

2017 Atmospheric Deposition Evaluation for the Tahoe Keys Lagoons



May 10, 2018

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Prepared for



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TAHOE KEYS INTEGRATED
MANAGEMENT PLAN

May 10, 2018
-Final-

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1.0 ATMOSPHERIC DEPOSITION IN THE TAHOE BASIN

Population expansion and urban development of the Lake Tahoe Basin has led to increased levels of pollution and urban runoff, causing high nutrient loading in the streams and lakes. Multiple studies have been conducted to measure pollutant loading into Lake Tahoe. Section 2.0 of this report reviews previously reported air quality and atmospheric deposition data as well as site information for the Tahoe Keys lagoons.

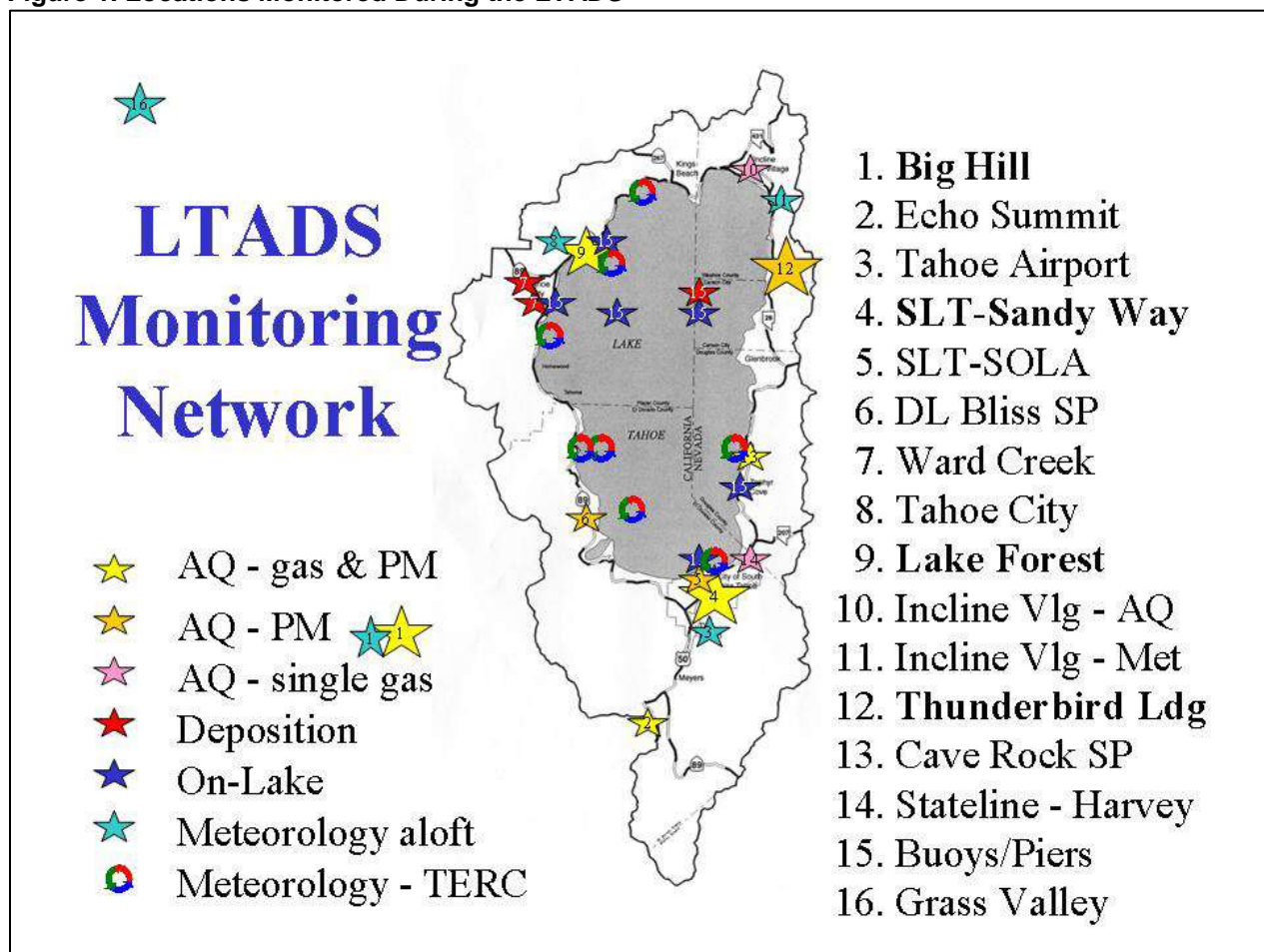
The efforts undertaken by the Tahoe Keys Property Owners Association (TKPOA) in 2016 and 2017 to collect water quality and sediment data and evaluate alternative sources (including nonpoint sources and atmospheric deposition) were conducted in order to identify the relative sources that are being used by the invasive macrophytes present in the Tahoe Keys lagoons. This report will review atmospheric deposition in the Tahoe Basin and its potential impact on Tahoe Keys lagoons' water quality and aquatic weed growth through nutrient contribution calculations.

1.1 Sources of Atmospheric Deposition

The Lake Tahoe Atmospheric Deposition Study (LTADS) and the Lake Tahoe Watershed Assessment determined that pollutants from agriculture (manure and enteric fermentation), transportation, energy generation, and industrial output produced in the San Francisco Bay area and Stockton, Sacramento and Los Angeles areas (Jassby 1994, Dolislager 2012) have the potential to be deposited in the Tahoe Basin but are not believed to be the main source for atmospheric deposition into Lake Tahoe. This is due in part to the mixing of air masses in higher elevations along the western slopes of the Sierra Nevada, acting to dilute atmospheric pollutants. A further requirement of vertical mixing near the lake's surface, causing further dilution, would be required for deposition into the lake (Gertler 2006, Dolislager 2012). Figure 2 depicts sites where atmospheric deposition monitoring has occurred throughout the Basin.

Fires within a five-hour transit time of Lake Tahoe are more likely to deposit additional nitrogen into the atmosphere above the lake, the concentration of particles dependent on the size and distance from the Lake Tahoe Basin, impacting visibility and potentially violating air quality standards (Gertler 2009). From these conclusions, it appears that most pollutants contributing to atmospheric deposition to Lake Tahoe originate from within the basin itself.

Figure 1. Locations Monitored During the LTADS



Source: Dolislager 2012

1.1.1 Nitrogen¹

Atmospheric deposition in the Tahoe Basin has been measured, albeit infrequently in the beginning, since the 1980's. From 1980 to the early 1990's, the relative deposition rates of nitrate (NO_3^-) and ammonium (NH_4^+) ions in precipitation ('wet' deposition) were measured and found to be $13.1 \mu\text{mol}/\text{m}^2\text{d}$ NO_3^- and $9.6 \mu\text{mol}/\text{m}^2\text{d}$ NH_4^+ . Moreover, the 'dry' deposition (deposition occurring without precipitation) was measured at $7.3 \mu\text{mol}/\text{m}^2\text{d}$ NO_3^- and $8.1 \mu\text{mol}/\text{m}^2\text{d}$ NH_4^+ respectively (Jassby 1994).

In the early 2000's, studies conducted by the Tahoe Environmental Research Center (TERC), the Desert Research Institute (DRI), CARB, and the Tahoe Regional Planning Agency (TRPA) suggested that atmospheric deposition contributes 200 metric tons per year of inorganic and organic nitrogen, roughly 55% of total nitrogen loaded into Lake Tahoe (Gertler 2009).

¹ Concentration values discussed in nutrient sections were determined from multiple reports. As such, different units and area/volume sizes were used. Please note that values reflect per day deposition but differ in m^2 and m^3 .

Following these previous studies, the California Air Resources Control Board (CARB) completed the Lake Tahoe Atmospheric Deposition Study (LTADS) in 2006 to continue studies on Tahoe Basin atmospheric deposition. The results of the LTADS further illustrated that the South Lake Tahoe area has an annual estimated 450 ng/m³ (1.23ng/m³d) and 1000 ng/m³ (2.74ng/m³d) of particulate nitrogen, ammonium and nitrate (NH₄⁺ and NO₃⁻), respectively. Furthermore, annual mean concentrations of ammonia (NH₃), a primary emissions pollutant from vehicle usage as well as waste and residential wood burning, were found to fall between 200-1700² ng/m³ (0.5-4.66ng/m³d) with the highest concentration determined from South Lake Tahoe sites. Nitrate emissions from transportation in the Basin has been estimated to contribute roughly 80µmol/m²d of nitrogen (Jassby 1994). It was determined that nitric acid (HNO₃), a secondary pollutant formed from chemical reactions in the atmosphere, is a primary pollutant leading to nitrogen deposition in the lake (Gertler 2006). Concentrations of nitric acid were found to be between 300-1000 ng/m³ (0.82-2.74ng/m³d), with higher mean values for the South Lake Tahoe area (Dolislager 2012).

Table 1 below provides an overview of atmospheric deposition rates for forms of nitrogen determined in the studies discussed above.

Table 1. Overview of Atmospheric Deposition – Nitrogen Forms

Study Reference	Area	Nitrogen Form	Concentration
Jassby 1994	Tahoe Basin	'wet' deposition - NO ₃ ⁻	13.1 µmol/m ² d
Jassby 1994	Tahoe Basin	'wet' deposition - NH ₄ ⁺	9.6 µmol/m ² d
Jassby 1994	Tahoe Basin	'dry' deposition - NO ₃ ⁻	7.3 µmol/m ² d
Jassby 1994	Tahoe Basin	'dry' deposition - NH ₄ ⁺	8.1 µmol/m ² d
Gertler 2009	Tahoe Basin	Inorganic + organic nitrogen	200 metric tons per year
Dolislager 2012; Gertler 2006	Tahoe Basin	NH ₄ ⁺	1.23ng/m ³ d
Dolislager 2012; Gertler 2006	Tahoe Basin	NO ₃ ⁻	2.74ng/m ³ d
Dolislager 2012; Gertler 2006	Tahoe Basin	NH ₃	0.5-4.66ng/m ³ d
Dolislager 2012; Gertler 2006	Tahoe Basin	HNO ₃	0.82-2.74ng/m ³ d

1.1.2 Phosphorus

Most phosphorus in nature is found as phosphate, including orthophosphorus, which has a high affinity to bind with cations that possess positive charges (especially iron). This includes binding to sediment or clay particles. This means that fine sediment or particulate matter deposited into Lake Tahoe via atmospheric deposition is important to measure as it more than likely contributes phosphorus to the lake.

² Wide range in study due to variations of output from areas around the lake; study included entire Basin.

Between 1980 and the mid 1990's, the soluble reactive phosphorus (SRP) deposition rate in precipitation was measured and found to be 0.42 $\mu\text{mol}/\text{m}^2\text{d}$ SRP. Moreover, the mean 'dry' deposition was measured and found to be 1.1 $\mu\text{mol}/\text{m}^2\text{d}$ SRP (Jassby et al 1994).

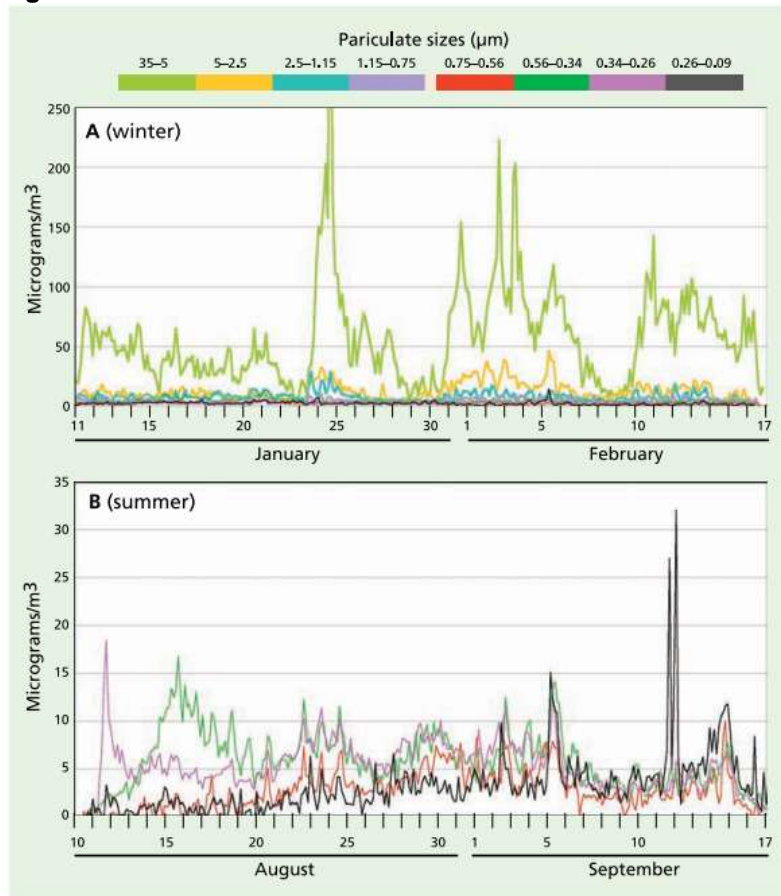
Studies conducted in the early 2000s built upon previous studies and expanded in scope to include fine soils less than 10 μm in diameter, previously unmeasured. As most phosphorus is associated with fine soils with these diameters, this was important in estimating total phosphorus load via atmospheric deposition. Results suggested that roughly 6-8 metric tons per year of total phosphorus and 750 metric tons per year of fine sediment, soil-derived, were loaded from atmospheric sources (Gertler 2009).

In the later part of the 2000's, results of the LTADS showed that the South Lake Tahoe area has an annual estimated base phosphorus concentration³ of 40 ng/m^3 (0.11 $\text{ng}/\text{m}^3\text{d}$) and an estimated annual total soluble phosphorus (TSP) concentration of approximately 21.15 ng/m^3 (0.057 $\text{ng}/\text{m}^3\text{d}$) from atmospheric deposition (Dolislager 2012). In general, SRP deposited into the lake originates from fine sediment particles/particulate matter from unvegetated or disturbed soil or roads where dust becomes windblown. This particulate matter (primarily less than 10 μm in diameter) originates from road dust (traction control materials, tire and brake wear, and exhaust), particles from vegetative/wild fires, wood stoves, plant detritus, and pollen and represents a majority of the particulate matter deposited in the basin (Jassby 1994, Dolislager 2012). Urban roads with high traffic provide the highest emissions, especially winter road dust emissions (Zhu 2009).

In 2017, TERC estimated that total phosphorus and fine sediment, contributed to Lake Tahoe via atmospheric loading, contributes to the reduction in clarity and blueness of Lake Tahoe (TERC 2017). This is due in part to the increased availability of nutrients in the upper layer of the water column providing nutrients for algae and phytoplankton, as well as increasing the amount of light scattered by suspended particles.

³ The minimum concentration of phosphorus present year round.

Figure 2. Seasonal Particle Sizes from the LTADS



Size-segregated phosphorus measurements ($\mu\text{g}/\text{m}^3$) in 2002 for (A) winter (eight particulate size fractions) and (B) summer (four fine particulate size fractions to better show smoke and exhaust). The maximum levels of phosphorus were observed in the largest size fractions, winter and summer, indicating that resuspended geological material was the major pollutant source.

Source: Gertler 2006

Table 2 below provides an overview of atmospheric deposition rates for forms of phosphorus determined in the studies discussed above.

Table 2. Overview of Atmospheric Deposition – Phosphorus Forms

Study Reference	Area	Phosphorus Form	Concentration
Jassby 1994	Tahoe Basin	'wet' deposition - SRP	0.42 $\mu\text{mol}/\text{m}^2\text{d}$
Jassby 1994	Tahoe Basin	'dry' deposition - SRP	1.1 $\mu\text{mol}/\text{m}^2\text{d}$
Gertler 2009	Tahoe Basin	Total phosphorus	6-8 metric tons per year
Gertler 2009	Tahoe Basin	Fine sediment	750 metric tons per year
Dolislager 2012; Gertler 2006	South Lake Tahoe	Total phosphorus	0.11 $\text{ng}/\text{m}^3\text{d}$
Dolislager 2012; Gertler 2006	Tahoe Basin	SRP	0.057 $\text{ng}/\text{m}^3\text{d}$

1.2 Plant Nutrient Uptake

Aquatic plants differ from land plants through a variety of characteristics, including their unique ability to uptake necessary nutrients through their roots or shoots, depending on nutrient demand and availability. Eurasian watermilfoil and curlyleaf pondweed possess rhizomes and are considered rooted aquatic plants, therefore they are more efficient at sediment uptake of nitrogen and phosphorus. Free-floating plants without roots, like coontail, must absorb all necessary nutrients from the water column as they have no connection to nutrient-containing sediment (Angelstein 2008).

Chloroplasts are distributed throughout the entire epidermal layer of aquatic macrophytes, as light is more difficult to capture in submerged environments. Leaves are thin and often highly dissected with a slight cuticle. These characteristics allow for light penetration and diffusion of dissolved gases necessary for photosynthesis. Oxygen, carbon dioxide and bicarbonate diffuse into the lacunar system in leaves and stems before photosynthesis can occur. Upon cessation of photosynthesis, oxygen diffuses from the stem into the roots and is released into the sediment (Sculthorpe 1967). Terrestrial plants absorb nutrients by their roots through a combination of water potential, transpiration, and root pressure. However, uptake of nutrients by aquatic macrophyte roots is driven by exudation pressure, a combination of both metabolic processes and osmosis. The accumulation of carbohydrates, gases and ions create a concentration gradient that favors movement through the tissues of the xylem and phloem in the plant (Sculthorpe 1967).

More than half of available phosphorus and nitrogen, mostly as ammonia, are moved into macrophyte tissues via root uptake (Smith 1990, Melzer 1999). The forms of nitrogen used by aquatic macrophytes include leaf absorption of ammonium and nitrate or ammonium uptake via roots in sediment. Nitrogen is most readily absorbed by the plant as ammonium, but other forms are used, such as nitrate, but these require more expenditure of energy for uptake (Smith 1990, Walstad 2014). Additionally, the pool of available phosphorus in sediment is a hundred fold of that found in the surrounding water column (Søndergaard 2003), which makes uptake via roots and the mobilization of phosphorus so important.

Results of the 2016 and 2017 TKPOA Baseline Water Quality Sampling Program show that total phosphorus and total nitrogen levels in the water column of the Tahoe Keys lagoons exceed water quality objectives set forth by the Lahontan Board that apply to all of Lake Tahoe's waters (TKPOA 2016b, TKPOA 2017c). Additionally, sediment of the Tahoe Keys lagoons has notably higher concentrations of aluminum, nutrient, and organic matter than levels found in Lake Tahoe sediment (TKPOA 2017d).

Overall, the results of the 2017 monitoring programs suggest that a majority of the available nitrogen for uptake by aquatic plants is located in the sediment as there appears to be more ammonia in the sediment than the surrounding water column. In most aquatic systems, the concentration of ammonium in the sediment is greater than that of the surrounding water column, often a hundred fold greater, and is therefore the most common form of nutrient uptake for most aquatic plants (Smith 1990; Søndergaard 2003).

pH values collected from the sediment in the Fall of 2017 suggest that ammonia is potentially the primary form of nitrogen, rather than ammonium or nitrate-nitrogen, in the sediment of the Tahoe Keys lagoons. Changes in chemical form are dependent on temperature and chemical structure as well as individual logarithmic acid dissociation constant (pK_a) that react in different pHs. For example, ammonium has a pK_a of 9.24, meaning it will donate a proton (becoming ammonia) in more acidic conditions, however, the structure of the molecule could affect the exact pH that causes deprotonation. This is also supported by the low levels of the other forms of nitrogen measured from collected sediments (TKPOA 2017d).

2.0 CONCLUSION

A literature review of atmospheric deposition in Lake Tahoe illustrates that nutrients deposited into the water column via atmospheric deposition are likely to influence the available nutrients that may contribute to the prolific growth and dispersal of aquatic macrophytes in the Tahoe Keys lagoons. Studies have estimated that roughly 200 metric tons per year of inorganic and organic nitrogen forms (primarily as ammonia), 6-8 metric tons per year of total phosphorus, and 750 metric tons of fine particulate matter are deposited into Lake Tahoe annually (Gertler 2009, Dolislager 2012).

The majority of nitrogen loading via atmospheric deposition occurs from deposition of nitrogen in the form of ammonia, with an annual concentration range⁴ of 200 ng/m³ to 1700 ng/m³. Furthermore, the South Lake Tahoe area has an annual estimated base phosphorus concentration⁵ of 40 ng/m³ and an estimated TSP concentration of around 21.15 ng/m³ from (Dolislager 2012). By and large, the Tahoe Keys lagoons accounts for less than 1% of the area occupied by Lake Tahoe. As such, deposition of nutrients and pollutants is estimated to be comparatively a fraction of the total atmospheric deposition as measured in the LTADS and other studies.

Oligotrophic lakes at high altitude are sensitive to climatic changes and often have observable increases in productivity. As such, previous studies of atmospheric loading have found that clarity is more rapidly affected than other sources as the pollutants are directly deposited into the water column and the impacts are more immediate and pronounced (Sahoo 2010).

⁴ Concentrations fluctuate during the course of the year leading to the wide range; higher concentrations were determined from the South Lake Tahoe sites.

⁵ The minimum concentration of phosphorus present year round; fluctuates during the course of the year.

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4.0 ABBREVIATIONS AND ACRONYMS

CARB	California Air Resources Board
DRI	Desert Research Institute
'dry'	deposition of nutrients that takes place without precipitation
GHG	Greenhouse gases
HNO ₃	Nitric Acid
IMP	Integrated Management Plan
LRWQCB	Lahontan Regional Water Quality Control Board's
LTADS	Lake Tahoe Atmospheric Deposition Study
Kg	kilograms
µg/L	Microgram per liter
mg/kg	Milligram per kilogram
NH ₃	Ammonia
NH ₄ ⁺	Particulate Ammonium
NO ₃ ⁻	Particulate Nitrate
NPS Plan	Nonpoint Source Plan for Water Quality
ng/m ³	Nanograms per meters cubed
ng/m ³ d	Nanograms per meters cubed per day
µg	Micrograms
µm	Micrometer
µmol/m ² d	Micromoles per meter squared per day
ppm	Parts Per Million
SRP	Soluble Reactive Phosphorus
TERC	Tahoe Environmental Research Center
TKPOA	Tahoe Keys Property Owners Association
TRPA	Tahoe Resource Planning Agency
USACE	United States Army Corps of Engineers
US EPA	U.S. Environmental Protection Agency
'wet'	deposition of nutrients that takes place along with precipitation
WDRs	Waste Discharge Requirements

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