ATMOSPHERIC POLLUTANT DEPOSITION MONITORING

NITROGEN AND PHOSPHORUS DEPOSITION AT THE MID-LAKE STATION OF LAKE TAHOE

DATA SUMMARY:

OCTOBER 1, 2020 – SEPTEMBER 30, 2021

SUBMITTED TO:

TAHOE REGIONAL PLANNING AGENCY

SUBMITTED BY:

TAHOE ENVIRONMENTAL RESEARCH CENTER

UNIVERSITY OF CALIFORNIA, DAVIS

BRANDON BERRY
SHOHEI WATANABE
GEOFF SCHLADOW

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UCDAVIS TAHOE ENVIRONMENTAL RESEARCH CENTER

WY 2021 Mid-lake Atmospheric Deposition Data Summary

This document presents the data and a summary of results for atmospheric deposition monitoring of nitrogen (N) and phosphorus (P) at TERC's mid-lake atmospheric deposition station for the period October 1, 2020 – September 30, 2021. It includes results for water year (WY) 2021 N and P loads. Particulate data for PM2.5 from the CARB monitoring station in Tahoe City are also presented. A spreadsheet accompanying this document "WY2021_TERC_Mid-lake_AD_FINAL" presents summaries of the mid-lake atmospheric deposition since July, 2013, along with QA/QC data, estimated WY loading for N and P, and loading rate information.

This report forms part of Deliverable 2 under Contract #20C00008 between the TRPA and the Regents of the University of California.

Sampling Methods

Samples of atmospheric deposition to the lake were collected from mid-lake buoy TB1, in the north central portion of the lake (coordinates 39.1550000°N, 120.0041670°W). The collector consists of a modified 3 ½ gallon HDPE plastic bucket with reduced (6 inch) side-wall height, with 2.75 inch high removable plastic baffles inside (to dampen splash from the bucket). The bucket is partially filled with 4 liters of deionized water and placed on the buoy for a sampling period of 1-2 weeks. The collector at mid-lake is considered a "bulk collector" since it collects both wet deposition (precipitation) and dry deposition (settling particles, as well as gases and very small particles which are deposited due to their solubility or other physical or chemical attractions with the surface).

After boat retrieval, the bucket is returned to the lab where final water volume is measured and concentrations of NO_3-N, NH_4-N, TKN, SRP and TP are determined. The loading (g/ha) and loading rate (g/ha/day) for sample nutrients are calculated based on the bucket surface area and the duration of the deployment. Samples with contamination or otherwise compromised data were censored from the dataset (see QA/QC section). Total Water Year (WY) load (g/ha/yr) at mid-lake was estimated from the average loading for uncensored data. Dissolved inorganic nitrogen (DIN) (NO_3-N + NH_4-N) loading and total nitrogen (TN) (NO_3-N + TKN) loading were also determined.

For QA/QC samples, source deionized water samples, field blanks, and equipment blanks were analyzed. The source deionized water consisted of ultra-pure water collected from TERC's Milli-Q System. The field blank consisted of 4 liters of ultra-pure water added to a cleaned plastic bulk-deposition bucket, the bucket was enclosed in a plastic bag and held overnight in a cold room, then processed as a typical atmospheric deposition sample. The equipment blank consisted of 4 liters of ultra-pure water added to the carboy which is used to transport DI water. The equipment blank is held overnight in a cold room, then processed as a typical atmospheric deposition sample.

Data Summarized in Spreadsheet: "2021 TERC Mid-lake AD Final"

Data are summarized in the spreadsheet "WY2021_TERC_Mid-lake_AD_FINAL". 33 new mid-lake atmospheric deposition samples were collected during October 1, 2020 – September 30, 2021. The data for these samples are summarized in Table A along with consistent data collected for samples back to June 27, 2013. Table B presents the data for 3 source blanks, 5 field blanks, 1 equipment blank, QA/QC samples collected during the period along with all QA/QC values back through 2013. Table C presents a summary of estimated WY2021 DIN, TN, SRP and TP atmospheric deposition in loads per year (grams/hectare/year) along with the historical WY values. Table D in the spreadsheet presents a summary of atmospheric deposition as average daily loading rates of DIN, TN, SRP, TP (grams/hectare/day) for WY 2021 along with the historical values.

Project Quality Assurance

Standardized QA/QC practices for chemical analyses were followed as specified in the TERC QA/QC manual (Liston et al., 2013). For QA/QC in atmospheric deposition monitoring, a primary objective was to check for contamination associated with field monitoring equipment. Nutrient levels in field blanks and equipment blanks were compared with a source deionized water (ultra-pure Milli-Q deionized water) and also compared with the Method Detection Levels (MDLs) to check for contamination.

Three source blank, five bulk-deposition bucket field blanks, and one equipment blank were collected during the year and these showed very low or no contamination with N and P (Table B in the spreadsheet).

The atmospheric deposition data were reviewed and data subjected to quality control prior to calculation of loads. Atmospheric deposition samples may be contaminated with bugs, bird droppings, lake water splash or material from the buoy surfaces. Samples may be lost due to sample splash out of the bucket during very rough lake conditions. Samples may also sit for prolonged periods when researchers are unable to get to the buoy due to extended periods of rough lake conditions. When the buckets go dry, the deposition collection efficiency can change. Values censored from the data included mid-lake samples which: (1) had compromised sample bucket integrity with a crack in the bucket, and (2) potential contamination due to bird droppings in sample. In WY 2021, two samples were censored. The censored data in WY 2021 was during April 30, 2020 through May 18, 2020 and June 10, 2020 through June 22, 2020. The corresponding samples were during the early summer season, before the start of wildfires in the area. Due to the seasonality of the censored data, it is likely that N and P concentrations were not outlying data at the time, leading to little bias in the loading rates for WY 2021.

WY 2021 Wildfire Smoke

Atmospheric deposition data during WY 2021 was significantly impacted by wildfires and associated smoke. For the second year in a row, increases in N and P deposition in the Lake Tahoe Basin were directly correlated with wildfire activity. WY 2021 realized severe impacts from wildfire smoke due to the Tamarack, Dixie, and Caldor Fires burning in the immediate vicinity of the Lake Tahoe Basin. The Tamarack Fire started on July 4, 2021 and was contained on October 25, 2021, burning 68,637 acres. The Dixie Fire continued from July 13 through October 25, 2021, burning 963,309 acres. The Caldor Fire continued from August 14 though October 21, 2021, burning 221,835 acres and making its way into the Lake Tahoe Basin (Cal Fire. *2021 Fire Season*). The Lake Tahoe Basin experienced extended periods of heavy smoke during these fires contributing to unprecedented N and P loading rates for WY 2021.

Monitoring Results:

Dissolved Inorganic Nitrogen (DIN) Loading

Figure 1 shows the patterns for DIN loading rate (g/ha/d) from July 2013 through September 2021. The vertical axis, DIN Loading (g ha^{-1} day^{-1}), is displayed on two axes to compensate for the dramatic increase in loading during WY 2021. In WY 2021, DIN loading was estimated to be 4459 g ha^{-1} or 12.22 g/ha/d (Tables C and D in spreadsheet data summary). DIN loading in WY 2021 increased significantly compared to loading rates in WY 2020 (1696 g/ha/yr or 4.64 g/ha/d). WY 2021 included the largest estimated yearly load and highest daily loading rate for DIN since the inception of the atmospheric monitoring program in 1994.

Major sources of atmospheric nitrogen pollutants in the basin have been identified in other research studies. Motor vehicle emissions are thought to be the largest contributor to atmospheric nitrogen pollutants in the basin (Gertler et al., 2006; CARB, 2006 referenced in NDEP, 2011). However, the dramatic increase in loading rates in WY 2021 are likely associated with increased wildfires in California, especially those within close proximity to the Lake Tahoe Basin. On August 18, 2021, the state of California was facing "unprecedented fire conditions" as multiple fires including the Dixie Fire, Caldor Fire, and others raged on (Cal Fire. *2021 Fire Season*). Wildfire smoke from these fires, as well as others in Northern California, inundated the Lake Tahoe Basin for most of July and August, 2021. Extreme periods of wildfire smoke in the Lake Tahoe Basin are likely the cause of the substantial increase in DIN loading rates. It is noteworthy that during the peak periods of smoke activity in 2021, there was a mass exodus of tourists and residents from the Tahoe basin due to both the extremely hazardous air quality, the proximity of the Caldor Fire and the mandatory evacuations from the southern end of the lake. Consequently it is likely that vehicle related emissions were at very low levels.

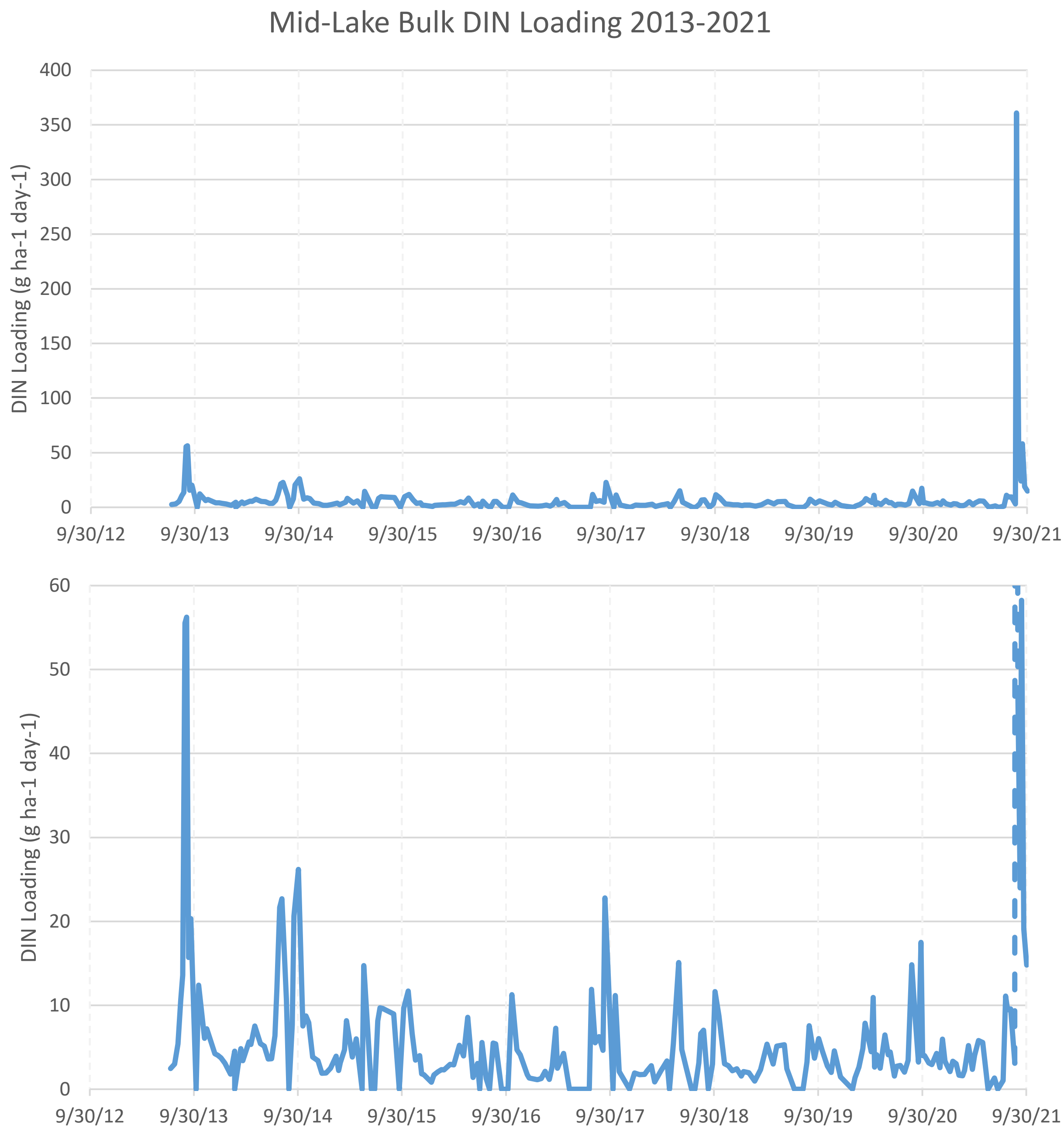

Figure 1. Loading rate of DIN (NO_3-N + NH_4-N) in bulk atmospheric deposition at mid-lake station during July 2013 – September 2021. Two different scales are used to highlight the exception values in 2021(upper figure) and to illustrate the seasonality (lower figure) with higher deposition rates in summer.

<u>Total Nitrogen (TN) Loading</u>

Figure 2 shows the patterns for TN loading rate (g/ha/d) from July, 2013 through September, 2021. The vertical axis, TN Loading (g ha^{-1} day^{-1}), is displayed on two axes to compensate for the dramatic increase in loading during WY 2021. In WY 2021, TN loading was estimated to be 5917 g ha^{-1} or 16.21 g/ha/d (Tables C and D in spreadsheet data summary). Assuming the same deposition rate over the entire 49,500 ha. surface area of the lake, this would be equivalent to 293 metric tons/year. By comparison the long-term average TN load from the Upper Truckee River is 18.2 metric tons/year. TN loading in WY 2021 increased significantly compared to loading rates in WY 2019 (2530 g/ha/yr or 6.91 g/ha/d). WY 2021 included the largest estimated yearly load and highest daily loading rate for TN since the inception of the atmospheric monitoring program in 1994.

Similar to DIN, TN levels are impacted by N from motor vehicle emissions, particulate-associated N (which may include such sources as inorganic and organic N associated with wind-blown dust, pollen, and wind-blown organic matter from forests), thunderstorms and smoke inputs. Past data indicates that spikes in TN loading are associated with wildfire smoke affecting the Lake Tahoe Basin. The summer of 2020 had a noticeable peak in TN directly correlated with wildfire smoke reaching the Tahoe basin. Increased loading of TN in the WY 2021 is also likely due to impacts from wildfire smoke. The dramatic increase in TN values can be attributed to the severity and close proximity of the wildfires. In wildfire smoke, small particulate matter (PM2.5) is one of the principal air pollutants and a good indicator of smoke related air quality. There is a distinct visual correlation between increases in TN loading and increases in PM2.5 during July – September, 2021 (Figure 3). There is also a clear statistical correlation between TN and PM2.5 for WY 2021 with an $R^2 = 0.90$. The PM2.5 concentrations displayed in Figure 3 are the average PM2.5 concentration during the atmospheric deposition sample period. Deposition deployment periods with the highest TN loading rates also represent the highest PM2.5 concentrations (August 20-24, August 24-27, 2021). Daily average PM2.5 concentrations were recorded at the Tahoe City site located at 221 Fairway Drive (CARB. Air Quality and Meteorological Information). Extreme wildfire smoke impacts in the Lake Tahoe Basin are likely the source of elevated levels of TN loading during the WY 2021.

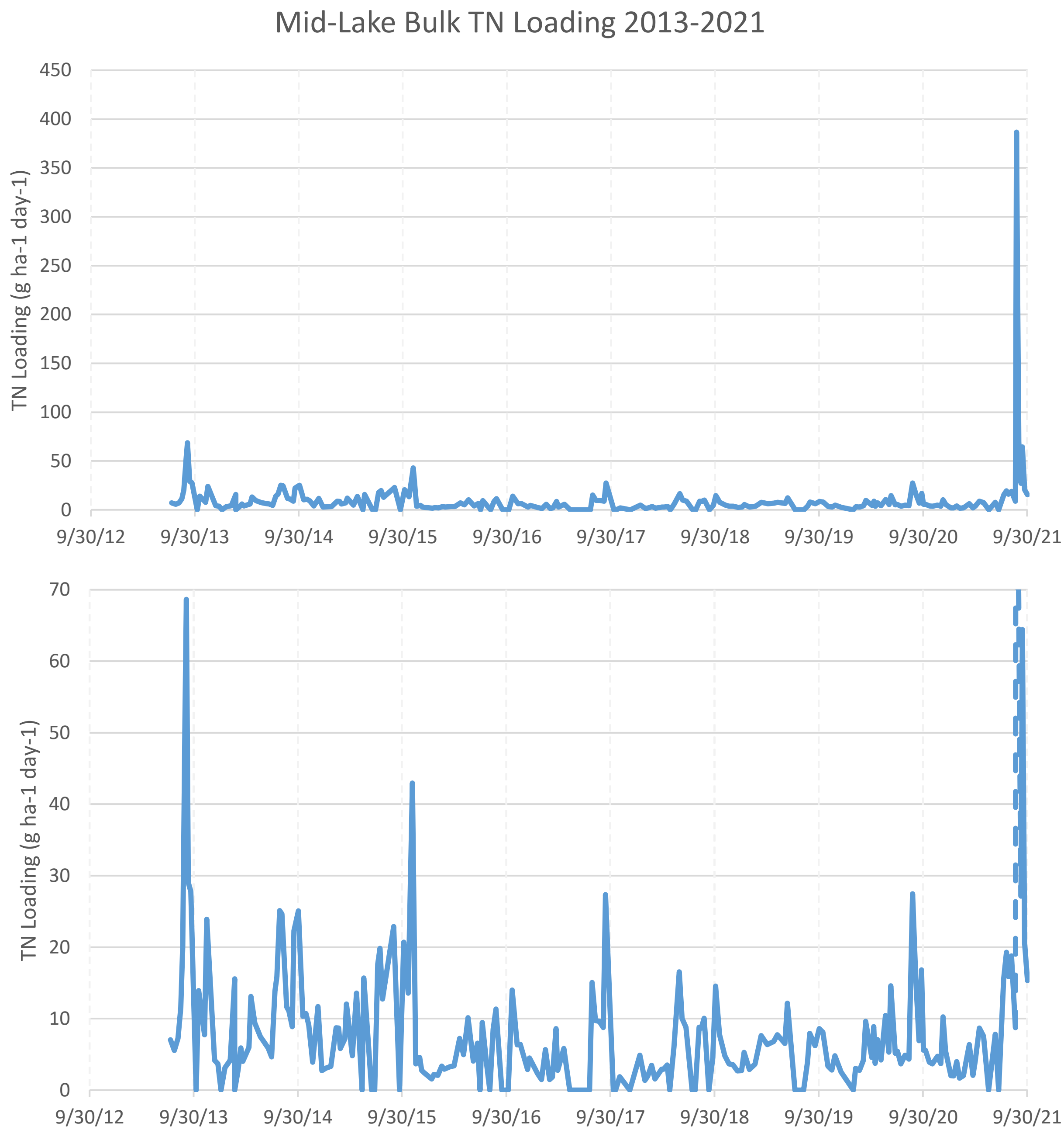

Figure 2. Loading rate of TN (NO_3-N + TKN) in bulk atmospheric deposition at mid-lake station during July 2013 – September 2021.

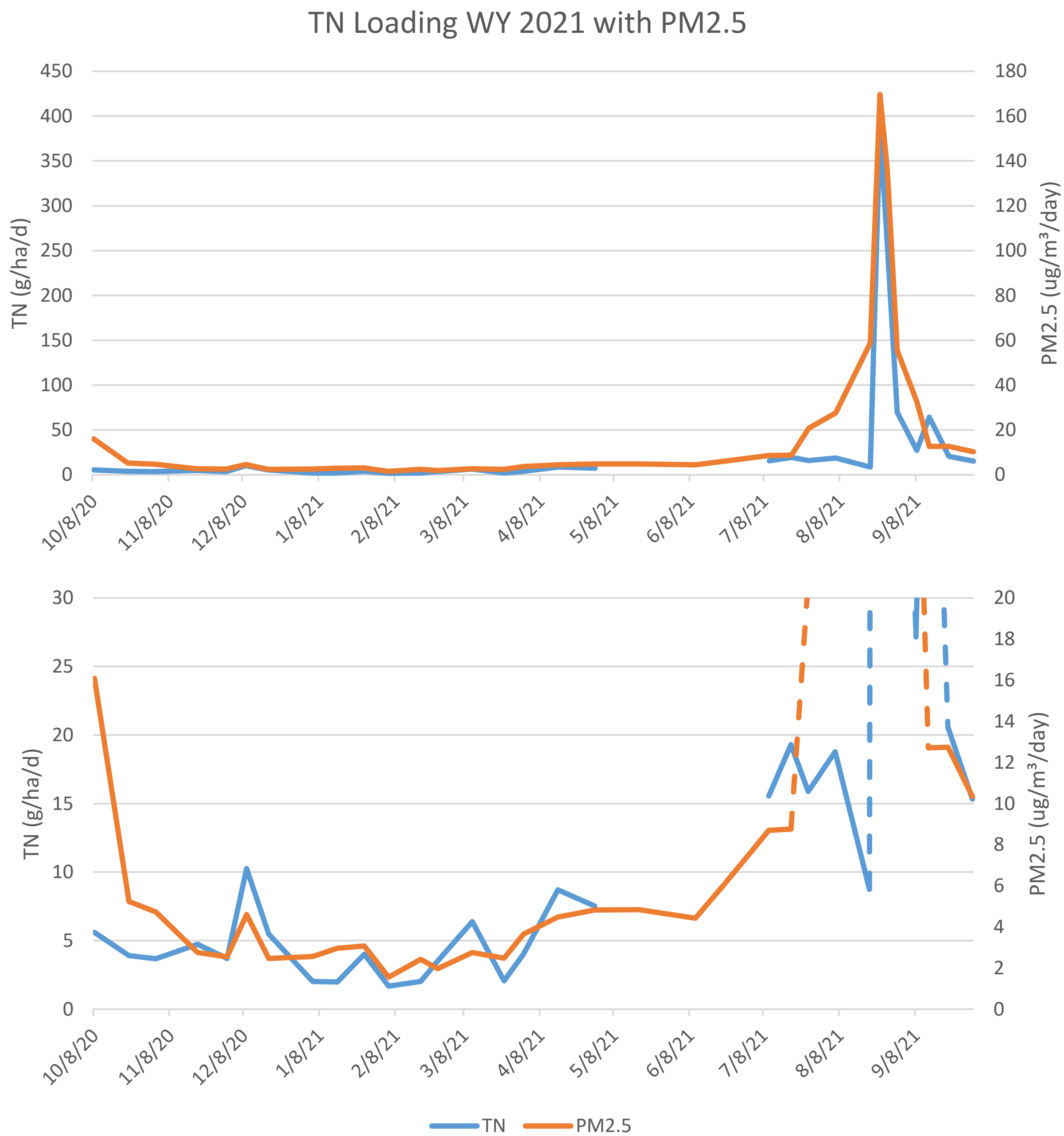

Figure 3. Loading rate of TN (NO_3-N + TKN) at mid-lake station for WY 2021 compared to average daily PM2.5 concentrations.

Soluble Reactive Phosphorus (SRP) Loading

Figure 4 shows the patterns for SRP loading rate (g/ha/d) from July 2013 through September 2021. The vertical axis, SRP Loading (g ha^{-1} day^{-1}), is displayed on two axes to compensate for the dramatic increase in loading during WY 2021. In WY 2021, SRP loading in bulk atmospheric deposition at mid-lake was an estimated 175.73 g/ha/yr or 0.48 g/ha/d (Tables C and D in spreadsheet data summary). Assuming the same deposition rate over the entire 49,500 ha.

surface area of the lake, this would be equivalent to 8.7 metric tons/year. By comparison the long-term average SRP load from the Upper Truckee River is 0.49 metric tons/year. SRP loading in WY 2021 increased compared to loading rates in WY 2020 (42.69 g/ha/yr or 0.12 g/ha/d). SRP loading rates in WY 2021 quadrupled in value from WY 2020.

WY 2021 exhibited the largest SRP loading rate on record over the past 30 years. Previous years with high SRP loading are correlated to wildfire smoke in the Tahoe basin. WY 2020 contained loading rates of 42.69 g/ha/yr which can be attributed to the record-breaking wildfire season in California during summer 2020. Loading rates in 2013 were 30.77 g/ha/yr as a result of the Rim Fire near Yosemite. Smoke in the basin from the American River Complex fire in 2008 contributed to an SRP loading of 52.40 g/ha/yr. However, past SRP loads are greatly exceeded when compared to inputs during WY 2021. The substantial increase in SRP loading within the Tahoe basin can be attributed to the Tamarack, Dixie, and Caldor wildfires and their immediate vicinity to Lake Tahoe.

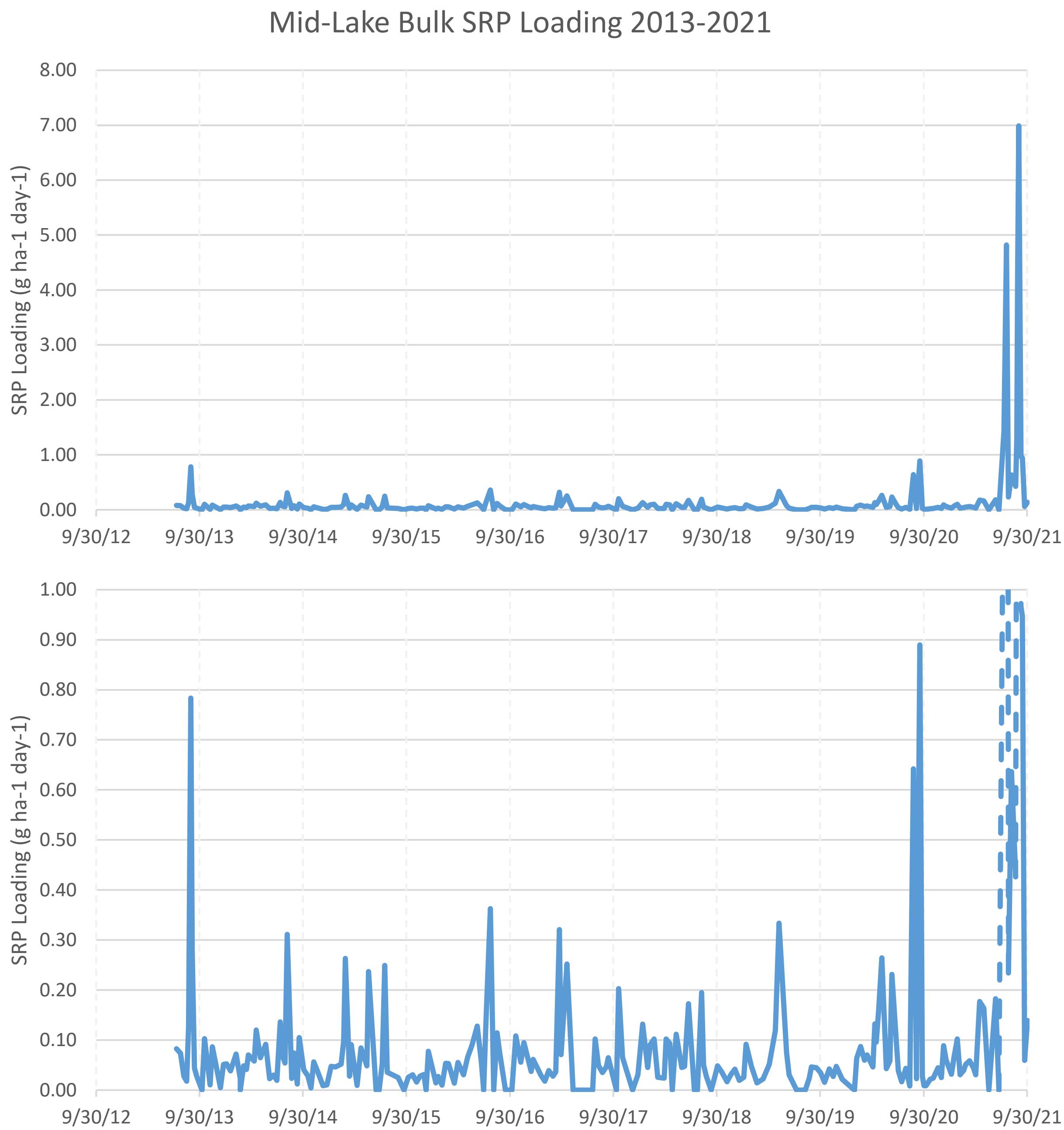

Figure 4. Loading rate of SRP in bulk atmospheric deposition at mid-lake station during July 2013 - September 2021.

Total Phosphorus (TP) Loading

Figure 5 shows the patterns for TP loading rate from July, 2013 through September 2021. The vertical axis, TP Loading (g ha^{-1} day^{-1}), is displayed on two axes to compensate for the dramatic increase in loading during WY 2021. In WY 2021, TP loading in bulk atmospheric deposition at mid-lake was an estimated 333.60 g/ha/yr or 0.91 g/ha/d (Tables C and D in spreadsheet data summary). Assuming the same deposition rate over the entire 49,500 ha. surface area of the lake, this would be equivalent to 16.5 metric tons/year. By comparison the long-term average Total Phosphorus load from the Upper Truckee River is 3.2 metric tons/year. TP loading in WY 2021 increased compared to loading rates in WY 2020 (141.15 g/ha/yr or 0.39 g/ha/d). Both TP daily loading rates and yearly load were the highest levels on record back through 1994.

A variety of factors impact levels of TP in atmospheric deposition samples in the basin. Gertler et al. (2006) indicate the primary factors are the mobilization of local sources from roadway sanding and salting in the winter, and from local soils in the summer and vehicle exhaust. Observations of material deposited in buckets indicates that wind-blown dust, pollen, wind-blown organic matter from the forests may also be potential sources of TP, along with TP contributed with smoke and ash. More recently, wildfire smoke and ash continue to play a larger role in P deposition in the Tahoe Basin. Significant increases in TP loading in the WY 2021 can be attributed to extensive wildfire smoke in the basin. Previous years with increases in TP loading were also affected by wildfire smoke. It is noteworthy that during the peak periods of smoke activity in 2021, there was a mass exodus of tourists and residents from the Tahoe basin due to both the extremely hazardous air quality, the proximity of the Caldor Fire and the mandatory evacuations from the southern end of the lake. Consequently it is likely that vehicle related emissions were at very low levels.

The data for WY 2021 contains the highest yearly TP load on record for the monitoring program, which was previously set during WY 2020. Similar to TN, the visual correlation between significant TP increases in the late summer of WY 2021 are directly related to increases in PM2.5 within the basin (Figure 6). The statistical correlation between TP and PM2.5 for WY 2021 is $R^2 = 0.39$. It is largely apparent that the 2021 wildfires contributed to a significant increase in TP loading in the Tahoe basin. Wildfires are quickly becoming the primary source of TP deposition in the Tahoe Basin.

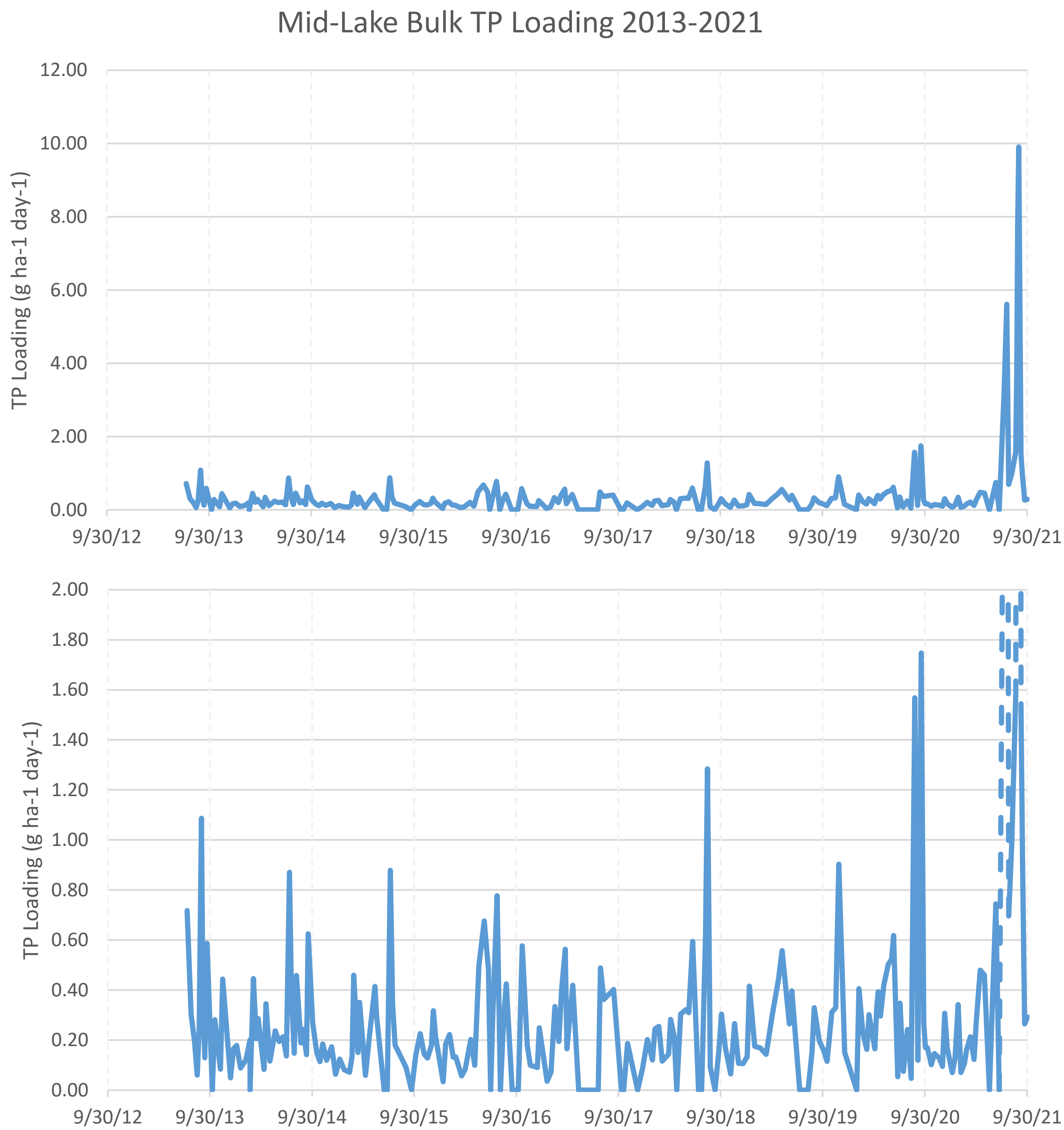

Figure 5. Loading rate of TP in bulk atmospheric deposition at mid-lake station during July 2013 – September 2021.

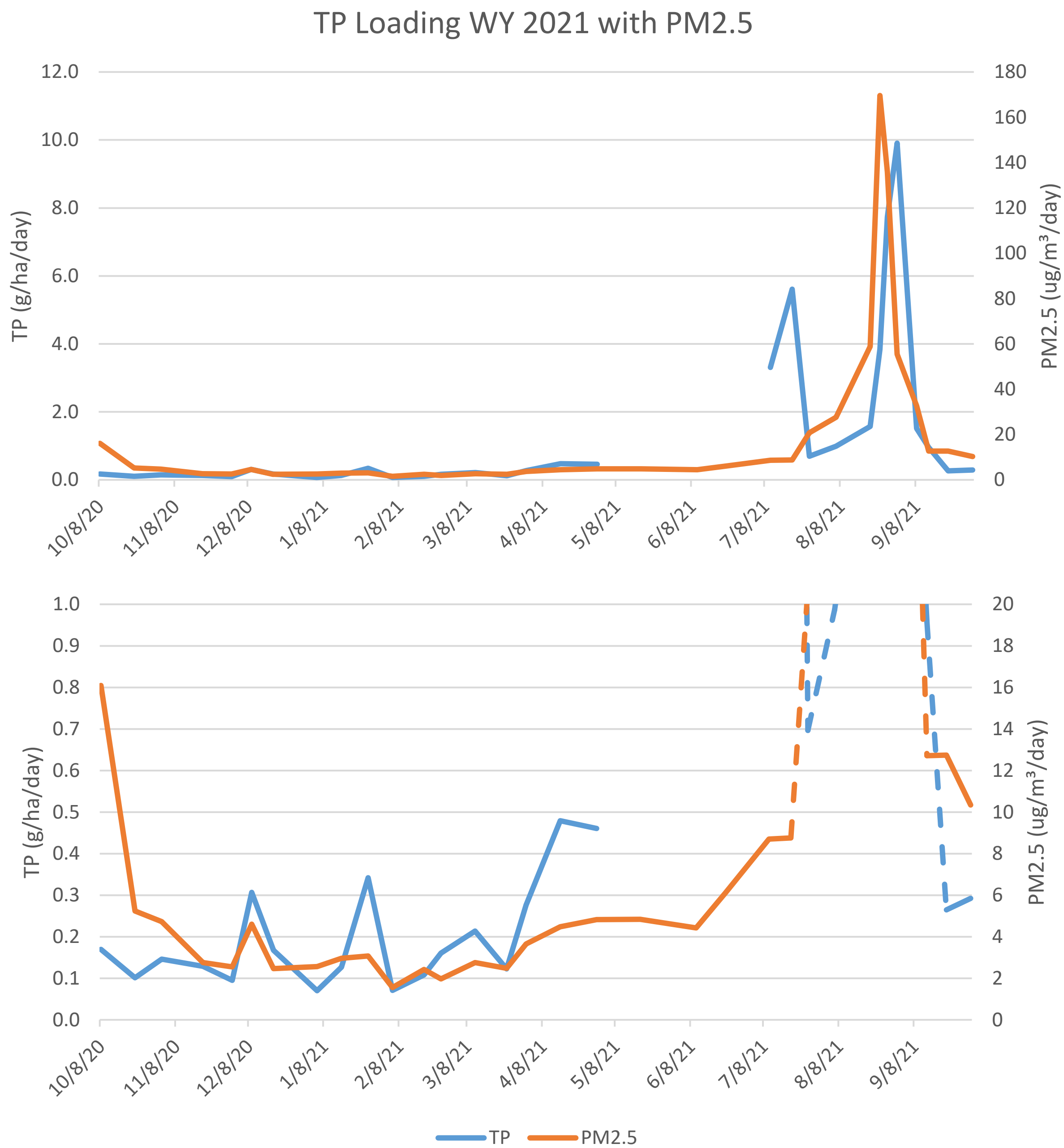

Figure 6. Loading rate of TP at mid-lake station for WY 2021 compared to average daily PM2.5 concentrations.

Acknowledgements

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References

Cal Fire. *2021 Fire Season.* 8 Feb. 2022: https://www.fire.ca.gov/incidents/2021/.

CARB (California Air Resources Board). 2006. Lake Tahoe Atmospheric Deposition Study (LTADS). Final Report – August, 2006. Atmospheric Processes Research Section, California EPA, Sacramento, CA.

CARB (California Air Resources Board). Air Quality and Meteorological Information. Tahoe City – 221 Fairway Dr Site. 8 Feb. 2022: https://www.arb.ca.gov/aqmis2/.

Gertler, A.W., Bytnerowicz, A., Cahill, T.A., Arbaugh, M., Cliff, S., Kahyaoglu-Koracin, J., Tarnay, L., Alonso, R. and W. Fraczek. 2006. Local air pollutants threaten Lake Tahoe's clarity. California Agriculture 60(2):53-58.

Liston, A., T. Hammell, V. Edirveerasingam, B. Allen, S. Hackley, J. Reuter and G. Schladow. 2013 Updated June 24, 2014). *Laboratory Procedure, Field Protocol and Quality Assurance Manual*, Tahoe Environmental Research Center, University of California, Davis. 158 p.

NDEP (Nevada Division of Environmental Protection). 2011. Final Lake Tahoe Total Maximum Daily Load. NDEP, Carson City, NV.