# 1. Background

## 1.1 Context

Lake Tahoe is a beautiful lake ringed by mountains. The lake surface covers 191 square miles (501 square kilometers) and is at an elevation of 6225 feet (1886 meters) MSL. The average water depth is 1000 feet and the maximum depth is 1645 feet, making it the 2$^{nd}$ deepest lake in the U.S. and the 10$^{th}$ 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. At one time, 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 flowing in subsurface water toward the streams and eventually the Lake.

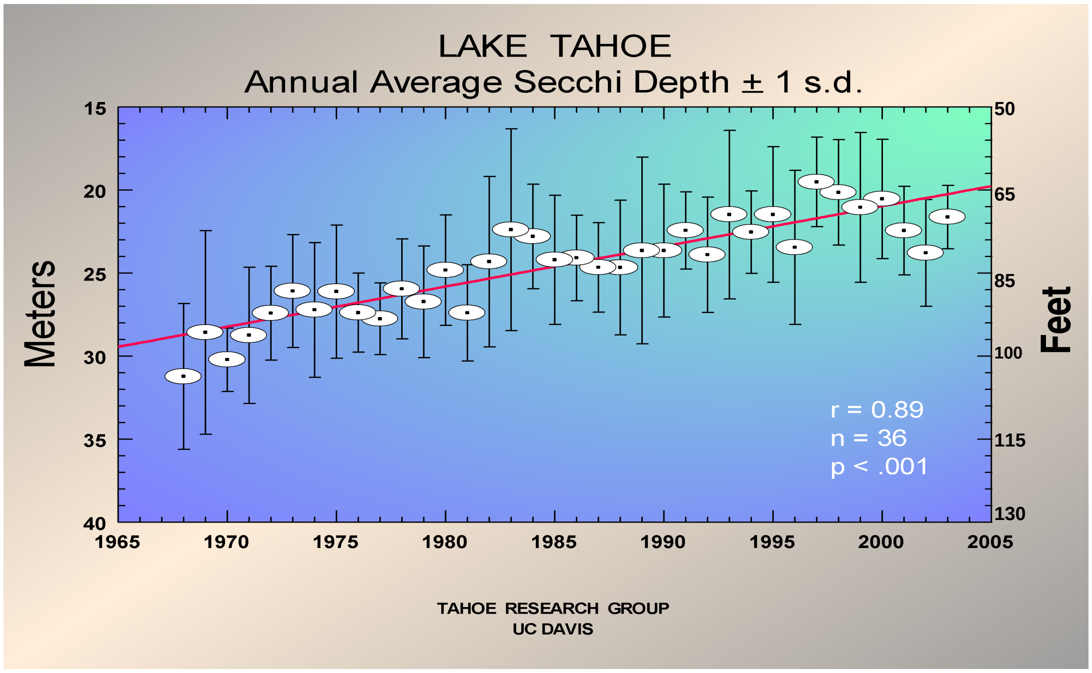
However, the water clarity of this once pristine lake has been declining (see **Figure 1-1**). Between the mid-1960s and the mid-1990s, the water clarity decreased from 100 feet to 65 feet, a decrease averaging over one foot per year. Data for recent years suggest an improvement but additional study is needed to clearly understand the factors impacting water clarity and to ensure environmental thresholds are attained.

Biologically accessible forms of phosphorus (P) and nitrogen (N) contribute to algal growth, which is a major factor in the decline of water clarity in most bodies of water. The sources of these nutrients entering Lake Tahoe are not easily differentiated and the amounts entering via air or water are not well quantified. Water runoff containing fertilizers, seepage of contaminated groundwater into the Lake, and direct atmospheric deposition are all likely contributors to the phosphorus and nitrogen loading of Lake Tahoe. Estimates prior to LTADS indicated that about half of the total N loading and one-quarter of the P loading to the Lake enters via atmospheric deposition (**Table 1-1**). Note however, that the table does not indicate the relative certainty of the individual estimates or of the total loading. Thus, there are no reported error bounds on the percentages assigned to the various media and sources.

More recently, the Tahoe Research Group (TRG), which has studied Lake Tahoe during the last five decades, also identified insoluble (inert) particles as a significant year-round contributor to the reduced water clarity of Lake Tahoe. Because of the growing concern about the potential impact of particles, LTADS featured a diverse and comprehensive measurement program related to the atmospheric deposition of particles in addition to nutrients.

Likely atmospheric sources of PM and nutrients (N and P) include smoke from planned and unplanned vegetative fires, wood stoves, and fireplaces; vehicle exhaust, roadway dust (e.g., dirt, sanding material), and potential transport from global and regional sources (e.g., Asian dust, ammonia and fine particles from the Central Valley). These emissions may be in the form of PM or gases that deposit directly to the Lake or gases that convert to PM in the atmosphere and then deposit.

**Figure 1-1.** Lake Tahoe Water Clarity Trend.




The California Air Resources Board (CARB) is collaborating with the Tahoe Regional Planning Agency (TRPA), the US Department of Agriculture Forest Service (USFS), the US Environmental Protection Agency (USEPA – Region IX) to support the Lahontan Regional Water Quality Control Board (LRWQCB) and the Nevada Division of Environmental Protection (NDEP) in the development of the Lake Tahoe Nutrient and Sediment Total Maximum Daily Load (TMDL). The CARB effort focused on the contribution of dry atmospheric deposition directly to the Lake to the total loading of nutrients and sediments to Lake Tahoe. The atmospheric nutrients can be deposited as gases, aerosols, or soluble ions in rain and snow. The particles by definition are deposited as aerosols but many particles include ionic salts that dissolve when in contact with water. A goal of LTADS was to address the relative contribution of local (within basin) and regional (transport into the basin) sources of nutrients and PM. A watershed analysis (separate from LTADS) will provide information on the atmospheric deposition to the Lake Tahoe watershed where runoff from rain storms and snow melt contribute to the total atmospheric contribution of the nutrients and PM loading to the Lake. CARB staff developed a research plan, which was reviewed by experts in the University of California, to address, within the constraints imposed by the regulatory timeline and the funding available, the informational needs in the Basin.

**Table 1-1.** Pre-LTADS matrix of annual nutrient loading to Lake Tahoe (metric tons).

| INPUTS | NITROGEN | PHOSPHORUS |
|---|---|---|
| Atmospheric Deposition | 234 (56%) | 12 (26%) |
| Stream Loading | 82 (19%) | 13 (28%) |
| Direct Runoff | 42 (10%) | 16 (33%) |
| Groundwater | 60 (14%) | 4 (8%) |
| Shoreline Erosion | 2 (<1%) | 2 (4%) |
| **TOTAL** | 419 (100%) | 47 (100%) |

**Source:** Murphy and Knopp (2000)
**Note:** The LTADS analysis summarized in this report results in the following updated central estimates for atmospheric deposition of N & P: 185 and 6 metric tons, respectively, or approximately 30% and 50% lower than the earlier estimates based on surrogate surface samplers. The LTADS direct deposition estimates have uncertainties characterized by upper and lower bounding assumptions. The lower and upper bounds of deposition are 100 to 320 metric tons for N and 2 to 12 metric tons for P. The revised percent contribution by atmospheric deposition will depend on how the inputs from the other pathways change due to the recent research.

The specific informational needs of the LRWQCB and NDEP for the TMDL (and related information needed for the TRPA 20-year Environmental Improvement Program plan update) addressed by this report are: 1) improved estimates of the annual and seasonal loading of phosphorus, nitrogen, and particulate matter from atmospheric deposition directly to Lake Tahoe (including confidence levels), 2) improved attribution of the in-basin and out-of-basin contributions of these materials, and 3) assessment of the effect of ozone concentrations on forest health.

The air quality improvement that has occurred in the Tahoe basin during the last two decades is summarized in **Table 1-2**. As shown, CO concentrations have declined over 80%, NOx concentrations have declined about 25%, and PM10 concentrations have declined over 30%. Ozone concentrations have remained steady near the California ambient air quality standards for ozone.

**Table 1-2.** Maximum ambient air quality concentrations observed in the Lake Tahoe Air Basin (1980 – 2000).

| **Pollutant (avg. period, units)** | **1980** | **2000** | **$\Delta$ (%)** |
|---|---|---|---|
| CO (8-hr, ppm) | 13.7 | 2.1 | -85 |
| $O_3$ (1-hr, ppm) | 0.089 | 0.089 | 0 |
| $O_3$ (8-hr, ppm) | 0.080 | 0.079 | -1 |
| $NO_2$ (1-hr, ppm) | 0.077 | 0.058 | -25 |
| $NO_2$ (annual, ppm) | 0.015 | 0.011 | -27 |
| PM10 (24-hr, $\mu g/m^3$) | 95 | 50 | -47 |
| PM10 (annual, $\mu g/m^3$) | 26.0 | 17.6 | -32 |

## 1.2 Total Maximum Daily Load Concept for Water Clarity

The LRWQCB and NDEP are working together to develop the Lake Tahoe Nutrients and Sediment TMDL to protect and restore the water clarity of Lake Tahoe (see index of activities - http://www.swrcb.ca.gov/rwqcb6/TMDL/Tahoe/Tahoe_Index.htm). A TMDL, or Total Maximum Daily Load, 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.

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 almost 700 water bodies on this list; almost 100 of these are in the Lahontan region.
2. Establishes “Priority Waters and Watersheds”. Lake Tahoe is considered a Priority Watershed.
3. Outlines a plan to achieve 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.

**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 U.S. EPA.

The Lake Tahoe Nutrients and Sediment 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 LTADS report supports the development of the Tahoe TMDL program by addressing critical informational needs regarding direct atmospheric deposition to Lake Tahoe.

## 1.3 Atmospheric 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 most useful, the estimates must be accompanied by a measure 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, season, and likely year.

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 it's 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 much more difficult to measure directly. Quantification 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. Convergence of the results from different approaches provides 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/m$^2$/second. The deposition rate of a specific substance divided by its atmospheric concentration is simply the deposition rate normalized for concentration. Because the deposition rate divided by concentration has units of velocity (distance/time; e.g., m/sec) it is known as the deposition velocity. The deposition velocity depends on the substance of interest in the atmosphere and the underlying surface. In addition the deposition velocity usually depends strongly on the meteorological conditions.

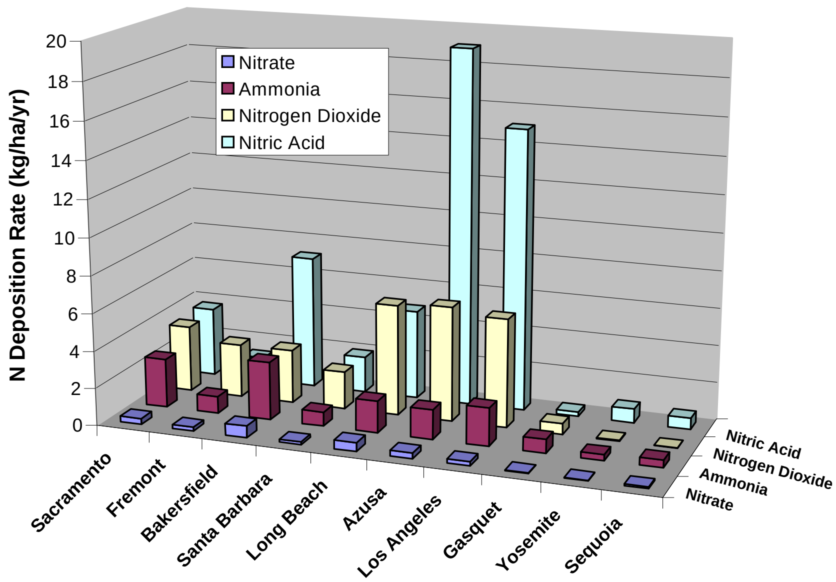
When considering larger particles of specified size and density we also calculate a settling velocity, which is the rate of fall for that particle resulting from the balance between frictional and gravitational forces. Although deposition and settling velocities may share common units (e.g., cm/second) a clear distinction should be made between these two terms. Deposition velocity and settling velocity are generally not equivalent nor are they physically analogous. Deposition rates and deposition velocities change with time and location because they depend strongly on many environmental factors, including the efficiency of the surface for removal of the substance of interest and the degree of meteorological mixing that either permits or denies surface contact for air originating from a particular height above ground level. Settling velocity however, is relatively insensitive to environmental conditions, depending mainly on particle size and the density difference between the particle and the air.

Observation (direct measurement) of deposition (and parameters used to estimate deposition) requires considerable 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 during periods of onshore wind direction (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 velocities are highly variable with meteorological conditions and thus they will vary with time of day as do concentrations of most chemical species of interest. For that reason, concentrations and meteorological parameters used to estimate deposition rates were measured or estimated on an hourly basis to the extent possible. The Lake itself provides some benefits to the calculations because it provides 1) a long upwind and spatially homogeneous fetch, and 2) well-defined surface temperatures for contrast with hourly air temperatures in the estimation of atmospheric stability.

The California Acid Deposition Monitoring Program (Watson et al., 1991) provided deposition estimates for a variety of locations in California (Blanchard et al., 1996). A summary of dry deposition estimates of selected nitrogenous species during 1988-1992 is shown in **Figure 1-2**. The results for Yosemite and Sequoia were anticipated to be 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 **Figure 1-2**). The LTADS results indicate that ammonia ($NH_3$) is the major nitrogen source in the Tahoe Basin.

**Figure 1-2.** Annual Dry Deposition Rates of Major Nitrogenous Species in California. (1988-1993)
(based on *Blanchard et al.*, 1996)




## 1.4 LTADS Objectives

The primary goal of the Lake Tahoe Atmospheric Deposition Study (LTADS) was to quantify the atmospheric dry deposition of substances thought to be significant to declining water clarity of Lake Tahoe. The LTADS focus was on direct deposition to Lake Tahoe. Because the Lake Tahoe occupies a large portion (~60%) of the watershed, the soils are nutrient deficient, and much of the precipitation falls as snow (slow runoff), it is anticipated that direct deposition predominates over the indirect deposition of material. The LTADS measurements made to support quantification of dry deposition included observations of ambient concentrations of particles and gases having water clarity implications in the air near and over the Lake and environmental variables needed for calculating the temporally and spatially resolved deposition velocities for these substances to the Lake. Because the prior estimates of wet and dry deposition with surrogate surfaces did not include particulate matter, which is a significant water clarity concern, staff used data collected during LTADS and a simple conceptual model to estimate direct wet deposition to Lake Tahoe. This enabled quantification of total PM (also sized in 3 bins) deposition directly to Lake Tahoe. The reader is reminded that deposition estimates via models or surrogate surfaces have significant uncertainties and unknowns that mean even the best deposition estimates probably have a precision no better than about 50%.

A secondary goal was to provide qualitative information on the major sources of emissions influencing pollutant concentrations in the air and subsequent atmospheric deposition. Identification and characterization of sources of atmospheric deposition required using additional types of information and inferences beyond those solely needed to quantify deposition. The data analysis process for source identification and source characterization is recursive – the historical data establish a regional-decadal context and portray a conceptual image of the major sources and processes controlling deposition to Lake Tahoe. Building on this historical resource, the LTADS data (both routine and special measurements) refined the understanding of the spatial and temporal dynamics of atmospheric processes influencing air quality near and within the Tahoe basin.

The challenge for LTADS was to balance available resources and multiple time sensitive regulatory informational needs of TRPA and LRWQCB with respect to air quality and atmospheric deposition of phosphorus, nitrogen, and particulate matter to Lake Tahoe. After quantification of deposition of these materials, the foremost general need was for analyses of the meteorological and air quality measurements useful for better understanding the atmospheric processes at work in the Tahoe Basin and estimating the contributions to the N, P, and PM deposition in the LTAB from local sources relative to the regional and global sources creating background concentrations.

The general objectives were:

1. To reach a technical consensus on the monitoring/sampling methods sufficient and necessary to meet the foremost informational needs within the constraints of available resources and the schedules (determined by regulatory timelines) for use of the results by TRPA and the LRWQCB.

2. To represent conditions under all seasons by enhancing the monitoring/sampling network for at least a one-year study period and to do so in a manner that would enable scientists to collect and analyze the appropriate emissions, meteorological, and air quality data to meet the following priorities:
    - Quantify deposition of N, P, and PM to Lake Tahoe at least seasonally,
    - Qualitatively refine out-of-basin and in-basin contributions to the seasonal loading, and
    - Qualitatively identify and characterize the source categories; and

3. To assess forest damage possibly related to air quality (i.e., ozone and nitric acid).

The specific approaches taken to implement the strategies evolved in the context of new information regarding specific needs, limitations, and resources. There is always tension between an ideal approach with unlimited time and resources and the prioritization and sacrifices necessitated by fiscal and staffing constraints. However, in the case of LTADS the schedule was a major constraint. A phased approach to monitoring and analysis that would sequentially address the priorities listed above was not feasible because neither the funding mechanisms nor the schedule of regulatory informational needs would support a lengthy program.

## 1.5 LTADS Design and Rationale

Although the regulatory program is called a total maximum daily loading plan, the cumulative annual (not the daily) loading of the Lake is thought to control the trend of water clarity in Lake Tahoe. Thus, improved estimates of the annual atmospheric deposition were requested of LTADS for input into the lake clarity and watershed models used to estimate the effects of the various emission sources on Lake. A difficulty with developing annual and seasonal loading estimates is that potentially significant emissions sources do not contribute in a constant or uniform manner, either spatially or temporally. Furthermore, meteorological conditions that affect the deposition of these emissions are not constant. Thus, an episodic field study to characterize deposition would be fraught with uncertainties about the representativeness of the specific episodes studied and how that information can be applied to generate an annual estimate.

Ideally, to address the deposition issues, one would prefer hourly-resolved air quality and meteorological data because the emission sources and meteorological conditions vary seasonally and diurnally. However, representing the chemical nature and sizes of particles with both spatial and temporal resolution sufficient to represent individual source types, physical and chemical transformation of the material, and meteorological redistribution for an annual study would be extremely expensive and even with funding would not be logistically feasible because of limitations in instrumentation and laboratory analytical capabilities. In addition, the generally clean air in the Tahoe Basin challenges the detection limits of many monitoring/sampling methods. The combination of low concentrations, harsh sampling conditions (e.g., wind, snow, cold temperatures) and the desire for fine temporal resolution created a unique field study challenge in the Tahoe Basin.

To address the particulate data needs, the CARB strategy was 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., 1998; Motallebi et al., 2003). The TWS can continuously collect PM samples in three size ranges (PM2.5, 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. By using a two-week-sampler, ARB sacrificed temporal resolution of concentrations for the sake of collecting samples characterizing an entire year and avoided the problems associated with episodic sampling, while staying within budgetary constraints for laboratory analyses.

One difficulty associated with the use of the TWS was its relatively low flow rate of about 1.3 liters/minute, requiring relatively strict tolerances on flow rate to avoid invalidation of samples. Icing or heavy loading of particles on the filter could restrict air flow and thereby invalidate a sampling period. Given the relatively pristine air quality at Lake Tahoe except during periods of local stagnation, heavy loading would rarely be a problem. However, on the other extreme, at times sufficient mass might not be collected to ensure detection or quantification of some elements/compounds. This was a problem for some species, including phosphorus, during LTADS.

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 refine the TWS measurements temporally, collocated continuous Beta Attenuation Monitors (BAM) provided hourly total mass measurements of PM2.5, PM10, and TSP at multiple sites. Site-specific hourly BAM measurements were averaged over each season to provide a seasonal diurnal mass profile. Assuming the relative mix of emission sources does not change significantly during the two-week period, the chemical species can be prorated using the diurnal profiles 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.

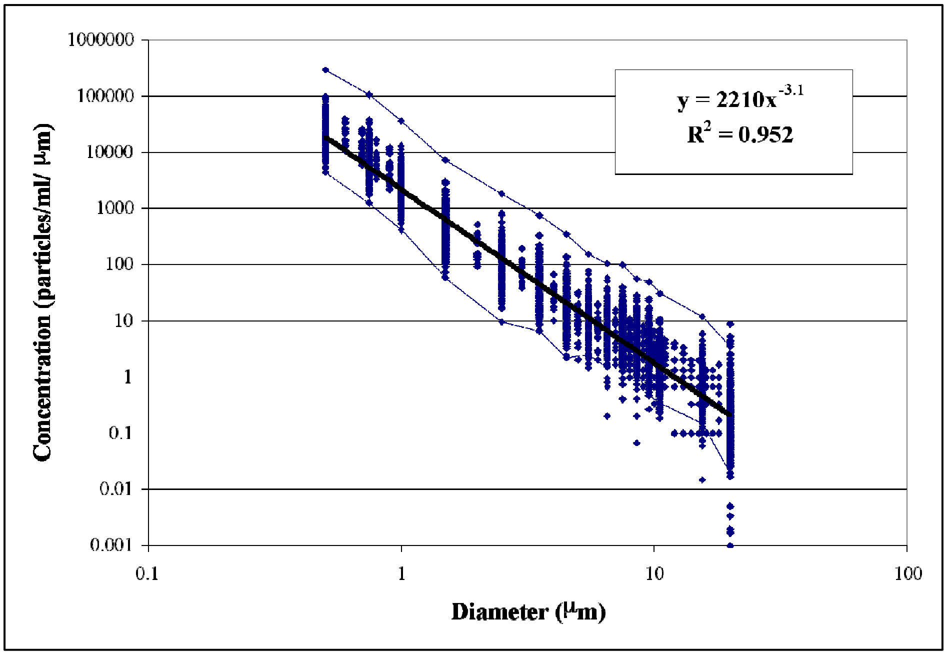
Time-and size-resolved ambient concentrations are combined with continuous meteorological data to refine estimates of the temporal variations in deposition amounts and origins. In addition to surface meteorological sites, three mini-sodar sites were located around the Lake to enable refined estimates 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 helped characterize the composition and frequency of air being transported to the Tahoe Basin. Measurements on buoys, piers, and a research vessel on the Lake helped characterize horizontal variations in conditions on the Lake.

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. Particles are important because they can scatter and absorb light in addition to serving as surfaces for algae to attach to. The exact nature of the particles has implications concerning the potential impacts. For example, the larger particles (e.g., diameters > 10 μm) are important because of their large mass and light absorption characteristics. However, the smaller particles (e.g., diameters < 1 μm) are also of interest because of their light scattering characteristics. Furthermore, the physical structure of the particle can be important. Once an atmospheric particle is deposited to a water surface, a number of significant transformations can occur that affect the light scattering and absorption characteristics of the original particle. For example, the original particles could disintegrate into smaller particles when deposited in the water, they could aggregate together and grow in size via various physical and biological processes, they could dissolve, they could undergo chemical transformations, they could be eaten, etc. Clearly, the particle size distribution in the air could be very different from the size distribution of the same particles once they have entered the water and begin transformations. 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, LTADS included experiments with optical particle sizing counters to characterize the spatial variations in particle numbers and sizes near sources. In addition, a particle sizing counter was installed on a boat (during winter) to provide critical information on the horizontal variations in particle counts and sizes. **Figure 1-3** provides an example of the particle size distributions observed in air and in the water of Lake Tahoe. The number of particles in water is roughly 10,000 times greater than the same size particle in air for particles less than 1 micron. This ratio of the number of particles in water to the number of particles in air decreases to about 1500 for particle diameters of 5 microns, to about 150 for particle diameters of 10 microns, to about 100 for particle diameters of 20 microns. The greater ratio of particle counts in water to air, especially for the smaller particles could be due to a combination of longer residence time in water than air (slower deposition rate in a thicker fluid), the breaking of aerosols into smaller particles as ionic bonds holding particles together dissolve in water, and additional sources of particles (e.g., runoff, turbulent resuspension by waves).

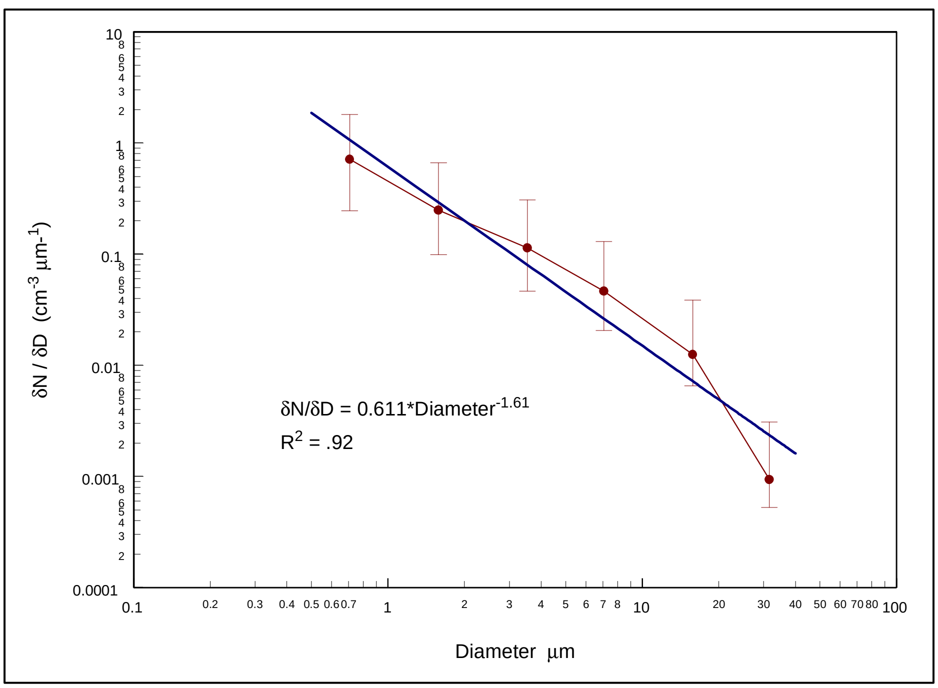
Analyses by TRG staff indicate that algal growth in Lake Tahoe was N-limited initially but that it has become P-limited in the last decade or two. It remains important though to understand the atmospheric nitrogen balance in case nitrogen again becomes the limiting nutrient. Knowing the N-balance is also an important tool for validating any airshed model performance to ensure it is getting reasonable results for the correct reasons. To this end, ammonia, nitric acid, organic nitrogenous compounds, and nitrates were significant components of the field measurement program. A laser-induced-fluorescence instrument for nitrogen dioxide, nitric acid, and organic nitrates as well as a continuous nitrate analyzer operated at the site upwind of the Basin. In addition, an instrument measuring oxides of nitrogen ($NO_X$) or total reactive oxides of nitrogen ($NO_Y$) was operated at most sites. Lastly, in addition to PM2.5, PM10, and TSP measures of N and $NO_3^-$, the TWSs were equipped with denuders to provide measurements of ammonia and nitric acid 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 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 to the Lake. To this end, the existing meteorological network was 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 were critical for understanding the dynamics of the air flow over the Sierra and mixing with the air inside the Tahoe Basin.

**Figure 1-3.** Particle size distributions observed in the air and water in the Tahoe Basin
Note that the units of the Y-axis are in terms of the number of particles per cubic centimeter (air unit) or milliliter (water unit), which are equivalent, per micron of diameter size (µm).




*Mid-lake water particle counts during 1999-2000* (Source: TRG)




*LTADS air particle counts at SOLA for September 2-9, 2003*

### 1.5.1 Overview of Monitoring Network

The monitoring network was designed to provide information on the spatial variations in the ambient concentrations of pollutants around the Lake and upwind of the Basin. The sites allow characterization of the spatial variations in local air quality due to variations in local emissions and meteorological conditions but also potentially the impact due to transport from emissions sources upwind of the Basin. The monitoring network needed to be sufficiently comprehensive to characterize the major source categories of N, P, and PM and the predominant meteorological processes. The unique setting of the Tahoe Basin created additional challenges compared to typical field studies conducted by the ARB. For example, the number of potential monitoring sites is greatly reduced by the limited number of facilities in many areas, limited access to power and phone lines, restrictions on site access and use by land owners, an extensive pine forest that causes many sites not to meet air quality monitoring guidelines, harsh winter conditions that potentially adversely impact instrument performance, power supply, ease of servicing the equipment, etc. Many of the monitoring sites do not fully meet the U.S. EPA criteria for siting equipment to be representative of neighborhood conditions but are the best options possible. In several cases, staff went to great efforts and costs to establish reasonable monitoring sites.

The air quality and aloft meteorological monitoring networks are summarized in **Tables 1-3 and 1-4**, respectively. Most of the air quality sites also had meteorological monitoring equipment. The locations of the monitoring sites are identified in **Figure 1-4**. The study "cornerstone" sites (Big Hill, South Lake Tahoe – Sandy Way, Lake Forest, and Thunderbird Lodge) were those collecting the two-week-samples, and are shown in bold type in the figure. They are also located near the mini-sodar sites characterizing low level air movements. 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 network of three mini-sodars, was distributed around the Lake.

Additional intermittent monitoring, including particle counters, was conducted with aircraft, boat, and ground-based studies to provide more information regarding spatial variations in ambient conditions. The aircraft flights occurred primarily during summer and fall 2002 while the UCD boat trips were conducted primarily during early 2003. Each of these intermittent monitoring episodes (4-5 during each season) consisted of two days, each with morning and afternoon sampling. The aircraft flight plan called for sampling during the transits between Davis and Lake Tahoe (beginning of first day and end of second day), spirals over the Sierra Nevada in the general vicinity of Big Hill and over Lake Tahoe itself, and horizontal orbits at ~600' and 1600' above lake level.

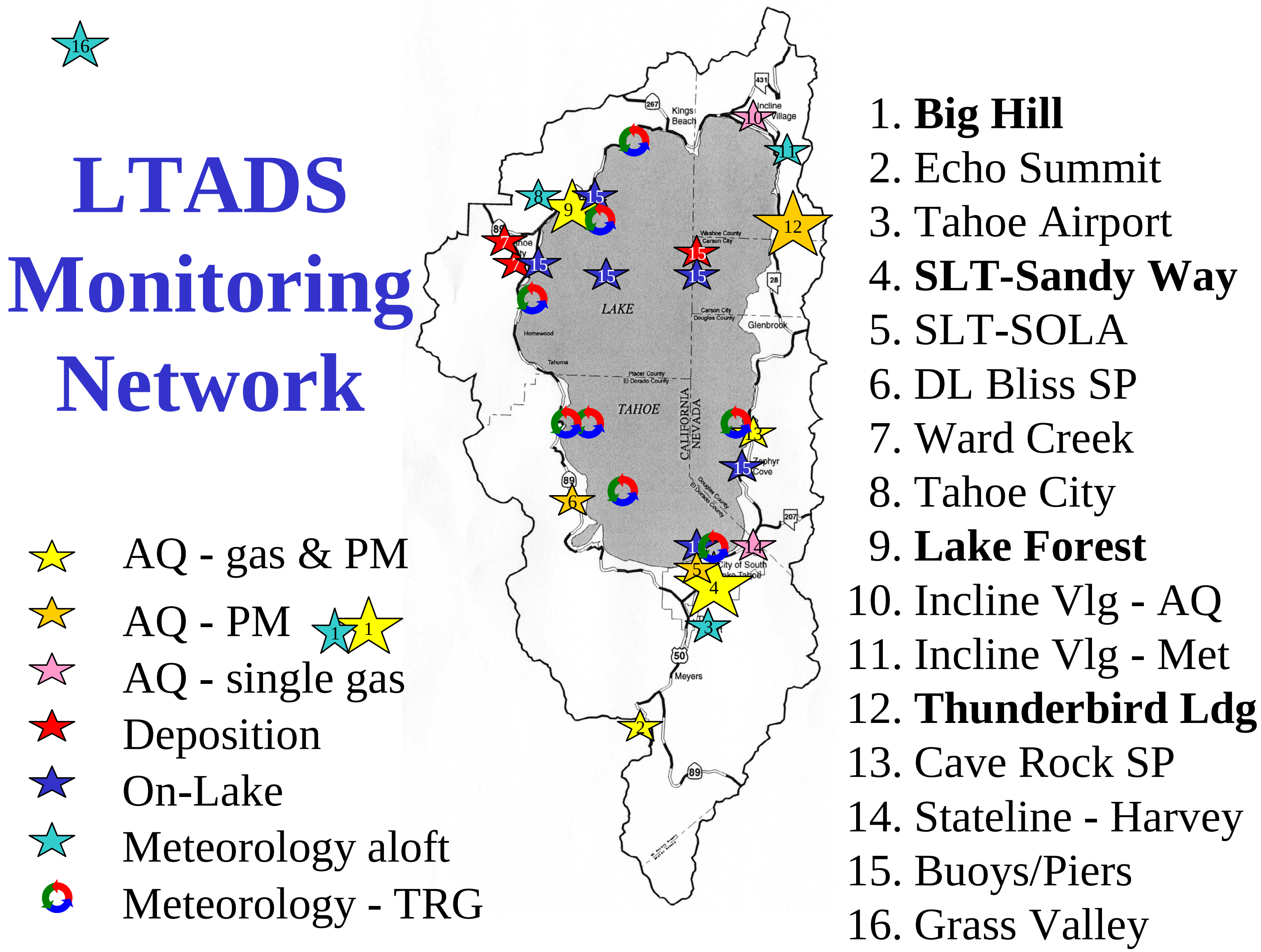
The network of air quality monitoring/sampling stations also represented different categories of sources and provides spatial coverage. Because deposition of material into the Lake was the primary focus of the study, particulate monitoring sites are distributed around the edge of the Lake to capture the full impact of materials that could be advected over the Lake. The three "super" monitoring sites established around the Lake were: 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 limited air quality sampling to occasional PM sampling on two buoys.

Although an existing monitoring station was in operation near the Sierra crest at Echo Summit to document any pollutants being transported up the Sierra and into the Tahoe Basin, it was also exposed to local influences (i.e. idling trucks and equipment). An effort was made to reduce the local impacts by raising the sampling inlet. However, another monitoring site in a more pristine and better exposed location (representing general air flow into the Sierra Nevada) was needed to investigate the amount and frequency of significant transport up the Sierra slopes. To meet that need, a transport site was established on Big Hill (elevation 6200’) about 30 miles west-southwest of Lake Tahoe. This isolated hilltop location 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 included a mini-sodar to better characterize the depth of the airflow up the Sierra slope toward the Sierra crest.

Because the long-term record of dry deposition data at Tahoe is based on an non-validated method, CARB staff conducted a 4-way dry deposition method comparison experiment in Sacramento. Staff collocated two traditional wet/dry deposition samplers (one with water (standard TRG method) and one without (standard acid deposition method)) and a snow tube bulk deposition sampler with a water surface dry deposition sampler (WSS) designed to minimize the disturbance of the air flowing over the sampler. The WSS design was used in the Lake Michigan Ozone Study (Yi, 1997). It was hoped that a comparison of data from the four dry deposition sampling methods would 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.

The text in the following sub-sections focuses on modifications to existing monitoring sites and the set-up of new monitoring sites.

**Figure 1-4.** Air Quality & Meteorology Aloft Monitoring Network. The four "cornerstone" sites of LTADS are shown in bold type.



## **Table 1-3.** Monitoring Matrix

**LAKE TAHOE ATMOSPHERIC DEPOSITION STUDY MEASUREMENTS - Air Quality & Surface Meteorology**

| Region: | | Regional | | In-Basin | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Location relative to Lake Tahoe: | | SW | SW | S | S | S | W | W | NW | NW | NW | | N | NE | E | SE | SE | L | L-N | L-S | L-N | L-N |
| | | | | | | | | | | | Lake Forest | | | | | | | | | | | |
| Parameter | Equipment | Big Hill - Sierra slope | Echo Summit - SN crest | SLT - Sandy Way | SOLA - beach | Timber Cove Pier | DL Bliss SP - IMPROVE | Rubicon Bay | Ward Crk (3)- Hi/Lo/Pier | Tahoe City | TRG lab | CG Pier | Incline Village | Thunderbird Lodge | Cave Rock | Zephyr Cove Pier | Harvey's | Plane (summer,fall) Boat (winter,spring) | Boat North (Kings Beach/Tahoe | Boat South (Tahoe City/ Zephyr Cove/Camp | Mid-Lake buoy TB4 (off Dollar Point) | Mid-Lake buoy TB1 (off Nevada Stateline) |
| CO | Dasibi 3008 | | | * | | | | | | | | | | | | | * | | | | | |
| | API 300 | * | | | | | | | | | * | | | | | | | | | | | |
| | API 300 (NV) | | * | | | | | | | | | | | | | | | | | | | |
| $O_3$ | API Model 400 | * | * | * | | | | | | | * | | * | | * | | | I | | I | | |
| $NO_X$ | TECO 42 | | * | * | | | | | | | | | | | | | | | | | | |
| $NO_Y$ | TECO 42CY | * | | * | | | | | | | * | | | | | | | I | I | I | | |
| $NO_2$ | Laser Induced Fluorescence | * | | | | | | | | | | | | | | | | | | | | |
| Nitric Acid | Laser Induced Fluorescence; denuder (on plane) | * | | | | | | | | | | | | | | | | I | | | | |
| Total Org. Nitrates | Laser Induced Fluorescence | * | | | | | | | | | | | | | | | | | | | | |
| TWS (PM2.5, PM10, TSP; HNO3; NH3) (spec) | filters; denuders | * | | * | * | | | | | | * | | | * | | | | | | | | |
| PM2.5 filter | R&P FRM | | | * | | | | | | | | | | | | | | | | | | |
| PM10 filter | Anderson SSI | | * | * | | | | | | | | | | | | | | | | | | |
| TSP filter (spec) | mini-vol | | | | W I | W I | W I | | W I[1] | | | W I | | | | W I | | | | | D I | D I |
| IMPROVE filter (spec) | PM2.5 species; PM10 mass only | | | | * | | * | | | | | | | * | | | | | | | | |
| PM2.5 Continuous | Met One BAM2.5 | * | | * | | | | | | | * | | | * | | | | | | | | |
| PM10 Continuous | Met One BAM10 | * | | * | | | | | | | * | | | * | | | | | | | | |
| TSP Continuous | Met One BAM w/o head | | | * | * | | | | | | * | | | * | * | | | | | | | |
| Particle Counter[2] | Climet CI-500 | | | | S | S | S | | | | | | | | | S | | I | S | S | | |
| Nephelometer | Met One CS-840 | | * | | * | | | | | | | | | * | | | | | | | | |
| Deposition[3] (w/d/b) | wet bucket; TRG modified dry bucket; TRG bulk tube | | | | | | | | b w/d | | | | | | | | | | | | b | b |
| Atmospheric Resistance[4] | | | | | | | | * | | * | | | | * | | * | | | | | | |
| Wind Speed | | * | * | * | * | * | * | | | | * | * | | * | * | | | | | | * | * |
| Wind Direction | | * | * | * | * | * | * | | | | * | * | | * | * | | | | | | * | * |
| Temperature | | * | * | * | * | * | * | | | | * | * | | * | * | | | | * | * | * | * |
| Water Temperature | | | | | | | | | | | | | | | | | | | | | * | * |
| Relative Humidity | | * | * | * | * | * | * | | | | * | * | | * | | | | | * | * | | |
| Solar Radiation | | | | * | | | * | | | | | * | | * | * | | | | | | | |
| Net Radiation | | | | | | | | | | | | | | | | | | | | | * | * |
| Pressure | | | * | * | | | * | | | | | | | * | * | | | I | | | * | * |

**Notes:**

Deposition is assessed through understanding of ambient concentrations, deposition velocity, size distribution, and time resolution:

shaded cell = no measurement

* = data were collected routinely

shaded parameter cell = included speciated analysis of aerosol filter

spec = aerosol speciation: X Ray Fluorescence, Ion Chromatography, Colorimetry, Flame Ionization Detection for elemental & organic carbon

I = intermittent sampling

D = 24-hour sampling

S = short-term special study

W = weekly sampling

[1] 2 sites on Wallis Residence (deposition platform & pier)

[2] multiple optical particle counters were used in studies associated with these sites and additional locations. Contact Research Division staff for details.

[3] various samplers (NADP dry, TRG dry, TRG snow tube, & water surface sampler) were used in a dry dep. methods comparison study in Sacramento

[4] atmospheric resistance is related to deposition velocity & collected through flux measurements by Professor Gayle Dana of DRI

**Table 1-4.** List of Meteorology Aloft Measured during LTADS

| LAKE TAHOE ATMOSPHERIC DEPOSITION STUDY MEASUREMENTS - Meteorology Aloft | | | | | |
|---|---|---|---|---|---|
| **Region:** | **Up-Basin** | | **In-Basin** | | |
| **Location relative to Lake Tahoe:** | **NW** | **W** | **S** | **NW** | **NE** |
| **Equipment (parameter)** | **Grass Valley - Sierra Nevada slope** | **Big Hill# - Sierra Nevada slope** | **South Lake Tahoe Airport** | **Tahoe City - Wetlands Treatment Center** | **Incline Village - Sewage Treatment Plant** |
| Radar Wind Profiler (WS/WD) | * | | * | | |
| Radio Acoustic Sounding System (T) | * | | * | | |
| Mini-Sodar (WS/WD) | | * | * | * | * |
| Surface wind speed & direction (WS/WD) | * | * | * | * | * |
| Surface temperature (T) | * | * | * | * | * |
| Surface relative humidity (RH) | * | * | * | * | * |
| UCD Aircraft (WS/WD, T, RH)[1] | | I | I | | |

**Notes:**
\# = see air quality table for listing of air quality measurements also being made at this site
shaded cell = no meteorological measurement made by this method
* = data were collected
I = intermittent sampling
[1] multiple flights per day (ten 2-day and two 1-day sampling periods during summer and fall)
Flight paths include:
1) traverses to & from Davis and Tahoe Basin,
2) spirals over western Sierra slope and Lake Tahoe,
3) traverses over Lake at 300' & 1000' above lake level, and
4) excursion over SLT-AP
abbreviations: WS=wind speed, WD=wind direction, T=temperature, RH=relative humidity

#### *1.5.1.1 Existing Monitoring Sites*

- **Echo Summit**

The height of the inlet probe was raised to reduce the impact of nearby idling vehicles.

- **South Lake Tahoe – Sandy Way**

Branches from a nearby pine tree likely impact the meteorological and PM2.5 measurements at this site. Permission to trim the branches was denied by local authorities. A NOy instrument, a TWS, and 3 beta attenuation monitors (BAM; for measuring PM2.5, PM10, and TSP) were installed.

- **SOLA**

A TWS and a BAM for TSP were added to the existing platform (IMPROVE Program).

- **DL Bliss**

Occasional TSP samples (by mini-volume sampler) were collected at this site in addition to the standard IMPROVE Program (PM2.5 and PM10).

- **Upper Ward Creek**

No changes were made to this site.

- **Lower Ward Creek (Wallis Residence)**

The only change made to this site was the intermittent collection of TSP samples by mini-vol samplers. It should be noted however that the deposition measurements at this long-term site are being impacted by the presence of an adjacent, growing, deciduous tree and almost certainly being impacted by the presence of nearby coniferous trees. TSP samples (mini-vols) were collected routinely. In addition, TSP mini-vol samples were frequently collected on the boat pier of the Wallis residence.

- **Incline Village**

No changes were made to this site

- **Thunderbird Lodge**

TWS and BAMs (PM2.5, PM10, & TSP) were added to the existing IMPROVE-equivalent sampling program. The site required an additional power upgrade. Wet/dry bucket deposition sampler was dropped from monitoring plans due to insufficient space for all the instruments.

- **Cave Rock**

A BAM instrument measuring TSP was added.

- **Stateline – Harvey's**

No changes were made to this site.

#### *1.5.1.2 New monitoring sites*

- **Big Hill**

This was a fully instrumented monitoring site established to help quantify the magnitude and frequency of transport up the slopes of the Sierra Nevada toward the Lake Tahoe Basin. The equipment trailer was blown over by 100+ mph winds in November 2002 after the instruments were installed but before monitoring began. The trailer was righted and secured in December 2002. The electricity was reinstalled in January 2003 but had frequent power failures until March. With the exception of the BAMs (May), most air quality instruments were reporting data of good quality by March. The mini-sodar was installed in January 2003 but instrument failure delayed data collection for several weeks. The equipment was repaired and reinstalled in May but was then shut off several days later due to concerns about the level of noise. During the fire season, the mini-sodar was only operated from 7 am to 8 pm to allow USFS fire lookouts to sleep.

- **South Lake Tahoe – Airport**

A radar wind profiler with a radio acoustic sounding system (RWP/RASS) was installed to continuously monitor wind and temperature conditions aloft. A mini-sodar system was also installed to monitor winds less than 200 meters above ground level.

- **Timber Cove pier**

Filter samples (24 – 36 hour periods) with a mini-vol sampler were collected at the end of the pier on occasion. Vandalism resulted in two samplers being tossed into the lake and the effective termination of sampling due to the lack of site security to reduce the possibility of future vandalism.

- **Tahoe City Wetlands Treatment Center**

A mini-sodar was set up at this site.

- **Lake Forest**

A “cornerstone” monitoring site was established on the grounds of the TRG lab (Old Fish Hatchery) to monitor PM in three size fractions (both TWS and BAM) and multiple gases (i.e., 2-week averages for $NH_3$ and $HNO_3$, and hourly averages for CO, $O_3$, and $NO_y$).

- **Coast Guard pier**

Filter samples (7-day period) with a mini-vol sampler were collected approximately weekly near the end of the pier.

- **Mid-lake buoys**

Battery-operated mini-volume samplers were deployed on two buoys to collect TSP samples (24-hour period). The goal was to collect approximately one sample per month at each buoy given that servicing by boat would be constrained by operator schedule, weather, and lake conditions.

- **Zephyr Cove Pier**

A mini-vol sampler (1-week samples) was established at this site during LTADS.

### 1.5.2 Overview of Measurements

Ambient measurements of air pollutants potentially associated with water clarity degradation or transport from sources outside the Tahoe Basin were the focus of this field study. ARB staff compared its deposition estimates with historical estimates made with surrogate surface deposition samplers and air quality field studies in the Basin. Because direct measurements of deposition are difficult and subjective, the ARB applied an indirect approach to estimating atmospheric deposition in the Tahoe Basin. This approach included direct measurement of important pollutant species and meteorological conditions. These data were used to calculate seasonal hourly deposition in four quadrants of the Lake. Source-specific emissions, improvement of the emission inventory, the use of a variety of data analysis techniques to elucidate the atmospheric processes in various locations in the Basin improve the understanding of factors that contribute to atmospheric deposition to Lake Tahoe.

Water clarity can be reduced by nitrogen and phosphorus species (biologically available forms) because they contribute to the growth of algae. Water clarity can also be reduced by the presence of particles, particularly in the one micrometer (μm) size. Most of the air pollutant monitoring effort focused on PM and nitrogen species to help identify the relative roles of the various contributing factors. Nitrogen containing compounds measured included nitric oxide (NO), oxides of nitrogen ($NO_X$, primarily NO and $NO_2$), total reactive oxides of nitrogen ($NO_Y$, primarily NO, $NO_2$, $HNO_3$, HONO, PAN, $N_2O_5$), ammonia ($NH_3$), nitric acid ($HNO_3$), and particulate nitrates ($NO_3$). Unlike nitrogen, atmospheric sources of phosphorus are limited and only in particulate form. Particulate samples were analyzed for elemental phosphorus (P) and phosphate ($PO_4^{-2}$). Particulate matter was generally measured in 3 size classes - <2.5 μm, <10 μm and total suspended particulate (TSP). Two particle-sizing counters (size cuts of 0.3, 0.5, 1, 2.5, 10, and 20 μm) were deployed in various short-term studies to characterize the spatial and seasonal variations in particle counts by size.

As discussed earlier, the objective of sampling with the Two-Week-Sampler was to make continuous measurement of particulate matter (PM) throughout the year so that the air quality impact of all emission sources, regardless of temporal scale of influence, is included. Details as to the specific parameters measured at each site can be found in **Table 1-5**.

Although ozone ($O_3$) and carbon monoxide (CO) are not critical components of the water clarity issue, they do provide insights into the relative impacts of transport and local emissions sources. Being components of a typical air monitoring program, these parameters were maintained at existing monitoring sites and included in new monitoring sites. Furthermore, as part of an assessment of ozone impacts on forest health, several temporary (summer season) sites were established with passive ozone samplers (2-week sampling period).

**Table 1-5.** LTADS Particulate Matter Air Quality Network

| Site | Location | Network | Sample Duration | Pollutants | Comments |
|---|---|---|---|---|---|
| Big Hill | western Sierra slope | TWS<br>BAM | 2-weeks<br>hour | TSP, PM10, PM2.5, $HNO_3$, $NH_3$<br>PM10, PM2.5 | remote location at ~6000' elevation |
| SLT-Sandy Way | SLT - south of Hwy 50 | TWS<br>BAM<br>FRM | 2-weeks<br>hour<br>24-hour | TSP, PM10, PM2.5, $HNO_3$, $NH_3$<br>TSP, PM10, PM2.5<br>PM10, PM2.5 | roof of 1-story building; 1 block south of Hwy 50 |
| SOLA | SLT - north of Hwy 50 | TWS<br>IMPROVE<br>BAM | 2-weeks<br>24-hour<br>hour | TSP, PM10, PM2.5, $HNO_3$, $NH_3$<br>PM10 (m), PM2.5<br>TSP | ~30 m north of Hwy 50 and ~40 m from shore |
| Timber Cove | SLT - pier | MVS | 24-hour | TSP | ~100 m from shore |
| Zephyr Cove | SELT - pier | MVS | 1-week | TSP | ~30 m from shore |
| Cave Rock | ELT – shore | BAM | hour | TSP | ~10 m from shore |
| Thunderbird Lodge | NELT – shore | TWS<br>IMPROVE<br>BAM | 2-weeks<br>24-hour<br>hour | TSP, PM10, PM2.5, $HNO_3$, $NH_3$<br>PM10 (m), PM2.5<br>TSP, PM10, PM2.5 | back of Elephant House |
| Coast Guard | NLT - shore | MVS | 1-week | TSP | ~100 m from shore |
| Lake Forest | NLT – south of Hwy 28 | TWS<br>BAM | 2-weeks<br>hour | TSP, PM10, PM2.5, $HNO_3$, $NH_3$<br>TSP, PM10, PM2.5 | ~25 m south of Hwy 28 |
| Wallis Tower | NWLT – dep site | MVS | 1-week | TSP | ~20 m east of Hwy 89 |
| Wallis Pier | NWLT – pier | MVS | 1-week | TSP | ~20 m from shore; ~120 m east of tower |
| Bliss State Park | WLT – west of Hwy 89 | MVS<br>IMPROVE | 1-week<br>24-hour | TSP<br>PM10 (m), PM2.5 | ~25 m above and ~50 m west of Hwy 89 |
| Buoy TB1 | on-lake northeast | MVS | 24-hour | TSP | ~6 km east of TB4 and ~5 km west of eastern shore |
| Buoy TB4 | on-lake northwest | MVS | 24-hour | TSP | ~5 km SE of Coast Guard |

TWS - Two-Week-Sampler
MVS - Mini-Volume Sampler
BAM – Beta Attenuation Monitor
FRM – Federal Reference Method
IMPROVE – Interagency Monitoring of PROtected Visual Environments (or equivalent)
(m) – mass only

## 1.6 Special Studies

CARB contracted with several groups to conduct specialized measurements useful in addressing atmospheric processes related to atmospheric deposition and emissions. The abstract for each project is listed below, and, where available, an electronic link to the full report.

### 1.6.1 Aircraft and Boat Measurements of Air Quality and Meteorology

UC Davis (ARB Contract No. 01-326)
During the summer and fall of 2002, aircraft measurements of meteorological and air quality variables were obtained over the western Sierra Nevada and the Lake Tahoe Basin. During the winter of 2003, similar measurements were made close to the lake's surface using a small research vessel on the lake. Aircraft air quality sampling included real-time monitoring of ozone, NO, NOy, and particulate concentrations plus grab samples of gaseous and particulate nitrogen species using annular denuder-filter pack (DFP) assemblies. Boat sampling involved the same instrumentation except that no ozone monitor was aboard. The primary objective of these field efforts was to document the concentrations of nitrogen-containing species as well as other pollutants in the air over and upwind of the lake, as these species can deposit into the lake and act as nutrients that accelerate eutrophication. This report describes the techniques used to acquire the data, assure their quality and summarizes the general conditions encountered. Descriptions of instrument calibrations and of the formats used for the QA/QC-ed data sets transferred to the ARB are also included.

Sampling was conducted on 20 days during the summer and fall with an aircraft and on 6 days during the winter with a boat. Two additional days were devoted to joint aircraft-boat sampling in the fall. Data recovery for the continuous real time measurements was nearly 100 percent. Analyses of the DFP samples from the aircraft also went well, although there were issues with blank levels for several chemical species. During our sampling days, the concentration of atmospheric N over Lake Tahoe ranged from 33 to 360 nmol-N/m$^3$-air, with an average value of 120 nmol-N/m$^3$-air. Gaseous ammonia was typically the dominant component, accounting for an average of 55% of total N, while particulate ammonium contributed an additional 10% of total N on average. Nitric acid/nitrate and organic nitrogen (gaseous and particulate) were also significant components that, on average, accounted for 20% and 14% of the total atmospheric N burden. In contrast, levels of nitrous acid and nitrite were generally insignificant.

A variety of weather conditions were encountered which clearly affect pollutant levels measured both in the Tahoe Basin and over the mountains to the west. On most days, late afternoon air quality was slightly to significantly worse to the west of the basin than in the basin. In the mornings, the variations among locations were more random. A preliminary analysis of our DFP measurements, in conjunction with meteorological data, suggests that nitrogen levels in the air above Lake Tahoe can be affected by a number of sources and factors including the regional "background" pollution level, in-basin emissions, local and distant forest fires, and pollution from the Central Valley.

Full Report (ftp://ftp.arb.ca.gov/carbis/research/apr/past/01-326.pdf )

### 1.6.2 Improvement of the PM Emission Inventory for the Lake Tahoe Region

CE-CERT (ARB Contract No. 0004-AP-ARB-01)
Lake Tahoe is a beautiful lake located in California and Nevada. The lake is well known for its pristine water clarity and color, and is a popular vacation destination. However, since the 1960's, the water clarity of the lake has been steadily declining. It is believed that the degradation in the water clarity is due to increases in the input of particles and biologically available phosphorus and nitrogen. A significant fraction of this input is estimated to be through the atmosphere. Possible sources of particles, phosphorus and nitrogen deposition from the atmosphere include smoke from residential wood burning, prescribed files, wildfires, vehicle exhaust, roadway dust, and regional transport. Currently, the quantity and impact from these and other sources are not well understood. This project explores characterizing the emissions contained in wood burning activities and quantifying the amount and type of wood burning in the Tahoe region. In addition, the type and amount of on-road vehicle activity is better characterized. This information will aid in understanding the magnitude and sources of nutrients and particulate matter deposited to Lake Tahoe, to enable the development of a plan for reducing emissions and improving water quality.

Full Report (ftp://ftp.arb.ca.gov/carbis/research/apr/past/01-733.pdf )

### 1.6.3 Lake Tahoe Source Characterization Study

Desert Research Institute (ARB Contract No. 01-734)
PM samples directly relevant to major PM sources in Lake Tahoe were collected and analyzed as part of this study. Sources sampled included residential wood combustion (RWC), motor vehicle exhaust, and entrainment of road dust, traction control material, and road deicing material.

In addition, several new emission measurement technologies were applied during this study. A portable emission test stand measured both gases and particles at 1 s resolution from RWC appliances and on-road motor vehicles. Measurements of plume concentrations were used to determine fuel-based emission factors based on the ratio of pollutant concentrations to $CO_2$, CO, and hydrocarbons. A background subtraction technique was applied to fast-response PM measurements to estimate the fraction of PM emitted by a source and collected on a filter.

A tower instrumented with fast-response PM monitors was erected downwind of a highway. The flux of particles past the tower was related to the number of vehicles traveling on the road to calculate a vehicle and distance-based emission factor for typical wintertime, post-storm, post-street sweeping, and post-deicing conditions.

An onboard road dust sampling system was operated on more than 2000 km of paved road in the Lake Tahoe Basin. The instrumented vehicle was operated on fixed routes around the lake and over Mt. Rose Pass to monitor the change in road dust emission factors between winter and summer. Onboard measurements were also related to the flux of PM downwind of the road to provide the first paved road calibration point for the mobile system. This data set permitted the extrapolation of fleet average emission factors to all areas surveyed by the mobile system.

Full Report (ftp://ftp.arb.ca.gov/carbis/research/apr/past/01-734.pdf)

#### 1.6.4 Keeping Tahoe Blue: Quantifying Atmospheric Nitrogen Oxides in the Lake Tahoe Basin

UC Berkeley (ARB Contract No. 01-327)
The motivation for collecting data at Big Hill and the focus for this analysis has been to quantify the distribution of reactive nitrogen oxides at a site upwind of Lake Tahoe and use those measurements to assess the role of transport along the western slope of the Sierra in contributing to nitrogen deposition in Lake Tahoe. By combining the data we obtained at Big Hill with corresponding measurements at Blodgett Forest, we have developed a highly constrained model of the processes that govern reactive nitrogen distribution during the summer months in the region. Data collected during winter months shows that the meteorology does not favor net transport of pollutants from west to east in the surface layer. Plumes from several prescribed burns were measured, often containing higher concentrations of reactive nitrogen than the urban plume, but likely having significantly reduced geographical influence. Total reactive nitrogen in the region is likely at a maximum during the summer, though observations from more sites would be necessary to quantify the importance of burning events as a source of reactive nitrogen to Lake Tahoe. Based on our analyses of the observations made, we can draw the following conclusions:

During summer months, the Sacramento region is the dominant source of reactive nitrogen in the plume on the western slope of the Sierra Nevada

$HNO_3$ deposition is sufficiently fast that very little remains in the plume by the time it reaches high elevation sites near the western rim of the Lake Tahoe Basin

At Big Hill, similar concentrations of $HNO_3$ are found in airmasses coming from the west and the east, suggesting that urban areas to the west of Lake Tahoe cannot be identified as important sources

Organic nitrates are significantly elevated in the plume compared to background conditions but their contribution to nitrogen deposition is poorly understood

During winter months, total reactive nitrogen is lower, net flow at the surface is downhill and the urban plume rarely reaches the western rim of the Basin

Individual winter episodes of high $NO_2$ and inorganic nitrates associated with small-scale burning events along the western slope and may generate $HNO_3$ that can reach Tahoe.

Full Report (ftp://ftp.arb.ca.gov/carbis/research/apr/past/01-327.pdf)

### 1.6.5 Evaluation of Ozone and $HNO_3$ Vapor Distribution and Ozone Effects on Conifer Forests in the Lake Tahoe Basin and Eastern Sierra Nevada

US Dept. of Agriculture, Forest Service (ARB Contract No. 01-334)
Two-week average concentrations of ambient ozone ($O_3$), nitric acid vapor ($HNO_3$), and ammonia ($NH_3$) were measured during the 2002 smog season in selected areas of the Sierra Nevada, California (i.e., Lake Tahoe Basin, San Joaquin River Drainage, portions of the eastern and southern Sierra Nevada). High $O_3$ concentrations were present along the San Joaquin River Drainage and southern Sierra Nevada throughout the summer. Ozone levels were also elevated in the eastern Sierra Nevada, although they were lower than in the San Joaquin River Drainage. The transport of nitrogen oxides, carbon monoxide, and volatile organic compound emissions generated by the McNalley fire is postulated to have contributed to the very high $O_3$ concentrations that occurred in August. In the San Joaquin River Drainage, ambient concentrations of $HNO_3$ and $NH_3$ were highest near the San Joaquin Valley and decreased gradually toward the east. In addition, an evaluation of $O_3$ injury symptoms was conducted on ponderosa pines in the Lake Tahoe Basin and along the San Joaquin River Drainage. At 25-sites in the Lake Tahoe Basin, 23 percent of the trees evaluated had symptoms of foliar $O_3$ injury, but only slight injury to the pines occurred in this area. Ozone injury was, on average, only slight along the San Joaquin River Drainage.

Full Report (ftp://ftp.arb.ca.gov/carbis/research/apr/past/01-334.pdf)

### 1.6.6 Radar Wind Profiler Support for the CARB Lake Tahoe Pollution Studies: 2002-2003

NOAA (ARB Contract No. 01-342)
As part of this contract, the NOAA Environmental Technology Laboratory (ETL) performed system audits at the four CARB Doppler SODAR/wind profiler sites in the Lake Tahoe area and at the ETL Grass Valley wind profiler site during June 2003. ETL used both radiosonde and tethered-balloon systems for the audit of the radar and sodar systems.

Full Report (ftp://ftp.arb.ca.gov/carbis/research/apr/past/01-342.pdf)

### 1.6.7 Sampling and Analysis for Lake Tahoe Atmospheric Deposition Study

Desert Research Institute (ARB Contract No. 01-351)
The CARB initiated the LTADS in 2002 to quantify the contribution of atmospheric deposition to the declining water clarity of Lake Tahoe. The initial study design, which was described in a June 10, 2002 draft work plan for LTADS, included two major components: 1) a monitoring network in the Lake Tahoe Basin and 2) supplemental special studies. The monitoring network used two-week integrated samples from the five key sites in the TWS network and shorter term (generally 1-week) TSP samples with Mini-Vol samplers deployed at remote sites and on-board buoys. Field blanks were collected to subtract the background contribution from the sampling environment and field operation; however, TWS field blanks were only collected at SOLA and only three field blanks were collected from the Mini-Vol samplers. The limited and site-specific

field blanks may affect the results of the ambient samples. The chemical data were evaluated for internal consistency by examining the physical consistency and balance of reconstructed mass, based on chemical species versus measured mass. In general, the samples collected met the criteria of internal physical consistency.

Full Report (ftp://ftp.arb.ca.gov/carbis/research/apr/past/01-351_app.pdf)

### 1.6.8 Literature Review and Summary of Previous Work Related to the Transformation of Nitrogen Emissions during Transport

UC Berkeley (ARB Contract No. 02-331)
In addition to local sources of reactive nitrogen to the Tahoe Basin, other potential upwind sources include emissions from the Sacramento urban area, industrial and agricultural activity in the Central Valley, transportation along highway corridors, biomass burning and biogenic emissions from ecosystems within the western Sierra Nevada. The ability of these emissions to affect the water quality of Lake Tahoe depends on their chemical processing and on the transport pathways that bring the air toward the Tahoe Basin. Analysis of long term ground level observations suggest that most $HNO_3$ within the urban plume deposits prior to reaching Lake Tahoe, though organic nitrates may persist. Short-term aircraft studies attempting to identify transport pathways for pollutants have occasionally observed higher concentrations of photochemical products lofted above the mixed layer. Downwind of biomass burning episodes, elevated levels of reactive nitrogen in both the gaseous and particulate phase have been observed [Zhang, 2002]. If these burning events occur within five hours transit time to the Tahoe Basin, they may be capable of delivering additional nitrogen to the atmosphere above the Lake.

Full Report (ftp://ftp.arb.ca.gov/carbis/research/apr/past/02-331.pdf)

### 1.6.9 The Use of Multi-Isotope Ratio Measurements as a New and Unique Technique to Resolve NOx Transformation, Transport, and Nitrate Deposition in the Lake Tahoe Basin

UC San Diego (ARB Contract No. 03-317)
This work is not yet completed but a final report is expected in 2006.

The objectives of this project are to evaluate the isotopic composition of nitrate in Lake Tahoe and in aerosols and deposition collections obtained within the basin and on transects outside the region. Evaluating the isotopic composition of atmospherically produced nitrate and comparing it with that found in the Lake will quantify the flux of atmospheric N deposited on the Lake and can be used as tracer of nutrient fluxes over the course of the year.

### 1.6.10 LTADS s-XRF Filter Analysis QA Report - Enhanced Measurements with Synchrotron-XRF

UC Davis (ARB Contract No. 03-334)
As part of the LTADS 71 ambient filter samples from various collection sites throughout the Lake Tahoe Basin were analyzed. The sample subset from the large LTADS sample base was selected from those with high reported phosphorous values from other analyses combined samples collected on the same dates at corresponding sites. In addition, several source and other specialized samples were analyzed. In this preliminary report we discuss only the ambient samples. Each of these samples was previously analyzed by the analytical facility at the DRI and the DRI data were shared. The samples were analyzed at the analytical facility at beam line 10.3.1 at the Advanced Light Source-Lawrence Berkeley National Laboratory (ALS-LBL). The analysis technique is commonly known as synchrotron x-ray fluorescence (S-XRF), but it is distinguished from traditional XRF (such as that employed by the analytical facility at DRI) by the source of the incident x-rays. The primary goals for understanding the LTADS filter QA study were to 1) determine the range of phosphorous concentration in the Lake Tahoe Basin, and 2) determine the statistical significance of reported phosphorous data from the S-XRF and DRI analyses as an additional quality assurance of the LTADS sampling and analytical program.

Full Report (ftp://ftp.arb.ca.gov/carbis/research/apr/past/03-344.pdf)

### 1.6.11 Shore Zone Dispersion Study

CARB staff
The LTADS Shore Zone Dispersion Study was a limited set of short-term field projects designed to provide anecdotal data on air flow and pollutant distribution in close proximity to major pollutant sources. The experiments of the study were broken into four different categories:

- Exploratory measurements
- Source-oriented dispersion experiments
- Shore zone process experiments
- Particle size distribution characterization experiments

Exploratory measurements consisted of short field experiments, primarily using portable particle counters. The goal was to gather enough data about particular sampling environments to allow for the development of sampling plans for later controlled experiments. Source-oriented dispersion experiments were designed to evaluate near source deposition and primary aerosols to calibrate dispersion estimation schemas applied to the long-term monitoring data. Shore zone experiments were designed to identify the spatial and temporal extent of near shore pollutant concentrations. Finally, particle size distribution experiments were used to develop particle size distribution curves to apply to the bulk chemical data collected by the TWS and mini-vols and to parse the concentrations collected by the BAMs into appropriate “bins” for deposition calculations.

Staff resource constraints limited the number of experiments to a few exploratory measurement efforts. Two Climet CI-500 particle counters (the main portable particle counter in use) have proven to produce comparable results. After the particle counters were proven to produce similar readings, they were dispersed at Sacramento and at Zephyr Cove Resort in Lake Tahoe. Preliminary data from the Zephyr Cove and Sacramento comparison experiment show that the Tahoe Basin does have significant local aerosol sources and that local aerosol is generally larger in size than urban aerosol in California and thus more prone to deposit in the lake. Data from another deployment shows that the particle counters are able to detect the tail end of the nighttime inversion and midmorning shift of night and morning offshore flow to midday lake breeze. The particle counter was also able to detect a morning episode of road transport caused by the morning traffic peak. Other experiments conducted on the UC Davis boat and aircraft show promising correlation with land-based particle counts and have been successful in tracking aerosol episodes.

Summaries of these measurements can be found in Chapter 3 of this report.

### 1.6.12 Comparison of Surrogate Surface Methods of Measuring Dry Deposition

CARB staff

Measurement of the deposition of gases and aerosols from the atmosphere to surfaces is difficult and fraught with complexities associated with disturbances during sampling, reaction/transformation/contamination during sampling and before chemical analysis, analytical detection of small quantities, etc. Measurement of deposition to a water surface is further complicated by access and logistical challenges. Questions have historically been raised about the representativeness of deposition measurements associated with surrogate surface deposition samplers like the bucket sampler, particularly for dry deposition. It is believed that the wet bucket measurements are reasonably realistic, assuming proper siting of the equipment away from buildings and trees. CARB staff conducted a dry deposition methods comparison study to better characterize the potential differences between surrogate surface sampling methods that are or could be used for dry deposition measurements. In general, the relationships between the methods are not well defined and tend to have significant scatter. However, the alternative methods all tend to “see” more nitrogen species and comparable phosphorus species than the standard dry deposition method.

The details of this comparison can be found in Appendix A of this report.

## 1.7 References

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