oceanic and Atmos heric Administration.
NW	National Weather Service.
RA	Remote Automated Weather Station (RAWS) network.
MM	Minerals Management Service

Data Type Codes:

SA	Surface Air Quality Data (O ₃ , NO, NO ₂ , NO _x , NO _y , CO, PM)
VC	Surface Canister VOC Data
VO	Surface Continuous GC VOC Data
CB	Surface Cartridge Carbonyl Data
HW	Radar Profiler, High Resolution Wind Speed and Direction Data
LW	Radar Profiler, Low Resolution Wind Speed and Direction Data
PV	Radar Profiler, Virtual Temperature Data
SD	Sodar, High Resolution Wind Speed and Direction Data

RA	Rawinsonde Upper Air Wind Speed, Wind Direction, Temperature, and RH Data
SM	Surface Wind Vane Wind Speed and Wind Direction Data
ST	Surface Temperature and Relative Humidity Data
SN	Surface Sonic Anemometer Wind Speed, Wind Direction, Temperature, and Turbulence Data
SS	Surface Solar Insolation Data

Averaging Interval Codes:

B	6-hour samples
C	12-hour samples
D	24-hour samples
H	Hourly
I	Instantaneous (< 1 min)
M	15 minute samples
P	Partial hour samples (< 60 min)
T	Two Week Sample

5.5 DATA FILE STRUCTURE AND FORMAT CONVENTIONS

Numerical values acquired by field measurement methods are stored in xBase (*.DBF) data formats. This format, though somewhat dated, is almost universally accessible by most commonly used software packages and an infrastructure for handling data in this form has already been established in the CARB's Planning and Technical Support Division. Programs for input, merging, calculations, unit conversions, validation, and output that were created for SARMAP and the California Regional Particulate Air Quality Study can be adapted to this study. Regardless of the data file formats, several conventions must be established that will be the same for all data in the numerical database.

Each record in a data file provides the site code, measurement date, start time, data values, validation level, and individual validation flags. Site codes are consistent with the codes in the LTSITE.DBF file. This allows the site documentation files to interact. For example, simple queries formulated by data management software allow site coordinates to be associated with any variable value for spatial plotting. All times are in Pacific Daylight Time (PDT), even when local times are in different time zones or follow standard time conventions. These times are listed as the beginning of the averaging period with 0000 for midnight of the current date. Where averaging times are variable, a sample duration is included as well as a sample stop time. All missing values are replaced by "-99" and flagged as invalid.

Each record includes a field (VAL) that shows the validation level for that record. The processes used to define the validation level are specified below. The last field in each record (LTFLG) contains the study measurement validation flags. This field contains as many characters as there are data fields preceding the (LTFLG) field, and the position

of the flag corresponds to the sequential position of the field to which it applies. This allows a compact method for identifying and filtering data that are valid, suspect, or invalid.

5.6 DATA AVAILABILITY

Because of the short timeline for providing critical information and guidance to the TMDL process, contractors will provide validated air quality data within three months of collection or laboratory analysis. Validated LTADS data will be available via CARB initially but also via the Tahoe Integrated Information Management System (TIIMS).

6. DATA VALIDATION PLAN

Although good protocols/plans for monitoring site selection, equipment acceptance testing, emission inventory development, quality assurance, and data management contribute to the likelihood of collecting good quality data, a well-defined data validation plan is necessary to facilitate the delivery of data suitable for addressing the issues/questions that necessitated the data collection. Furthermore, a data validation plan will help quantify the quality of the data that were actually collected. As the data are collected and used, they inherently are better understood and invalid or suspect data will be identified. As statistics about the problems observed with the data (e.g., missing, suspect, invalid) are compiled, a characterization and even quantification of the data set quality can be developed. Traditionally, data quality is classified at one of four possible levels depending on the amount of processing and review it has undergone:

- 1) **Level 0** – the data have been collected following standard operating procedures and quality assurance protocols and a crude data screening process has been followed to remove data that are physically impossible (e.g., negative concentrations that exceed any instrument offset or measurement precision estimate). Typically, data that have been collected properly and converted from engineering units (e.g., volts) to air quality units (e.g., parts of pollutant per million parts of air by volume – ppmV) meet Level 0 validation.
- 2) **Level 1** – when the sampled/monitored parameter is summarized (e.g., statistics, tables, graphs) and review has shown the data to be “internally” consistent (e.g., reasonable ranges and rates of change), the data meet Level 1 validation.
- 3) **Level 2** – data that has been reviewed and found to be consistent with other data collected at the same location (e.g., NO concentrations are low when O₃ concentrations are high) meet Level 2 validation.
- 4) **Level 3** – data that have been thoroughly reviewed and found to be consistent spatially and temporally with other data and consistent with the conceptual model of the physical and chemical processes involved (e.g., ozone formation) meet Level 3 validation.

Mueller (1980), Mueller et al., (1983), and Watson et al. (1983, 1989, 1995) define a three-level data validation process that should be mandatory in any environmental measurement study. Data records are designated as having passed these levels by

entries in the VAL column of each data file. These levels, and the validation codes that designate them, are defined as follows:

- Level 0 (0): These data are obtained directly from the data loggers that acquire data in the field. Averaging times represent the minimum intervals recorded by the data logger, which do not necessarily correspond to the averaging periods specified for the database files. Level 0 data have not been edited for instrument downtime, nor have procedural adjustments for baseline and span changes been applied.
- Level 1A (1A): These data have passed several validation that are specific to the network. Specific tests appropriate for each are described elsewhere in this plan. The data quality indicator in the SCSITE.DBF file is a qualitative judgment of how stringent these Level 1A tests are when data from different sources are compared. The general features of Level 1A are: 1) removal of data values and replacement with -99 when monitoring instruments did not function within procedural tolerances; 2) flagging measurements when significant deviations from measurement assumptions have occurred; 3) verifying computer file entries against data sheets; 4) replacement of data from a backup data acquisition system in the event of failure of the primary system; 5) adjustment of measurement values for quantifiable baseline and span or interference biases; and 6) identification, investigation, and flagging of data that are beyond reasonable bounds or that are unrepresentative of the variable being measured (e.g. high light scattering associated with adverse weather).
- Level 1B (1B): After data are received by the data manager, converted, and incorporated into the database, validation at level 1B is performed. This is accomplished by software which flags the following: 1) data which are less than a specified lower bound; 2) data which are greater than a specified upper bound; 3) data which change by greater than a specified amount from one hour to the next; and 4) data values which do not change over a specified period, i.e., constant data. Data identified by these filters are individually examined and verified with the data supplier. Obvious outliers (e.g. high solar radiation at midnight, 300 °C temperature) are invalidated. Others may be invalidated or flagged based on the results of the investigation. The bounds used in these tests are determined by agreement between the project manager and the measurement investigators. If a datum fails one or more of the above tests it is flagged, and corrective action is taken. This action may require re-submission of the data. The tests are performed in the order given above.
- Level 2 (2): Level 2 data validation takes place after data from various measurement methods have been assembled in the master database. Level 2 validation is the first step in data analysis, and the detailed tasks

are specified in Section 3.1. Level 2 tests involve the testing of measurement assumptions, comparisons of collocated measurements, and internal consistency tests.

- Level 3 (3): Level 3 is applied during the model reconciliation process, when the results from different modeling and data analysis approaches are compared with each other and with measurements. The first assumption upon finding a measurement that is inconsistent with physical expectations is that the unusual value is due to a measurement error. If, upon tracing the path of the measurement, nothing unusual is found, the value can be assumed to be a valid result of an environmental cause. The Level 3 designation is applied only to those variables that have undergone this reexamination after the completion of data analysis and modeling. Level 3 validation continues for as long as the database is maintained.

A higher validation level assigned to a data record indicates that those data have gone through, and passed, a greater level of scrutiny than data at a lower level. All data in the Lake Tahoe data set will achieve Level 1B status prior to use in data analysis and modeling. The validation tests passed by Level 1B data are stringent by the standards of most air quality and meteorological networks, and few changes are made in elevating the status of a data record from Level 1B to Level 2. Since some analyses are applied to episodes rather than to all samples, some data records in a file will achieve Level 2 designation while the remaining records will remain at Level 1B. Only a few data records will be designated as Level 3 to identify that they have undergone additional investigation. Data designated as Levels 2 or 3 validations are not necessarily “better” than data designated at Level 1B. The level only signifies that they have undergone additional scrutiny as a result of the tests described above.

7. SCHEDULE

General Timeline:

October 2001 to May 2002

Literature review, data analysis, Homewood site

Proposals, peer review of plan, contracts

August 2002 to July 2003 - Data collection

Late 2003

Data base of air quality and meteorology

Emission inventory

2000 loading and source attribution results

Early 2004

2002 loading and source attribution results using deposition calculations & chemical tracers

Late 2004

2002 loading and source attribution results using air quality model

Early 2005

Peer Review of ARB Report (Cal/EPA)

Task Schedule:

3.2 DATA ANALYSIS TASKS	DEADLINE
Estimate background concentrations (O ₃ , NO, NO ₂ , NO _y , HNO ₃ , PM ₁₀ -NO ₃ , PM _{2.5} -NO ₃) in & around Lake Tahoe Air Basin from historical data	8/02
Analyze historical wind data to confirm likely air parcel trajectories into Lake Tahoe Air Basin and to guide final siting of instrumentation	8/02
Estimate background concentrations (O ₃ , NO, NO ₂ , NO _y , HNO ₃) in & around Lake Tahoe Air Basin from 4-km gridded CCOS modeling runs	9/03
Characterize mobile source fleet in LTAB (e.g., vehicle mix, activity, emission factors, remote sensing)	9/03
Plan, implement, and manage emission inventory contracts needed to develop 1-km grid cell emission inventory (standard inventory plus NH ₃ , geologic P, and wood stove emissions) for Lake Tahoe AB	10/03
3.3 MODELING TASKS	DEADLINE
Quantify source-receptor relationships (e.g., receptor modeling)	8/03
Evaluate performance of 4-km CCOS model runs in LTAB	10/03
Develop air parcel trajectories to identify source-receptor relationships	11/03

Adapt CCOS models to 1-km grid cells in Lake Tahoe Air Basin	11/03
Validate meteorological performance of 1-km gridded Tahoe model	1/04
Incorporate best information into Lake Tahoe model & validate	2/04
Estimate local vs. regional PM, N, & P contributions with models	3/04
Evaluate performance of CRAPQS model runs in LTAB	6/04
3.4 DEPOSITION ESTIMATING TASKS	DEADLINE
Data Analysis Techniques	
Bowen	10/03
Modeling Techniques	
Estimate deposition of N-species from 4-km gridded CCOS modeling runs	10/03
Estimate deposition of P and PM from CRPAQS modeling runs	6/04
Estimate deposition of N-species, P, and PM from 1-km gridded LTAB modeling runs	6/04
Extrapolation Techniques	
Extrapolating episodic/seasonal numbers to annual numbers	11/03
Estimating bounds on annual average deposition	11/03

8. FUNDING AND COST ESTIMATES

The funding sources and the amounts dedicated to LTADS are shown in Table 26. Based on funding through a Budget Change Proposal (\$968,000) and the Extramural Research Fund (\$276,000), CARB is contributing almost \$1.25 million to the study. Additional funds are available from study partners. Based on funds available from all sources, there is a budget of \$1,870,000 total, approximately \$1,020,000 in 2001-2002 and \$850,000 in 2002-2003. Funding above \$1.87 million will permit additional measurements and analyses that will improve the accuracy, comprehensiveness, and confidence in the study results.

Table 26. LTADS funding.

Funding Source	FY2001-2002	FY2002-2003	Total
CARB	\$898,000	\$346,000	\$1,244,000
TRPA	\$92,000	\$50,000	\$142,000
USEPA	\$0	\$339,000	\$339,000
USFS	\$0	\$115,000	\$115,000
Lahontan	\$30,000 ¹		\$30,000
TOTAL	\$1,020,000	\$850,000	\$1,870,000

¹ contract with Tahoe Research Group for lab services (deposition & snow samples)

LTADS cost estimates by project activity/task are listed in Table 27.

Table 27. Estimated study costs by activity/task.

ID No.	Activity / Task	Item	Cost	Cost Certainty	Cost Option
1	General				
1a	3.4.1.1 Ozone and Forest Health in Tahoe Basin		29.945	F	30
1b	3.4.1.2 Characterize historical data				
		IMPROVE data	0		
		[background]s	0		
		aloft	0		
		compare w/ LODs	0		
		trends	0		
		ozone transport	0		
1c	Site preparations				
		Documentation	0		

		Loon Lake	49.9	G	
		Homewood	6	G	
		Cave Rock	0	E	
		TRG Lab	6	E	
		Thunderbird Lodge	4	E	
		Lake Tahoe Airport	7	E	
		Incline Village Waste Treatment Plant	4	E	
		Tahoe City Wetlands Treatment Facility	3	E	
		Sandy Way	0	E	
		Echo Summit	0	E	
1d	<i>Site maintenance</i>				
		Homewood/Loon Lake	0		
		LF, SLT-SW, Cave Rock, Echo Summit	0		
		SLT-SOLA, Thunderbird Lodge	0		
1e	3.4.1.3 Support equipment				
		Calibration gases	10	G	
		Calibrator	13.469	F	
		data loggers (2)	15.566	F	
		stripchart recorder	4.624	F	
		zero air system	7.599	F	
2	Deposition Related Measurements				
2a	3.4.1.4 Deposition bucket measurements				
		equipment	10	E	
		personnel	0		
		lab analysis	30		
2b	3.4.1.5 Snowpack measurements of N&P				
		sampling	5	G	
		lab analysis	0	F	
2c	<i>Eddy-Covariance analysis of heat, hum, chem species</i>			F	0
2d	3.4.1.6 Tracer observation of PM deposition			G	33
3	Emission Inventory Improvement				

3a	3.4.1.7 Tahoe-specific Source Characterization			
	wood-burning, neighborhood sampling, prescribed fires, MV activity	89.972	F	
	wood smoke sampling, fugitive dust (N&S soils, sanding, paved/unpaved road)	120.489	F	
	motor vehicle emissions	incl		
	MV remote sensing	0		
	Traffic counts	0		
	gridded emissions	0		
3b	<i>daily heating demand model</i>	0		
4	Meteorological Measurements			
4a	<i>surface met</i>			
	10' towers w/ the 4 sodars + Homewood	25.77	E	
4b	<i>low-level winds</i>			
	4 mini-sodars	223.377	F	
	QA & maintenance	85	E	
4c	<i>mid-level winds & temps</i>			
	RWS/RASS	76.0	F	
	RWS/RASS relocation		E	10
4d	<i>remote sensing - siting review, DM, & QC</i>	27.833	F	
4e	<i>in-situ met & AQ aloft w/ Cessna 182</i>	133.382	F	
4f	<i>in-situ low-level T & RH w/ tethersonde</i>		E	48
5	Air Quality Measurements			
5a	3.4.1.8 Two-Week-Sampler			
	construction (6)	21.289	E	
	flowmeters/denuders/impactors	17.345	F	
	denuder gaskets/mask filters to 29mm	1.462	F	
	operation	2.8		
	lab analysis	263.02	F	
	S&H	2.716	E	
5b	<i>NOy instruments (3)</i>			
	prep/training	10	E	
	parts replaced	4.758	E	
	calibrators & cal gases	0	E	
	operation	0	E	
5c	<i>N species with Laser Induced Fluorescence</i>	175.036	F	
5d	3.4.1.9 14 BAMs - 5 @ PM2.5 & PM10; 4			

	@ TSP			
		purchase	213.856	F
		shelters (5)	5.819	F
5e	3 hi resolution CO analyzers (API300)		25.87	F
5f	continuous nitrate analyzer		0	
5g	10 mini-vols @ Mid-Lake & source sampling		22.854	F
5h	2 ozone analyzers & support equipment		15.233	E
5i	3 nephelometers (MetOne ES-640)		17	E
5j	particle size counter (Particle Measuring Systems)		15	E
5k	hi-res particle sizing counter (TSI 3321)			E 40
5l	TRG support		32	E
5m	passive sampling @ 3 sites			
		O ₃		10
		NH ₃		5
6	Modeling			
6a	3.4.1.10 COS runs		0	
6b	CRPAQS runs		0	
6c	adaptation w/ 1-km grids in Tahoe Basin		0	
6d	LTAB-specific runs		0	
6e	CMB runs		0	
7	Field contingency fund		36	G
8	Quality Assurance			G 50
9	Data Management			G 50
10	3.4.1.10.1 Study data analysis for source attribution			
		trajectories	0	
		AQ & met analysis	0	
		deposition calculations	0	
		GIS	0	
		report	0	
11	Cal/EPA Peer Review			80

		Total:	1869.984		346
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