2. Deposition Model

2.1 Purpose

The primary goal of the Lake Tahoe Atmospheric Deposition Study (LTADS) is to quantify the contribution of atmospheric deposition to Lake Tahoe as an input to modeling lake clarity and developing a Total Maximum Daily Load (TMDL) –based water quality management program for the lake. The LTADS deposition estimate strives to include all optically and biologically significant materials in the air over the lake, including gas and particle-phase nitrogen and particle-phase phosphorus that fertilize phytoplankton, and non-soluble ("inert") particles that, once deposited in the lake, may scatter light or serve as growth sites for microscopic organisms.

This chapter provides an overview of the methodology used to derive the estimates of dry deposition to Lake Tahoe.

2.2 General Methodology

Due to cost, time, and physical constraints on the LTADS program, directly measuring the deposition of every compound or substance to the lake was not possible. Instead, a tiered, climatological approach was used, based on a simple concept: that the annual deposition of a species is the integral of the ambient concentration of that species multiplied by its deposition velocity. Deposition velocity is strongly dependent on meteorological conditions, as well as species and surface characteristics. Air quality and meteorology in the Tahoe basin have strongly repetitive temporal patterns. This approach is supported by both historical and LTADS observations that confirm that these parameters generally follow highly repetitious diurnal patterns. Figure 2-1 shows hourly concentrations of NOx measured during the winter months of LTADS at Sandy Way. The observed concentrations are a product of emissions and meteorology, both of which have consistent diurnal cycles. Figure 2-2, in which hourly wind direction data collected at Sandy Way during the summer of 2003 are plotted, clearly shows the repetitive diurnal meteorological cycle. Thus, concentration and deposition velocity, through relevant variables such as wind (speed and direction) and temperature (air and water), can be measured at time scales relevant to their intrinsic variations and yield temporal patterns of deposition.

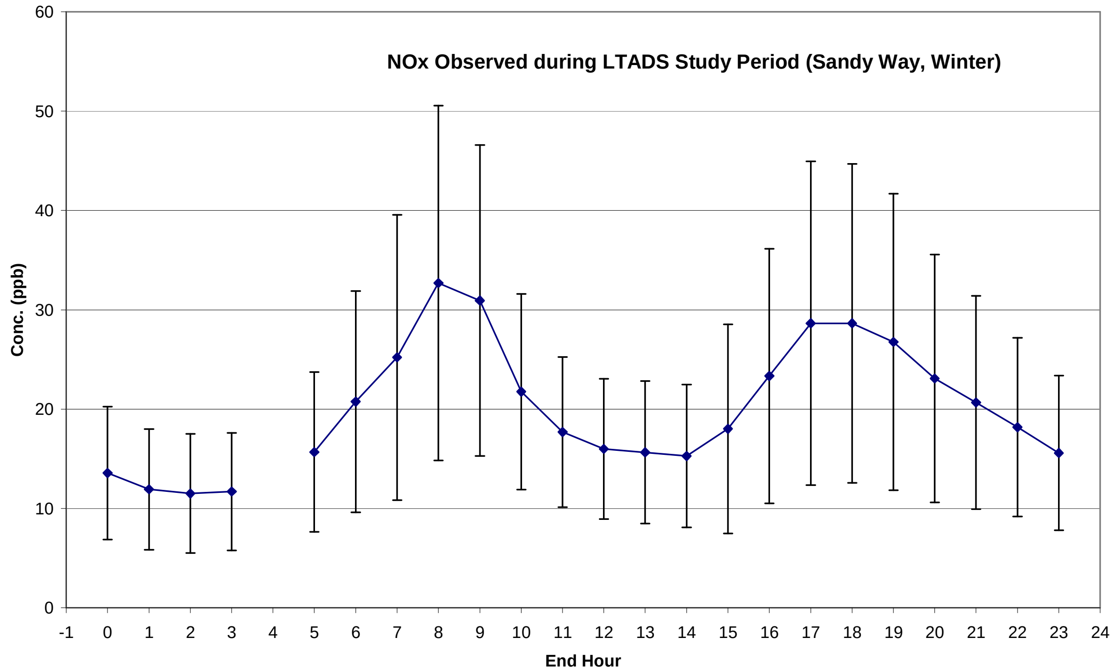


Figure 2-1. Historical monitoring shows strong, consistent diurnal cycles in the Tahoe Basin - example is NOx in winter at Sandy Way. (Note: the daily calibration check occurs during hour 4.)

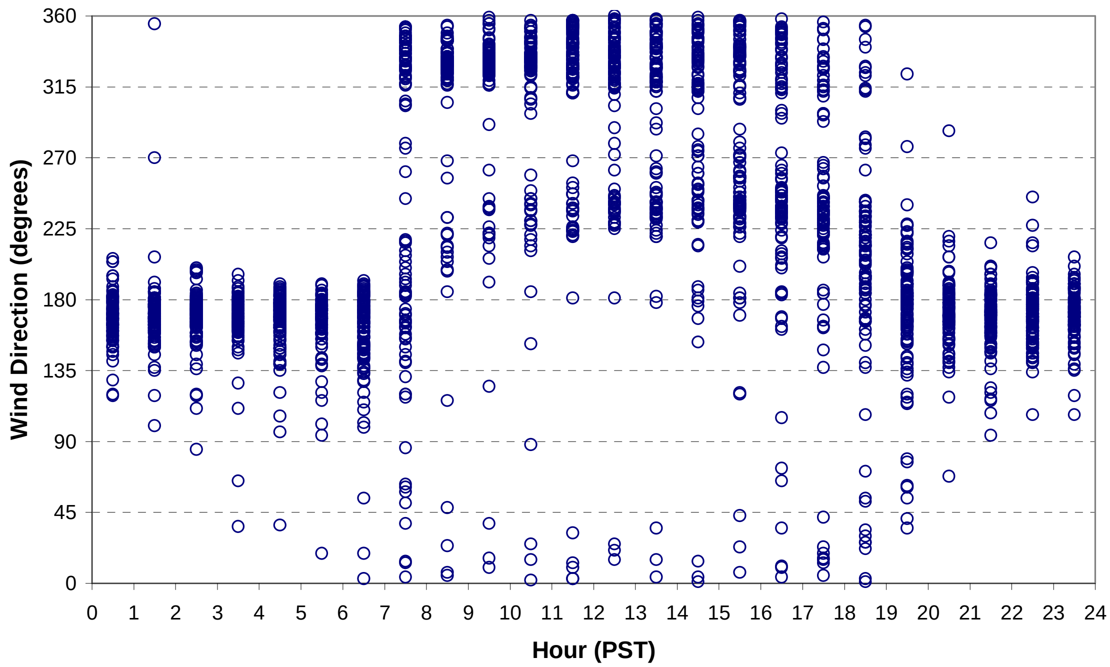


Figure 2-2. Repetitive meteorology was observed during LTADS. This is an example of the diurnal cycles in wind direction observed at Sandy Way during summer.

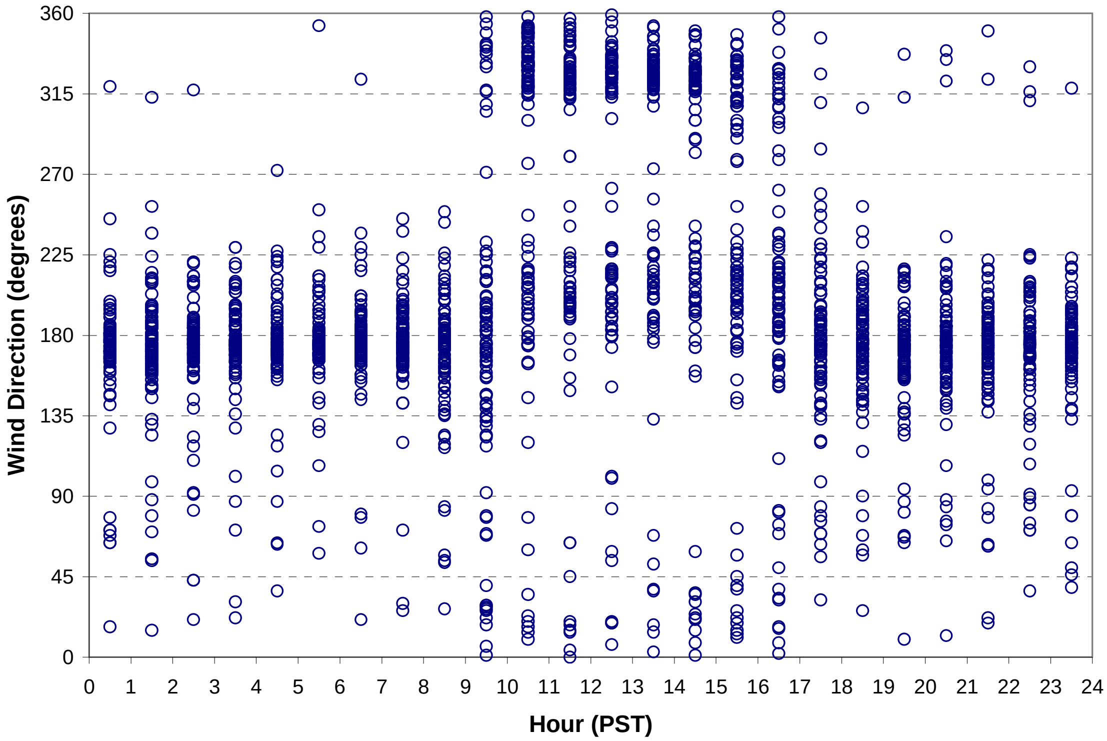


Figure 2-3. Repetitive meteorology was observed during LTADS. This is an example of the diurnal cycles in wind direction observed at Sandy Way during winter.

For many species, short-term concentrations show large variation due to the varying product of emission rates and dilution. This variation was captured by LTADS with hourly and diurnal air pollutant concentrations monitored by relatively simple continuous instruments reporting a limited set of gases and time-resolved (and sometimes size-resolved) bulk aerosol data.

Conversely, chemical composition is largely driven by socially and economically defined local and regional human activity patterns, which are strongly cyclical and regularly repeated. Within the precision required for annual deposition estimation, chemical composition variation is largely seasonal. Chemical characterization of air pollutants for LTADS was thus simplified to two-week integrated sampling to reflect the compositional modulations due to changing emission patterns and seasonal meteorology.

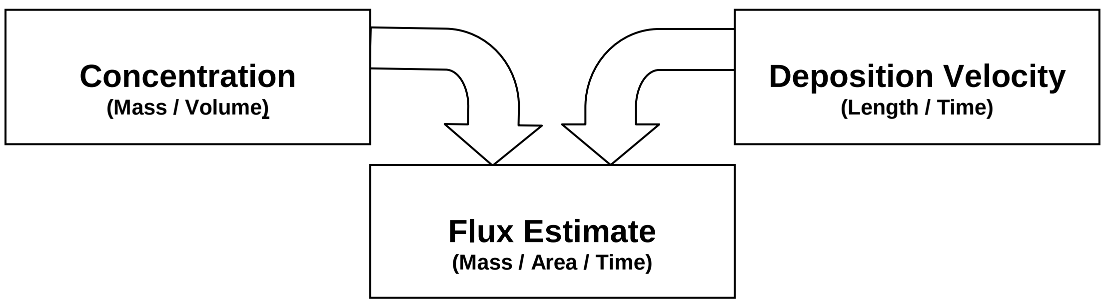
To generate an idealized diurnally and chemically resolved picture of air quality at a monitoring site, the two week sampler (TWS) data were interpreted into a “conceptual model” that describes the mean air quality observed in each season. The conceptual model was then merged with the observed seasonal diurnal concentration patterns. Finally, deposition calculations merged the idealized diurnally and chemically resolved air quality with diurnal patterns of airflow and deposition velocity derived from the meteorological data to generate a realistic chemically resolved deposition estimate.

During the LTADS field study, the atmospheric concentrations and composition of PM, nitrogen, and phosphorus were measured. This report provides estimates of the rates of dry deposition physically consistent with the observed concentrations and environmental variables (e.g., wind speed and direction, air and water temperatures). Wet deposition is also important as an input to the Lake, but was not a major focus of the LTADS field study for a number of reasons. LTADS did not emphasize observations of wet deposition because, with proper siting and care in sampling, observed wet deposition to surrogate surfaces may be used to infer wet deposition to the Lake.

2.3 Atmospheric Deposition Model Used in LTADS

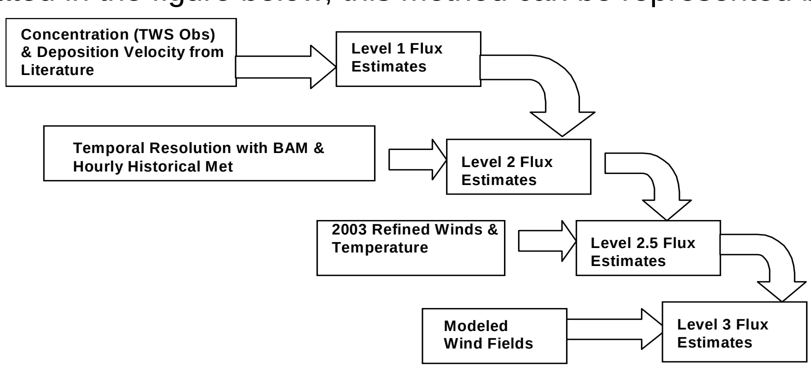
LTADS calculates the deposition of a pollutant to the lake surface as the product of that pollutant's concentration and its deposition velocity. Ambient concentrations (C) and deposition velocities (Vd) vary temporally, spatially, and by pollutant. However, at each level of analytical complexity, the basic deposition calculation remains the same:

Deposition Flux (F) = C x Vd.



The pollutant concentrations are based on observations and were interpolated or extrapolated by various means to compensate for missing data. Physically reasonable deposition velocities were calculated from observed meteorological values (e.g., wind direction, wind speed, air temperature, water temperature). For unknown or poorly-known parameters associated with ambient concentrations or deposition velocities, upper and lower estimates of these parameters enable bounding limits of the atmospheric deposition to the Lake to be provided.

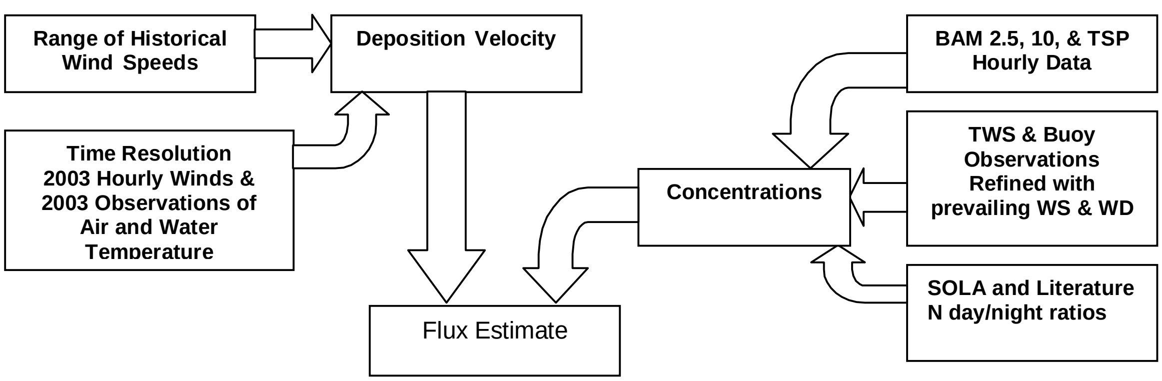
As demonstrated in the figure below, this method can be represented by a tiered



approach, with each succeeding level requiring more data and yielding progressively smaller improvements in estimates of the flux.

The deposition estimates presented in this document correspond to the Level 2.5 approach, where TWS and mini-vol concentration measurements were used to provide mean seasonal concentrations. These seasons were defined as winter (December, January, and February), spring (March, April, and May), summer (June, July, and August), and fall (September, October, and November). These seasonal concentrations were then refined to diurnal concentrations based on ancillary hourly data (e.g., BAM PM data, gas measurements). These hourly seasonally averaged concentration data were then merged with hourly meteorological data, defining deposition velocities (e.g., wind speed and direction, air temperature, water temperature), to produce the deposition calculations. Assumptions associated with the calculation of deposition velocities (e.g., mean particle size within size fractions, limits on maximum deposition velocities) were varied over a range of feasible values to provide bounding estimates of the atmospheric deposition of N, P, and PM.

At this level, both the estimates of deposition velocity and estimates of the spatial variation in concentration are improved by use of meteorological observations made during LTADS but without use of meteorological models. Because both deposition velocity and concentration are expected to vary over the course of a day, the actual deposition rate would likely not be reliably estimated as the product of an average deposition velocity and average concentration. Accordingly, the hourly deposition rates were calculated based on the hourly meteorological observations and air quality at each site.



The annual average deposition rate to the lake surface is calculated based on the average of the seasonal deposition rates calculated from four air quality quadrants representing equal areas of the Lake (Figure 2-4).

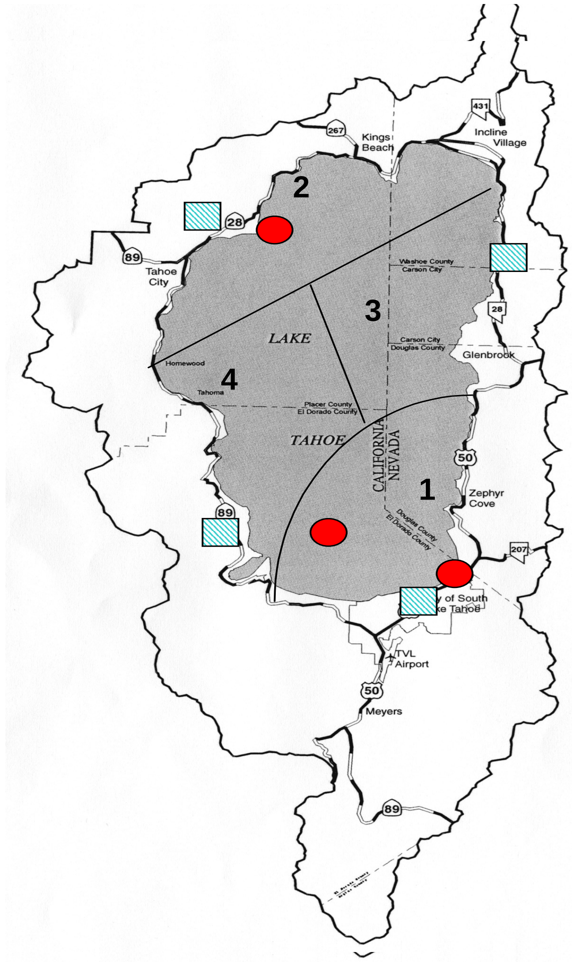


Figure 2-4. Lake quadrants used to calculate annual deposition. The shaded boxes represent air quality sites and the shaded circles represent meteorology sites used in the annual deposition calculation.

The quadrants, which are labeled in Figure 2-4 were chosen based on air quality measurements and population/ activity densities, are:

- Quadrant 1: S & SE Lake – meteorological data from Timber Cove (TC) and a southern buoy (TDR2) and concentration data from the South Lake Tahoe - Sandy Way site (SW) were used to calculate deposition estimates for this sector of Lake Tahoe.
- Quadrant 2: N & NW Lake – For this area, meteorological data from U.S. Coast Guard (USCG) Pier and concentration data from Lake Forest (LF) were used to calculate deposition estimates for this sector of Lake Tahoe.
- Quadrant 3: E &NE Lake and Quadrant 4: W & SW Lake – For the purposes of a lake-wide estimate concentrations for the NE and SW quadrants were assumed to be 33% of the PM mass and 58% of the gaseous and aerosol nitrogen observed at

Lake Forest. These concentrations are based on a preliminary review of the air quality data. A refined analysis, currently underway, will yield improved estimates of concentrations for these quadrants.

Details of the calculations of the annual dry deposition estimates are found in chapter 5.

The primary purpose of LTADS is to characterize the atmospheric deposition of air pollutants to the Lake. However, a secondary purpose was to provide a qualitative assessment of the most significant emission sources contributing to deposition. The final report will draw on available data to make such an assessment. Because deposition rates will generally respond linearly to any increase or decrease in ambient concentrations the identification of the relative contributions of the major emissions sources to the concentrations observed near the Lake is expected to also provide a reasonable first-order estimate of the relative contributions of those sources to deposition to the Lake.

2.4 Report Organization

The subsequent chapters of this document will cover the following topics. Chapter 3 contains a description of the ambient monitoring of the atmospheric concentrations of N, P, and PM in the Tahoe Basin and then presents the seasonal diurnal profiles which are used in the deposition estimates. Chapter 4 contains a description of the calculation of deposition velocities from observed meteorology. The calculation of annual dry deposition based on the data presented in Chapters 3 and 4 is covered in Chapter 5. Chapter 5 also contains a short section on theoretical estimates of possible magnitudes of wet deposition. This report concludes with a comparison of the estimates derived as part of LTADS with previous estimates, as well as recommendation for further research.

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