Review, Chronology and Summary of the Atmospheric Deposition Program

Sponsored by the Wasatch Front Water Quality Council

# Draft

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# Executive Summary

Utah Lake has been the focus of investigation since it was placed on Utah's 303(d) list of impaired waters in 2002. The cause was identified as total phosphorus (TP) exceeding the narrative criteria of 0.025 mg $L^{-1}$ for aquatic life. No violations of numeric standards associated with eutrophication (such as high pH or low dissolved oxygen) have been documented and the lake is noted for its diverse and productive fishery. An assessment of the risk to human health for the potential toxicity of cyanobacterial toxins was initiated after cyanobacteria blooms were noted in 2016. Thus started an intense monitoring and research program focused on nutrient sources, P speciation, sediment nutrient recycling and other environmental conditions that trigger these potentially harmful algal blooms. As part of bringing more certainty to the sources and loads contributing to the nutrient budget for Utah Lake, the Wasatch Front Water Quality Council (Council) initiated an intensive atmospheric deposition program to quantify the contribution of all sources resulting from human activities (urban development, agricultural activities) as well as dusts from playas of ancient Lake Bonneville mobilized by prevailing winds, passing cold fronts and monsoonal dust and rainstorms that regularly occur in central Utah. These projects were initiated under to guidance of Council scientists and two professors at Brigham Young University. We deployed several bulk deposition samplers around Utah Lake and in surrounding urban areas starting in 2017. Samples were collected from each sampler as quickly as possible following a rain event and this allowed analysis of the aqueous solution by ICP for total P and colorimetric for ortho-P nitrate-nitrite and ammonia. We also constructed five wet/dry samplers following the early design of the National Atmospheric Deposition Program (NADP). Samplers included a lid covering the wet-side bucket during dry periods and is opened by an actuator that is triggered by a moisture sensor as rain events begin. These samplers were placed near the shoreline at locations surrounding Utah lake. Because there was a critical question as to how far dust/aerosols travel across the lake surface, we installed an elevated wet/dry sampler at Bird Island to capture representative samples of material falling near the center of the lake.

Early in this process and in response to Council/BYU initial findings, Utah Division of Water Quality (UDWQ) contracted to a professor at Utah State University to provide alternative estimates of AD on Utah Lake using literature values of various regional and global measurements of wet and dry, urban, and regional measurements. The report presented here provides details of methods employed during Council projects, key variables affecting results, and a detailed evaluation of the merits and assumptions used in estimating AD values based on literature review.  We also contracted with the director of the NADP to review our data and methods and made recommended adjustments to our analytical processes and to our equipment, including purchasing two wet/dry samplers sanctioned by the NADP.

The results of hundreds of samples collected by each of the bulk deposition and wet/dry deposition programs and the results of the UDWQ contractor are summarized in the table below (Table 1). BYU data indicates that TP deposition on Utah Lake ranges from about 77 to 350 tons and dissolved inorganic nitrogen ranges from perhaps 50 to greater than 1000 tons per year. Based on careful evaluation of the methods and data, we suggest the best estimate of average AD is 175 tons per year for TP and 700 tons per year of DIN.

Table 1. Summary of all sampling programs and the review of literature values used to estimate phosphorus and nitrogen deposition on Utah Lake.

| Author | Years sampled | Sample type | Total P Load (tons) | SRP/O-P Load (tons) | Inorganic N (tons) |
|---|---|---|---|---|---|
| W. Miller 2021 | 2017-2020 | Bulk | 77 | 24.9 | 316 |
| W. Miller 2021 | 2017-2020 | Bulk, Precipitation-weighted | 115 | | 422 |
| Olsen et al. (2018) | 2017 | 8 Mo. Wet/dry, sample removed from dataset if any visible particle present | 8 | NA | 46 |
| Olsen et al. (2018) | 2017 | 8 Mo. Wet/dry All data used | 430 | | 460 |
| Reidhead (2019) | 2018 | 7.5 Mo. Wet/dry floating debris removed but no outliers removed | 193 | 71 | 636 |
| Barrus et al. (2021) | 2019 | Wet/dry no screens, floating debris removed | 262 | NA | 1052 |
| Barrus et al. (2021) | 2020 | Wet/dry screens in place, Bird Is. installed | 133 | NA | 482 |
| Brahney (2019) | Lit review | Multiple types, Global, regional, Modelling | 3.5-13.4 | 2.7-7.9 (“Bioavailable”) | 153-288 |
| USGS | 2020 | Bulk samplers surrounding Great Salt Lake | NA | NA | 355 |

## Table of Contents …

## List of Tables

List of Figures

# Introduction

## Background: Nutrient Regulations and Utah Lake

The Utah Division of Water Quality (UDWQ) placed Utah Lake on the 303(d) list of impaired waters in 2002 because total phosphorus exceeded the narrative lake criterion for aquatic life of 0.025 mg/L. This listing is unique because the longstanding policy was to list for TP only if it is supported by violation of a related numeric standard such as low dissolved oxygen or pH > 9.0. The presence of other impairment indicator such as the presence of s Cyanobacteria dominance during summer or fish kills may also support the decision for impairment. Yet, although technically considered eutrophic to hypereutrophic, DO or pH violations or fish kills have never been documented and the lake only occasionally experiences cyanobacterial blooms at locations other that the bays or marinas. The fishery is considered one of the most diverse and productive fisheries in Utah, including the state's best white bass and walleye fishery and is continuing to support an increasing population and delisting of the June sucker from Endangered status to Threatened status under the Endangered Species Act (e.g., see Richards 2022).

Nevertheless, the UDWQ proceeded with a preliminary Total Maximum Daily Load for Phosphorus in Utah Lake (TMDL; PSOMAS 2007). Based on this initial study, the tributaries were estimated to contribute 97.2% of the Phosphorus, approximately 80% of which was attributed to the surrounding POTWs (PSOMAS 2007). Merritt (2017) estimated 79% of P entering the lake came from these POTWs. This information placed focus on Utah County's POTWs for plant upgrades to reduce P inputs.

With this growing concern, several of Utah County's special service districts and municipalities joined the Wasatch Front Water Quality Council (Council) with the intent of supporting studies to clarify and quantify the relative importance of loading sources including POTWs. The assignment from the Council was to bringing more focus on water column and sediment chemistry of P dynamics and bioavailability in Utah Lake and the ecology of the lake with reference to the listing for aquatic life impairment. In addition, evaluation of the discharge characteristics determined that except for Timpanogos Special Service District, all the local POTWs discharged into slow moving tributaries or sloughs upstream from the edge of Utah Lake - allowing an undetermined amount of nutrient assimilation prior to entry in the Lake. As such, the Council sponsored studies focused on aquatic and sediment chemistry and nutrient transformations (Randall et al. 2019, Goel and Carling 2021, Taggert 2021). These studies began describing the ability of Utah lake sediments to sequester P from the water column as well as understanding the chemical conditions under which P recycles from the sediments to the water column. Further, the Council is developing the first food web model for Utah Lake designed to understand and predict the diversity and interrelationship between nutrients, phytoplankton, zooplankton benthic macroinvertebrates, and its fisheries. (Richards, 2022).

Council also began measuring flows and nutrient concentrations in all major tributaries and POTW discharges (at end of pipe as well as entry to the lake) to improve the accuracy of the nutrient budget for Utah Lake. These investigations are continuing and will reach an important level of understanding by the end of 2022.

## Importance of Atmospheric Deposition to Utah Lake's Nutrient Budget

During our initial sampling visits, we observed both morning inversions and occasional dust storms that covered the entire lake. Ensuing literature review revealed that AD may represent an important contribution to the nutrient budget of lakes. The study of AD on Lake Tahoe by Jassby et al. (1994) confirmed that atmospheric deposition on Utah Lake could be an important contribution to its nutrient budget. We hypothesized that AD of dust and aerosols from the frequent dust storms from the west and southern deserts, agricultural activities, and reoccurring smog-laden inversions over the lake (Miller and Barrus 2019) contribute significant quantities of nutrients to Utah Lake. This report focuses on two atmospheric deposition (AD) studies, using three different collection methods to measure the deposition of P and N directly on the surface of Utah Lake.

## Methods and Materials

The Council initiated its atmospheric deposition program in 2017 in response to recent observations of aerial dust and inversions over Utah Lake and reports by the National Atmospheric Deposition Program (NADP; http://nadp.slh.wisc.edu/) describing the significance of atmospheric deposition across western US. Accordingly, we constructed atmospheric deposition samplers based on the original design by the NADP (Figure 1) and made further modifications after considerable experience and recommendations by the Utah Lake Science Panel and Dr. David Gay, current Director of the NADP. Simultaneously, the Council entered into a contract with Dr. Wood Miller to design and establish a network of bulk atmospheric deposition samplers distributed around Utah Lake and in subsequent years added additional sites in the urban areas of Utah County and around Farmington Bay of Great Salt Lake.

Figure 3. Photograph of AD samplers located within the Ambassador Duck Club. The samplers are equipped with a solar-powered battery that powers a moisture sensor and actuator/motor that shifts the lid to expose the "wet side" bucket and cover the "dry side" bucket when rain or snow occurs. When the moisture sensor dries (a few minutes after a rain event), the actuator returns the lid to cover and preserve the rain sample. The sampler on the right was the original design (top of bucket at about 1.2 m above the ground). After concern expressed by the Utah Lake Science Panel, the legs were extended in 2020 to situate the top of the bucket at 2 m above ground level (sampler on left).

Two low tables were retained and placed side by side with two tall tables at two locations in 2020 to provide a comparison of data between the two designs. Also, starting in 2020, two commercially available samplers, recommended by the NADP, (obtained by N-Con Systems Company, Arnoldsville, GA), were placed beside the high and low tables at the Central Davis and Orem City Water Reclamation Facilities and to provide a comparison with our original design.

Concurrent, with our deployment of the automated wet/dry samplers, Dr. Wood Miller of BYU deployed eight bulk deposition samplers (Figure 2) around Utah Lake and on the BYU campus (Figure 3).

Dr. Miller uses a simple apparatus comprised of a glass funnel (mouth ~ 12 in. or 31 cm diameter), leading to a collection vessel. Samples were collected following each rain event so that all samples were in liquid form. Thus, sampling intervals ranged from a few days to several weeks. Dr. Gay noted that these samples are considered conservative estimates of wet deposition in that dry particles are added to the wet deposition collection (bias higher), but that these same particles that settle on the funnel are subject to resuspension by subsequent wind events and the ammonia may be subject to subsequent volatilization. Nevertheless, these inexpensive and low-maintenance samplers are considered an appropriate tool for estimating bulk deposition (David Gay, personal communication). These samples were immediately transported to a local commercial laboratory, Chem-Tech Ford, for analysis of total phosphorus and total nitrogen during 2017 and 2018. Ortho-phosphate analysis was added for 2019 and 2020.

Sites included (Figure 3):

BYU Campus: located at: 40.248440° N, -111.647195° W

Lincoln Point: Located at: 40.143923° N, -111.811227° W

Pelican Point: Located at: 40.268533° N, -111.828533° W

Genola: Located at: 40.011484° N, -111.841839° W

Elberta: Located at: 39.982625° N, -111.923862° W

Mosida: Located at: 40.077020° N, -111.925883° W

Lehi: (near the pump Station): Located at: 40.360367° N, -111.896509° W

Orem: Located at: 40.276325 N,-111.896509° W

Spanish Fork: Located at: 40.083900° N, -111.593577° W

# Results and Discussion

## Bulk Deposition Measurements

Data were analyzed in several different ways. Annual means were first calculated by taking the average values for each site and presented as 1) the sum of all data, 2) summer and winter values, 3) and arbitrarily removing "outliers" based on exceeding 1 mg/L or 5 mg/L (Tables 1a, 1b. and 1c.). These tables of raw data are included to provide the details of sampling results.

Figure 2. Typical mounting of a bulk deposition sampler. This sampler is located on Antelope Island of Great Salt Lake.

Using all data (since 2017, the beginning of the bulk sampling program), for total P resulted in an estimate of 77 tons of total P falling on the lake per year (Table 2a). Ortho-P data are presented in Table 1b. Notably, the total mass of ortho-P, without "outliers" removed, is 24.9 tons per year falling on the lake, or about 32% of total P. Notably, although winter samples collected approximately 1/3 of the summer mass, the ratio of ortho-P/total P did not change significantly between seasons. This suggests that the source material does not change significantly seasonally.

Total inorganic nitrogen results are displayed in Table 1c. As with P all TN data for all three years are listed for each site and then averaged and summed. For all data, as of July 1, 2020, the total Nitrogen falling on Utah Lake is estimated to be 316 tons per year. Again, much more nitrogen was deposited during summer than winter (Table 1c.).

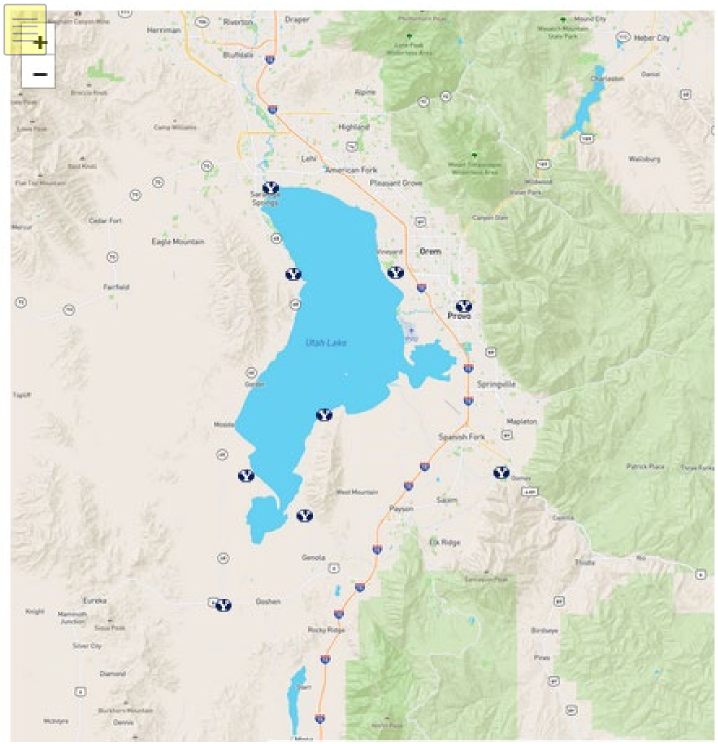



Figure 4. Map of Utah Lake depicting the locations (Y) of the bulk deposition samplers during 2018.

Also notable, the highest concentrations of P and N were typically measured at sites on the southern end of Utah Lake. This is closest to the direction of the prevailing winds and the strongest winds associated with thunderstorms and storm fronts.

**TABLE 3a. Averages at all 9 locations for all phosphorus samples collected from 2019 – 2020 summarized by season (summer =April-September) and winter (October-March). Outlier data are retained as per original tables developed by Dr. Wood Miller (2021).**

| Location | Total Phos (mg/l) **all data** | Total Phos (mg/l) **summer** | Total Phos (mg/l) **winter** | Total Phos (mg/l) **TP < 1** | Total Phos (mg/l) **summer** | Total Phos (mg/l) **winter** | Total Phos (mg/l) **TP < 5** | Total Phos (mg/l) **summer** | Total Phos (mg/l) **winter** | all TP samples | TP outliers >1 mg/l | >5 mg/l |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BYU | 0.09 | 0.12 | 0.08 | 0.09 | 0.12 | 0.08 | 0.09 | 0.12 | 0.08 | 47 | 0 | 0 |
| Lincoln Pt | 1.04 | 1.62 | 0.45 | 0.23 | 0.35 | 0.13 | 0.51 | 0.78 | 0.24 | 51 | 12 | 4 |
| Pelican Pt | 0.74 | 0.75 | 0.74 | 0.23 | 0.23 | 0.24 | 0.43 | 0.41 | 0.44 | 43 | 7 | 2 |
| Genola | 1.21 | 1.93 | 0.20 | 0.22 | 0.25 | 0.20 | 0.44 | 0.65 | 0.20 | 48 | 10 | 5 |
| Elberta | 0.43 | 0.42 | 0.44 | 0.34 | 0.35 | 0.32 | 0.43 | 0.42 | 0.44 | 46 | 4 | 0 |
| Mosida | 0.99 | 1.46 | 0.31 | 0.31 | 0.39 | 0.23 | 0.99 | 1.46 | 0.31 | 39 | 11 | 0 |
| Lehi | 0.79 | 1.17 | 0.35 | 0.22 | 0.28 | 0.16 | 0.47 | 0.58 | 0.35 | 52 | 10 | 2 |
| Orem | 0.57 | 0.77 | 0.27 | 0.22 | 0.26 | 0.16 | 0.38 | 0.46 | 0.27 | 45 | 7 | 1 |
| Sp Fork | 0.23 | 0.37 | 0.08 | 0.13 | 0.17 | 0.08 | 0.23 | 0.37 | 0.08 | 45 | 2 | 0 |
| averages | 0.68 | 0.96 | 0.32 | 0.22 | 0.27 | 0.18 | 0.44 | 0.58 | 0.27 | 416 | 63 | 14 |
| no.samples | 416 | 217 | 199 | 353 | 168 | 185 | 402 | 205 | 197 | 416 plus 14 BDL as of July 1, 2020 | | |
| tonsTP/yr at avg area 83,800 ac & 12"/yr rain or 6"/half yr at given avg | 77.1 | 54.4 | 18.5 | 25.1 | 15.2 | 10.2 | 50.2 | 33.2 | 15.3 | | | |

**Table 2b. Averages at all 9 locations for all ortho-phosphorus: total phosphorus ratiosfor the whole year and for summer (Apr-Sept) and winter (Oct-Mar).**

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **( W. Miller 2021.)** | | | | | | | | | | | | |
| Location | Ortho-P | Ortho-P | Ortho-P | all | OP/TP | OP/TP | OP/TP | OP/TP | OP/TP | OP/TP | OP/TP | OP/TP | OP/TP |
| | (mg/l) | (mg/l) | (mg/l) | Ortho-P | % | % | % | % | % | % | % | % | % |
| | **all data** | **summer** | **winter** | samples | **all data** | **summer** | **winter** | **TP < 1** | **summer** | **winter** | **TP < 5** | **summer** | **winter** |
| | | | | | | | | | | | | | |
| BYU | 0.01 | 0.02 | 0.00 | 2 | 10.83 | 16.57 | 0.00 | 10.83 | 16.57 | 0.00 | 10.83 | 16.57 | 0.00 |
| Lincoln Pt | 0.40 | 0.68 | 0.04 | 16 | 37.95 | 41.79 | 8.01 | 175.13 | 190.46 | 28.26 | 77.90 | 86.18 | 14.68 |
| Pelican Pt | 0.11 | 0.11 | 0.10 | 11 | 14.28 | 15.00 | 13.69 | 45.48 | 48.81 | 42.66 | 24.89 | 27.25 | 22.87 |
| Genola | 0.12 | 0.17 | 0.04 | 13 | 10.07 | 9.02 | 19.00 | 54.92 | 70.92 | 19.00 | 27.49 | 26.62 | 19.00 |
| Elberta | 0.19 | 0.14 | 0.26 | 12 | 43.87 | 32.62 | 59.21 | 55.61 | 38.89 | 81.02 | 43.87 | 32.62 | 59.21 |
| Mosida | 0.75 | 1.09 | 0.14 | 11 | 75.64 | 74.99 | 45.51 | 244.15 | 280.77 | 60.90 | 75.64 | 74.99 | 45.51 |
| Lehi | 0.15 | 0.16 | 0.15 | 13 | 19.56 | 13.96 | 41.18 | 69.01 | 57.38 | 88.26 | 33.02 | 28.30 | 41.18 |
| Orem | 0.17 | 0.25 | 0.08 | 16 | 29.28 | 32.87 | 29.79 | 76.86 | 98.49 | 49.81 | 43.84 | 55.45 | 29.79 |
| Sp Fork | 0.08 | 0.10 | 0.02 | 8 | 33.98 | 26.68 | 18.23 | 62.36 | 58.01 | 18.23 | 33.98 | 26.68 | 98.76 |
| | | | | | | | | | | | | | |
| averages | 0.22 | 0.30 | 0.09 | 102 | 30.61 | 29.28 | 26.07 | 88.26 | 95.59 | 43.13 | 41.27 | 41.63 | 36.78 |
| | | | | | | | | | | | | | |
| no.samples | 102 | 58 | 44 | 102 plus 25 BDL | | | | | | | | | |
| | | | | as of July 1, 2020 | | | | | | | | | |
| Tons OP/yr | 24.9 | 17.3 | 5.2 | | | | | | | | | | |
| at avg area | | | | | | | | | | | | | |
| 83,800 ac | | | | | | | | | | | | | |
| & 12"/yr rain | | | | | | | | | | | | | |
| or 6"/half yr | | | | | | | | | | | | | |
| at given avg | | | | | | | | | | | | | |
| OP conc. | | | | | | | | | | | | | |

Table 2 c. Averages at 9 locations for nitrogen samples for whole year and for summer and winter. Outlier values were arbitrarily considered as exceeding 10 mg/L. Table from W. Miller (2021)

| Location | Total Nitro | Total Nitro | Total Nitro | Total Nitro | Total Nitro | Total Nitro | all TN | TN outliers |
|---|---|---|---|---|---|---|---|---|
| | (mg/l) | (mg/l) | (mg/l) | (mg/l) | (mg/l) | (mg/l) | samples | >10 mg/l |
| | **all data** | **summer** | **winter** | **TN <10** | **summer** | **winter** | | |
| | | | | | | | | |
| BYU | 2.15 | 2.14 | 2.16 | 2.15 | 2.14 | 2.16 | 43 | 0 |
| Lincoln Pt | 4.73 | 5.61 | 3.48 | 2.19 | 2.53 | 1.73 | 46 | 6 |
| Pelican Pt | 2.43 | 2.33 | 2.54 | 2.23 | 2.33 | 2.13 | 41 | 1 |
| Genola | 1.92 | 2.54 | 1.12 | 1.69 | 2.15 | 1.12 | 44 | 1 |
| Elberta | 1.97 | 1.64 | 2.28 | 2.89 | 1.64 | 2.28 | 39 | 0 |
| Mosida | 5.73 | 6.67 | 4.38 | 2.49 | 2.65 | 2.29 | 39 | 5 |
| Lehi | 2.55 | 3.35 | 1.71 | 2.55 | 3.35 | 1.71 | 49 | 0 |
| Orem | 2.03 | 2.22 | 1.76 | 2.03 | 2.22 | 1.76 | 43 | 0 |
| Sp Fork | 1.47 | 1.88 | 1.09 | 1.47 | 1.88 | 1.09 | 52 | 0 |
| | | | | | | | | |
| averages | 2.77 | 3.15 | 2.28 | 2.19 | 2.32 | 1.81 | 396 | 13 |
| | | | | | | | | |
| no. samples | 396 | 205 | 191 | 383 | 196 | 187 | 396 plus 32 BDL | |
| | | | | | | | as of July 1, 2020 | |
| Tons TN/yr | 316.0 | 179.5 | 129.7 | 249.2 | 132.2 | 102.8 | | |
| at avg area | | | | | | | | |
| 83,800 ac | | | | | | | | |
| & 12"/yr rain | | | | | | | | |
| or 6"/half yr | | | | | | | | |
| at given avg | | | | | | | | |
| TN conc. | | | | | | | | |

Separation of the higher concentration (as outliers) data > 1 mg/L and > 5 mg/L from the analyses substantially reduced estimates of P deposition to 25.1 tons TP/yr and 33.2 tons per year, respectively. However, the likely source of these outliers lies in the fact that samples are collected only after a measurable rain event. Thus, and which has been the case during all sampling years, there are often long intervals between rain events, again suggesting very important dry deposition addition to the lake. Extended dry periods (up to several weeks) allow for significant dry deposition, of all sized particles, to accumulated on the funnel surface. Examples of this occurrence are illustrated in the following tables 3 through 8 Most of the outlier results occur following several weeks of dry weather before the next rain event that triggers sample collection. Hence, the ensuing rain event washes this extended accumulation of particles into the collection vessel. This phenomenon has been discussed with Dr. David Gay, (Director of NADP), with agreement that these extended periods of accumulation are the likely source of these elevated values. Therefore, 77 tons/yr (including all sample data) should be considered a conservative estimate.  However, at the suggestion of Dr. Gay, additional analyses, using precipitation-weighted values was also performed.

Ortho-P or soluble reactive P (SRP) are universally considered a measure of biologically available P as it relates to algal growth. Table 2b lists mean values for ortho-P at each sampling site. Table 2b also lists ortho-P as a percentage of total P. Using all data, an estimated average of 30.61 tons of ortho-P (or about 40% of TP), were deposited to Utah Lake. While there is no question as to the analytical accuracy of this value, the true value of ortho-P in these samples requires some additional understanding and investigation. For example, the accumulated particles on the sample funnel are being diluted by rainwater. While rain was once considered to be pure (perhaps approximating distilled water in solutes and pH except for the slight reduction in pH due to atmospheric $CO_2$), we now know that, in addition to dust or aerosol particles that become suspended or dissolved in the rainwater, gases such as ammonia, carbon dioxide or sulfur dioxide are in equilibrium partial pressures with the surrounding atmospheric pressure. The increase in atmospheric concentrations of these gases with urbanization and industrialization has lowered the pH to the range of 5.0 to 6.0, closer to 5.0 in the eastern US and about 6.0 in northern Utah (NADP/USGS data, 2002 (https://www.usgs.gov/media/images/ph-rainfall-usa-2002). With the importance of pH in determining the speciation of P, the large difference between rainwater pH and Utah Lake pH leaves the resultant speciation and bioavailability of P somewhat in question. For example, the mildly acidic rainwater may provide a slightly higher relative concentration of ortho-P by favoring desorption from particulate matter – the degree to which would require additional careful study, related to that proposed by Dr. Josh LeMonte of BYU. This change in pH, from rainwater to lake water, presents a challenge in determining the final speciation and bioavailability of P from AD sources. As such, the Council, in collaboration with BYU, is currently in the process of developing protocols to examine P speciation in captured air samples, that in rainwater, and after any changes that occur in Utah Lake water.

**Table 3. Record of total and ortho-P and DIN collected in bulk samples at Genola. The entire record is displayed to illustrate the variability in sample results and particularly with respect to sampling intervals.**

| Sampling Date | TP>1 outliers | Total Phos (mg/l) w/o outlrs | TP>5 outliers | Total Phos (mg/l) w/o outlrs | Total Phos (mg/l) all data | OrthoPhos mg/l all data | TN>10 outliers | Total Nitro (mg/l) w/o outlrs | Total Nitro (mg/l) all data |
|---|---|---|---|---|---|---|---|---|---|
| 22-Feb-17 | | | | | | | | | |
| 27-Feb-17 | | | | | | | | | |
| 5-Mar-17 | | BDL | | BDL | BDL | | | 2.19 | 2.19 |
| 23-Mar-17 | | 0.28 | | 0.28 | 0.28 | | | 1.89 | 1.89 |
| 27-Mar-17 | | 0.02 | | 0.02 | 0.02 | | | 1.19 | 1.19 |
| 30-Mar-17 | | 0.04 | | 0.04 | 0.04 | | | 1.43 | 1.43 |
| 8-Apr-17 | | 0.28 | | 0.28 | 0.28 | | | 2.37 | 2.37 |
| 19-Apr-17 | | 0.09 | | 0.09 | 0.09 | | | 1.24 | 1.24 |
| 21-Apr-17 | | 0.03 | | 0.03 | 0.03 | | | 1.31 | 1.31 |
| 25-Apr-17 | 10.00 | | 10.00 | | 10.00 | | | 1.60 | 1.60 |
| 6-May-17 | 2.10 | | | 2.10 | 2.10 | | | 2.30 | 2.30 |
| 17-May-17 | 2.60 | | | 2.60 | 2.60 | | | 7.30 | 7.30 |
| 21-May-17 | 9.80 | | 9.80 | | 9.80 | | | 0.90 | 0.90 |
| 17-Jul-17 | 7.80 | | 7.80 | | 7.80 | | 11.80 | | 11.80 |
| 25-Jul-17 | 5.30 | | 5.30 | | 5.30 | | | 3.55 | 3.55 |
| 10-Aug-17 | | 0.64 | | 0.64 | 0.64 | | | BDL | BDL |
| 15-Sep-17 | | 0.07 | | 0.07 | 0.07 | | | 0.51 | 0.51 |
| 24-Sep-17 | | 0.07 | | 0.07 | 0.07 | | | 1.10 | 1.10 |
| 5-Nov-17 | | 0.62 | | 0.62 | 0.62 | | | 1.80 | 1.80 |
| 17-Nov-17 | | 0.34 | | 0.34 | 0.34 | | | 1.50 | 1.50 |
| 9-Jan-18 | | 0.06 | | 0.06 | 0.06 | | | 1.00 | 1.00 |
| 15-Feb-18 | | 0.16 | | 0.16 | 0.16 | | | 2.20 | 2.20 |
| 16-Mar-18 | | 0.04 | | 0.04 | 0.04 | | | 0.40 | 0.40 |
| 23-Mar-18 | | 0.02 | | 0.02 | 0.02 | | | 0.40 | 0.40 |
| 7-Apr-18 | | 0.09 | | 0.09 | 0.09 | | | 0.80 | 0.80 |
| 20-Apr-18 | | 0.55 | | 0.55 | 0.55 | | | 1.60 | 1.60 |
| 30-Apr-18 | | 0.91 | | 0.91 | 0.91 | | | 1.10 | 1.10 |
| 3-May-18 | 2.70 | | | 2.70 | 2.70 | | | 8.90 | 8.90 |
| 11-May-18 | 1.80 | | | 1.80 | 1.80 | | | 1.00 | 1.00 |
| 22-Aug-18 | 6.00 | | 6.00 | | 6.00 | | | 4.40 | 4.40 |
| 3-Oct-18 | | 0.73 | | 0.73 | 0.73 | | | 1.30 | 1.30 |
| 10-Oct-18 | | 0.07 | | 0.07 | 0.07 | | | 0.50 | 0.50 |
| 30-Nov-18 | | 0.10 | | 0.10 | 0.10 | | | BDL | BDL |
| 18-Jan-19 | | 0.46 | | 0.46 | 0.46 | 0.01 | | BDL | BDL |
| 7-Mar-19 | | 0.24 | | 0.24 | 0.24 | 0.07 | | 1.10 | 1.10 |
| 29-Mar-19 | | 0.05 | | 0.05 | 0.05 | 0.02 | | 1.00 | 1.00 |
| 10-Apr-19 | | 0.26 | | 0.26 | 0.26 | 0.02 | | 1.50 | 1.50 |
| 21-Apr-19 | | 0.06 | | 0.06 | 0.06 | 0.02 | | | |
| 7-May-19 | | 0.05 | | 0.05 | 0.05 | 0.02 | | 0.80 | 0.80 |
| 21-May-19 | | 0.10 | | 0.10 | 0.10 | 0.09 | | 0.40 | 0.40 |
| 21-Jun-19 | | 0.39 | | 0.39 | 0.39 | 0.08 | | 1.00 | 1.00 |
| 1-Aug-19 | | 0.44 | | 0.44 | 0.44 | 0.04 | | 0.90 | 0.90 |
| 9-Aug-19 | 1.40 | | | 1.40 | 1.40 | 1.10 | | 4.10 | 4.10 |
| 11-Sep-19 | | 0.02 | | 0.02 | 0.02 | BDL | | BDL | BDL |
| 20-Nov-19 | | 0.10 | | 0.10 | 0.10 | 0.04 | | 0.60 | 0.60 |
| 23-Jan-20 | | 0.47 | | 0.47 | 0.47 | 0.05 | | 1.10 | 1.10 |
| 8-Feb-20 | | 0.04 | | 0.04 | 0.04 | BDL | | 0.90 | 0.90 |
| 13-Mar-20 | | 0.10 | | 0.10 | 0.10 | BDL | | 0.50 | 0.50 |
| 25-Mar-20 | | 0.06 | | 0.06 | 0.06 | BDL | | 0.20 | 0.20 |
| 23-May-20 | | 0.28 | | 0.28 | 0.28 | | | 2.40 | 2.40 |
| 8-Jun-20 | | 0.08 | | 0.08 | 0.08 | 0.02 | | 0.50 | 0.50 |
| | | | | | | | | | |
| | 10 | 38 | 5 | 43 | 48 | 13 | 1 | 43 | 44 |
| | | | | | | | | | |
| averages | 4.950 | 0.221 | 7.780 | 0.442 | 1.206 | 0.122 | 11.800 | 1.693 | 1.922 |
| | | | | | | | | | |
| summer (Apr-S | 4.950 | 0.245 | 7.780 | 0.653 | 1.925 | 0.174 | 11.800 | 2.149 | 2.535 |
| winter (Oct-Mar | #DIV/0! | 0.200 | #DIV/0! | 0.200 | 0.200 | 0.038 | #DIV/0! | 1.116 | 1.116 |
| summer count | 10 | 18 | 5 | 23 | 28 | 8 | 1 | 24 | 25 |
| winter count | 0 | 20 | 0 | 20 | 20 | 5 | 0 | 19 | 19 |

| too big | Sampling Date | TP>1 outliers | Total P (mg/l) w/o outlrs | TP>5 outliers | Total P (mg/l) w/o outlrs | Total P (mg/l) all data | Ortho-P mg/l all data | | TN>10 outliers | Total N (mg/l) w/o outlrs | Total N (mg/l) all data |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Table 4. Entire sample record of Total and ortho-P and DIN for the bulk sampler at Lincoln Point.** | | | | | | | | | | |
| | 10-Feb-17 | | 0.08 | | 0.08 | 0.08 | | | | 1.42 | 1.42 |
| | 22-Feb-17 | 1.96 | | | 1.96 | 1.96 | | | 24.40 | | 24.40 |
| | 27-Feb-17 | | 0.17 | | 0.17 | 0.17 | | | | 5.31 | 5.31 |
| | 5-Mar-17 | | 0.20 | | 0.20 | 0.20 | | | | 4.83 | 4.83 |
| | 23-Mar-17 | | 0.37 | | 0.37 | 0.37 | | | | 3.06 | 3.06 |
| | 27-Mar-17 | | 0.08 | | 0.08 | 0.08 | | | | 1.35 | 1.35 |
| | 30-Mar-17 | | 0.06 | | 0.06 | 0.06 | | | | 2.46 | 2.46 |
| | 8-Apr-17 | | 0.07 | | 0.07 | 0.07 | | | | 2.11 | 2.11 |
| | 19-Apr-17 | | 0.07 | | 0.07 | 0.07 | | | | 0.95 | 0.95 |
| | 21-Apr-17 | | 0.06 | | 0.06 | 0.06 | | | | 5.03 | 5.03 |
| | 25-Apr-17 | | 0.06 | | 0.06 | 0.06 | | | | 1.00 | 1.00 |
| | 6-May-17 | | 0.37 | | 0.37 | 0.37 | | | | 1.50 | 1.50 |
| | 17-May-17 | 8.90 | | 8.90 | | 8.90 | | | | 6.90 | 6.90 |
| | 21-May-17 | 1.40 | | | 1.40 | 1.40 | | | | 1.70 | 1.70 |
| 25 | 13-Jun-17 | | | | | | | | 14.00 | | 14.00 |
| | 25-Jul-17 | 8.80 | | 8.80 | | 8.80 | | | 23.60 | | 23.60 |
| 21 | 10-Aug-17 | | | | | | | | 21.40 | | 21.40 |
| | 15-Sep-17 | | 0.69 | | 0.69 | 0.69 | | | | 1.00 | 1.00 |
| | 24-Sep-17 | | 0.18 | | 0.18 | 0.18 | | | | 1.05 | 1.05 |
| | 5-Nov-17 | 1.10 | | | 1.10 | 1.10 | | | | BDL | BDL |
| | 17-Nov-17 | | 0.18 | | 0.18 | 0.18 | | | | 0.90 | 0.90 |
| | 9-Jan-18 | | 0.10 | | 0.10 | 0.10 | | | | 1.20 | 1.20 |
| | 15-Feb-18 | | 0.03 | | 0.03 | 0.03 | | | | 2.40 | 2.40 |
| | 16-Mar-18 | | 0.01 | | 0.01 | 0.01 | | | | 0.50 | 0.50 |
| | 23-Mar-18 | | 0.03 | | 0.03 | 0.03 | | | | 0.50 | 0.50 |
| | 7-Apr-18 | 1.60 | | | 1.60 | 1.60 | | | | 1.20 | 1.20 |
| | 20-Apr-18 | | 0.55 | | 0.55 | 0.55 | | | | 0.40 | 0.40 |
| | 30-Apr-18 | | 0.49 | | 0.49 | 0.49 | | | | 1.30 | 1.30 |
| | 3-May-18 | | 0.23 | | 0.23 | 0.23 | | | | 1.70 | 1.70 |
| | 11-May-18 | | 0.18 | | 0.18 | 0.18 | | | | 2.70 | 2.70 |
| | 22-Aug-18 | 6.30 | | 6.30 | | 6.30 | | | 34.20 | | 34.20 |
| | 3-Oct-18 | 5.30 | | 5.30 | | 5.30 | | | 12.40 | | 12.40 |
| | 10-Oct-18 | | 0.09 | | 0.09 | 0.09 | | | | 0.70 | 0.70 |
| | 30-Nov-18 | | 0.40 | | 0.40 | 0.40 | | | | 0.30 | 0.30 |
| | 18-Jan-19 | | 0.04 | | 0.04 | 0.04 | 0.01 | | | BDL | BDL |
| | 6-Mar-19 | | 0.11 | | 0.11 | 0.11 | 0.02 | | | BDL | BDL |
| | 29-Mar-19 | | 0.04 | | 0.04 | 0.04 | 0.04 | | | BDL | BDL |
| | 10-Apr-19 | | 0.57 | | 0.57 | 0.57 | 0.29 | | | 2.60 | 2.60 |
| | 21-Apr-19 | | 0.60 | | 0.60 | 0.60 | 0.10 | | | 1.20 | 1.20 |
| | 7-May-19 | | 0.23 | | 0.23 | 0.23 | 0.08 | | | 1.30 | 1.30 |
| | 21-May-19 | | 0.39 | | 0.39 | 0.39 | 0.27 | | | 1.00 | 1.00 |
| | 21-Jun-19 | 2.20 | | | 2.20 | 2.20 | 0.51 | | | 3.60 | 3.60 |
| | 1-Aug-19 | 3.70 | | | 3.70 | 3.70 | 2.20 | | | 9.60 | 9.60 |
| | 9-Aug-19 | 1.40 | | | 1.40 | 1.40 | 1.00 | | | 4.80 | 4.80 |
| | 11-Sep-19 | 1.70 | | | 1.70 | 1.70 | 1.40 | | | 3.70 | 3.70 |
| | 20-Nov-19 | | 0.12 | | 0.12 | 0.12 | BDL | | | BDL | BDL |
| | 16-Jan-20 | | 0.42 | | 0.42 | 0.42 | 0.11 | | | 1.80 | 1.80 |
| | 23-Jan-20 | | 0.04 | | 0.04 | 0.04 | 0.03 | | | 1.20 | 1.20 |
| | 8-Feb-20 | | 0.04 | | 0.04 | 0.04 | BDL | | | BDL | BDL |
| | 13-Mar-20 | | 0.11 | | 0.11 | 0.11 | 0.02 | | | 1.10 | 1.10 |
| | 25-Mar-20 | | 0.06 | | 0.06 | 0.06 | 0.02 | | | 0.30 | 0.30 |
| | 23-May-20 | | 0.94 | | 0.94 | 0.94 | BDL | | | BDL | BDL |
| | 8-Jun-20 | | 0.35 | | 0.35 | 0.35 | 0.23 | | | 1.80 | 1.80 |
| | count | 12 | 39 | 4 | 47 | 51 | 16 | | 6 | 40 | 46 |
| | averages | 3.697 | 0.226 | 7.325 | 0.508 | 1.043 | 0.396 | | 21.667 | 2.187 | 4.728 |
| summer (Apr-Sept) | | 4.000 | 0.355 | 8.000 | 0.784 | 1.617 | 0.676 | | 23.300 | 2.528 | 5.605 |
| winter (Oct-Mar) | | 2.787 | 0.126 | 5.300 | 0.243 | 0.446 | 0.036 | | 18.400 | 1.725 | 3.481 |
| summer count | | 9 | 17 | 3 | 23 | 26 | 9 | | 4 | 23 | 27 |
| winter count | | 3 | 22 | 1 | 24 | 25 | 7 | | 2 | 17 | 19 |

**Table 5. Entire record of total or ortho-P and DIN in bulk deposition samples from the Pelican Point. (From Miller 2021)**

| too | Sampling | TP>1 | Total P | TP>5 | Total P | Total P | Ortho-P | | TN>10 | Total Nitro | Total Nitro |
|---|---|---|---|---|---|---|---|---|---|---|---|
| big | Date | outliers | (mg/l) | outliers | (mg/l) | (mg/l) | mg/l | | outliers | (mg/l) | (mg/l) |
| | | | w/o outliers | | w/o outliers | all data | all data | | | w/o outliers | all data |
| | | | | | | | | | | | |
| | 10-Feb-17 | | 0.09 | | 0.09 | 0.09 | | | | BDL | BDL |
| | 22-Feb-17 | | 0.18 | | 0.18 | 0.18 | | | | 1.04 | 1.04 |
| | 27-Feb-17 | | 0.05 | | 0.05 | 0.05 | | | | 3.33 | 3.33 |
| | 5-Mar-17 | | 0.21 | | 0.21 | 0.21 | | | | 3.33 | 3.33 |
| | 23-Mar-17 | | 0.11 | | 0.11 | 0.11 | | | | 1.36 | 1.36 |
| | 27-Mar-17 | | 0.16 | | 0.16 | 0.16 | | | | 2.04 | 2.04 |
| | 30-Mar-17 | | 0.06 | | 0.06 | 0.06 | | | | 2.20 | 2.20 |
| | 8-Apr-17 | | 0.14 | | 0.14 | 0.14 | | | | 4.07 | 4.07 |
| | 19-Apr-17 | | 0.06 | | 0.06 | 0.06 | | | | 0.84 | 0.84 |
| | 21-Apr-17 | | 0.14 | | 0.14 | 0.14 | | | | 2.76 | 2.76 |
| | 25-Apr-17 | | 0.05 | | 0.05 | 0.05 | | | | 1.30 | 1.30 |
| | 6-May-17 | | 0.10 | | 0.10 | 0.10 | | | | 1.10 | 1.10 |
| | 17-May-17 | | 0.04 | | 0.04 | 0.04 | | | | 1.10 | 1.10 |
| | 21-May-17 | | 0.21 | | 0.21 | 0.21 | | | | 0.70 | 0.70 |
| 66 | 13-Jun-17 | | | | | | | | | BDL | BDL |
| | 20-Jun-17 | | 1.00 | | 1.00 | 1.00 | | | | 9.91 | 9.91 |
| 83 | 10-Aug-17 | | | | | | | #### | | | |
| | 15-Sep-17 | | 0.14 | | 0.14 | 0.14 | | | | 0.70 | 0.70 |
| | 24-Sep-17 | | 0.06 | | 0.06 | 0.06 | | | | 0.66 | 0.66 |
| | 5-Nov-17 | | 0.82 | | 0.82 | 0.82 | | | | 3.60 | 3.60 |
| | 17-Nov-17 | | 0.12 | | 0.12 | 0.12 | | | | 1.70 | 1.70 |
| | 9-Jan-18 | | 0.03 | | 0.03 | 0.03 | | | | 0.80 | 0.80 |
| | 15-Feb-18 | 6.70 | | 6.70 | | 6.70 | | | | 1.60 | 1.60 |
| | 16-Mar-18 | | 0.67 | | 0.67 | 0.67 | | | | 3.60 | 3.60 |
| | 23-Mar-18 | 2.50 | | | 2.50 | 2.50 | | | | 6.30 | 6.30 |
| | 7-Apr-18 | | 0.55 | | 0.55 | 0.55 | | | | 0.70 | 0.70 |
| | 20-Apr-18 | 1.80 | | | 1.80 | 1.80 | | | | 7.80 | 7.80 |
| | 30-Apr-18 | | 0.30 | | 0.30 | 0.30 | | | | 0.70 | 0.70 |
| | 3-May-18 | | 0.02 | | 0.02 | 0.02 | | | | 0.90 | 0.90 |
| | 11-May-18 | 1.40 | | | 1.40 | 1.40 | | | | 2.40 | 2.40 |
| | 22-Aug-18 | 1.30 | | | 1.30 | 1.30 | | | | 5.70 | 5.70 |
| 21 | 3-Oct-18 | | | | | | | | 10.20 | | 10.20 |
| | 10-Oct-18 | | 0.04 | | 0.04 | 0.04 | | | | 0.40 | 0.40 |
| | 30-Nov-18 | | 0.19 | | 0.19 | 0.19 | | | | 0.40 | 0.40 |
| | 18-Jan-19 | | 0.01 | | 0.01 | 0.01 | 0.02 | | | 0.20 | 0.20 |
| | 29-Mar-19 | | 0.40 | | 0.40 | 0.40 | 0.12 | | | 3.10 | 3.10 |
| | 10-Apr-19 | | 0.19 | | 0.19 | 0.19 | 0.08 | | | 1.80 | 1.80 |
| | 7-May-19 | | 0.53 | | 0.53 | 0.53 | 0.23 | | | 1.30 | 1.30 |
| | 21-May-19 | | 0.08 | | 0.08 | 0.08 | 0.02 | | | 0.50 | 0.50 |
| | 11-Sep-19 | 7.800 | | 7.800 | | 7.800 | | | | | |
| | 20-Nov-19 | | 0.62 | | 0.62 | 0.62 | 0.17 | | | 4.10 | 4.10 |
| | 23-Jan-20 | | 0.43 | | 0.43 | 0.43 | 0.07 | | | 1.10 | 1.10 |
| | 13-Mar-20 | 2.10 | | | 2.10 | 2.10 | 0.21 | | | BDL | BDL |
| | 25-Mar-20 | | 0.10 | | 0.10 | 0.10 | 0.02 | | | 0.30 | 0.30 |
| | 23-May-20 | | 0.25 | | 0.25 | 0.25 | 0.08 | | | 2.60 | 2.60 |
| | 8-Jun-20 | | 0.27 | | 0.27 | 0.27 | 0.15 | | | 1.30 | 1.30 |
| | | | | | | | | | | | |
| | | 7 | 36 | 2 | 41 | 43 | 11 | | 1 | 40 | 41 |
| | | | | | | | | | | | |
| | averages | 3.371 | 0.234 | 7.250 | 0.427 | 0.745 | 0.106 | | 10.200 | 2.234 | 2.428 |
| summer (Apr-S | | 3.075 | 0.229 | 7.800 | 0.411 | 0.747 | 0.112 | | #DIV/0! | 2.326 | 2.326 |
| winter (Oct-Mar | | 3.767 | 0.238 | 6.700 | 0.445 | 0.742 | 0.102 | | 10.200 | 2.132 | 2.535 |
| summer count | | 4 | 18 | 1 | 21 | 22 | 5 | | 0 | 21 | 21 |
| | winter count | | 18 | | 1 | 20 | 21 | 3 | 1 | 19 | 20 |

**Table 6. Entire record of total and orth-P and DIN in bulk deposition samples from the Lehi site. (From Miller 2021)**

| Sampling Date | TP>1 outliers | Total P (mg/l) w/o outliers | TP>5 outliers | Total P (mg/l) w/o outliers | Total P (mg/l) all data | Ortho-P mg/l all data | | TN>10 outliers | Total Nitro (mg/l) w/o outliers | Total Nitro (mg/l) all data |
|---|---|---|---|---|---|---|---|---|---|---|
| 21-Jan-17 | | 0.02 | | 0.02 | 0.02 | | | none | 0.33 | 0.33 |
| 10-Feb-17 | | 0.07 | | 0.07 | 0.07 | | | | 2.94 | 2.94 |
| 11-Feb-17 | | 0.02 | | 0.02 | 0.02 | | | | 1.07 | 1.07 |
| 21-Feb-17 | | 0.05 | | 0.05 | 0.05 | | | | 2.94 | 2.94 |
| 23-Feb-17 | | 0.02 | | 0.02 | 0.02 | | | | 2.33 | 2.33 |
| 23-Mar-17 | | 0.05 | | 0.05 | 0.05 | | | | 2.31 | 2.31 |
| 27-Mar-17 | | 0.01 | | 0.01 | 0.01 | | | | 1.40 | 1.40 |
| 30-Mar-17 | | 0.01 | | 0.01 | 0.01 | | | | 5.33 | 5.33 |
| 8-Apr-17 | | 0.18 | | 0.18 | 0.18 | | | | 8.05 | 8.05 |
| 19-Apr-17 | | 0.46 | | 0.46 | 0.46 | | | | 3.91 | 3.91 |
| 21-Apr-17 | | 0.06 | | 0.06 | 0.06 | | | | 2.13 | 2.13 |
| 25-Apr-17 | | 0.10 | | 0.10 | 0.10 | | | | 4.30 | 4.30 |
| 17-May-17 | | 0.06 | | 0.06 | 0.06 | | | | 3.20 | 3.20 |
| 21-May-17 | | 0.76 | | 0.76 | 0.76 | | | | 2.10 | 2.10 |
| 20-Jun-17 | 11.00 | | 11.00 | | 11.00 | | | | BDL | BDL |
| 23-Jul-17 | 6.70 | | 6.70 | | 6.70 | | | | BDL | BDL |
| 25-Jul-17 | | 0.71 | | 0.71 | 0.71 | | | | 3.47 | 3.47 |
| 10-Aug-17 | 1.50 | | | 1.50 | 1.50 | | | | 7.11 | 7.11 |
| 15-Sep-17 | 1.30 | | | 1.30 | 1.30 | | | | 2.33 | 2.33 |
| 22-Sep-17 | | 0.47 | | 0.47 | 0.47 | | | | 1.21 | 1.21 |
| 24-Sep-17 | | 0.40 | | 0.40 | 0.40 | | | | 2.70 | 2.70 |
| 17-Nov-17 | 2.30 | | | 2.30 | 2.30 | | | | 1.50 | 1.50 |
| 9-Jan-18 | | 0.43 | | 0.43 | 0.43 | | | | 2.00 | 2.00 |
| 16-Mar-18 | | 0.07 | | 0.07 | 0.07 | | | | 1.20 | 1.20 |
| 20-Mar-18 | | 0.34 | | 0.34 | 0.34 | | | | 1.00 | 1.00 |
| 23-Mar-18 | 1.60 | | | 1.60 | 1.60 | | | | 0.60 | 0.60 |
| 7-Apr-18 | | 0.10 | | 0.10 | 0.10 | | | | 3.00 | 3.00 |
| 20-Apr-18 | | 0.14 | | 0.14 | 0.14 | | | | 0.90 | 0.90 |
| 30-Apr-18 | 1.30 | | | 1.30 | 1.30 | | | | 5.00 | 5.00 |
| 3-May-18 | | 0.07 | | 0.07 | 0.07 | | | | 2.50 | 2.50 |
| 11-May-18 | | 0.16 | | 0.16 | 0.16 | | | | 3.70 | 3.70 |
| 21-Aug-18 | 2.10 | | | 2.10 | 2.10 | | | | 5.70 | 5.70 |
| 22-Aug-18 | | 0.42 | | 0.42 | 0.42 | | | | 2.40 | 2.40 |
| 3-Oct-18 | 1.10 | | | 1.10 | 1.10 | | | | 0.40 | 0.40 |
| 10-Oct-18 | | 0.04 | | 0.04 | 0.04 | | | | 1.20 | 1.20 |
| 30-Nov-18 | | 0.02 | | 0.02 | 0.02 | | | | 1.60 | 1.60 |
| 18-Jan-19 | | 0.03 | | 0.03 | 0.03 | BDL | | | 0.80 | 0.80 |
| 8-Mar-19 | | 0.29 | | 0.29 | 0.29 | 0.11 | | | 1.00 | 1.00 |
| 13-Mar-19 | | 0.13 | | 0.13 | 0.13 | 0.01 | | | 1.90 | 1.90 |
| 29-Mar-19 | | BDL | | BDL | BDL | | | | 1.80 | 1.80 |
| 10-Apr-19 | | 0.03 | | 0.03 | 0.03 | 0.02 | | | 2.50 | 2.50 |
| 21-Apr-19 | | 0.03 | | 0.03 | 0.03 | 0.01 | | | 2.60 | 2.60 |
| 7-May-19 | | 0.09 | | 0.09 | 0.09 | 0.02 | | | 0.90 | 0.90 |
| 21-May-19 | | 0.24 | | 0.24 | 0.24 | 0.05 | | | 1.20 | 1.20 |
| 9-Aug-19 | | 0.10 | | 0.10 | 0.10 | 0.04 | | | 0.40 | 0.40 |
| 11-Sep-19 | | 0.76 | | 0.76 | 0.76 | 0.52 | | | BDL | BDL |
| 20-Nov-19 | | 0.90 | | 0.90 | 0.90 | 0.22 | | | 2.70 | 2.70 |
| 23-Jan-20 | | 0.11 | | 0.11 | 0.11 | 0.02 | | | 1.70 | 1.70 |
| 8-Feb-20 | | 0.08 | | 0.08 | 0.08 | | | | 1.40 | 1.40 |
| 13-Mar-20 | | 0.70 | | 0.70 | 0.70 | 0.44 | | | BDL | BDL |
| 25-Mar-20 | | 0.06 | | 0.06 | 0.06 | 0.07 | | | 1.70 | 1.70 |
| 23-May-20 | | 0.62 | | 0.62 | 0.62 | 0.48 | | | 3.90 | 3.90 |
| 8-Jun-20 | 2.8 | | | 2.80 | 2.80 | | 2.30 | | 8.50 | 8.50 |
| | 10 | 42 | 2 | 50 | 52 | 13 | | 0 | 49 | 49 |
| averages | 3.170 | 0.224 | 8.850 | 0.468 | 0.791 | 0.155 | | #DIV/0! | 2.548 | 2.548 |
| summer (Apr | 3.814 | 0.284 | 8.850 | 0.575 | 1.166 | 0.163 | | #DIV/0! | 3.348 | 3.348 |
| winter (Oct-M | 1.667 | 0.164 | #DIV/0! | 0.352 | 0.352 | 0.145 | | #DIV/0! | 1.715 | 1.715 |
| summer cou | 7 | 21 | 2 | 26 | 28 | 7 | | 0 | 25 | 25 |
| winter count | 3 | 21 | 0 | 24 | 24 | 6 | | 0 | 24 | 24 |

**Table 7. Entire record of total and ortho-P bulk in bulk deposition samples from the Orem site. (From Miller 2021)**

| Date | TP>1 | | Total Phos | TP>5 | Total Phos | Total Phos | Ortho Phos | TN>10 | Total Nitro | Total Nitro |
|---|---|---|---|---|---|---|---|---|---|---|
| | outliers | (mg/l) | outliers | (mg/l) | (mg/l) | mg/l | | outliers | (mg/l) | (mg/l) |
| 23-Feb-17 | | w/o outlrs | | w/o outlrs | all data | all data | | | w/o outlrs | all data |
| 5-Mar-17 | | | | | | | | | | |
| 23-Mar-17 | | | | | | | | | | |
| 27-Mar-17 | | 0.07 | | 0.07 | 0.07 | | | | 1.38 | 1.38 |
| 30-Mar-17 | | 0.02 | | 0.02 | 0.02 | | | | 1.13 | 1.13 |
| 8-Apr-17 | | 0.16 | | 0.16 | 0.16 | | | | 3.10 | 3.10 |
| 19-Apr-17 | | 0.24 | | 0.24 | 0.24 | | | | 2.90 | 2.90 |
| 21-Apr-17 | | 0.14 | | 0.14 | 0.14 | | | | 1.91 | 1.91 |
| 25-Apr-17 | | 0.18 | | 0.18 | 0.18 | | | | 2.67 | 2.67 |
| 6-May-17 | | 0.15 | | 0.15 | 0.15 | | | | 4.40 | 4.40 |
| 17-May-17 | | 0.37 | | 0.37 | 0.37 | | | | 3.30 | 3.30 |
| 21-May-17 | | 0.50 | | 0.50 | 0.50 | | | | 1.60 | 1.60 |
| 20-Jun-17 | | 0.46 | | 0.46 | 0.46 | | | | 1.40 | 1.40 |
| 20-Jul-17 | 1.10 | | | 1.10 | 1.10 | | | | 4.25 | 4.25 |
| 25-Jul-17 | | | | | | | | | 1.53 | 1.53 |
| 10-Aug-17 | 2.00 | | | 2.00 | 2.00 | | | 11.40 | | |
| 15-Sep-17 | | 0.46 | | 0.46 | 0.46 | | | | BDL | BDL |
| 24-Sep-17 | | 0.16 | | 0.16 | 0.16 | | | | 1.16 | 1.16 |
| 5-Nov-17 | 1.30 | | | 1.30 | 1.30 | | | | 4.70 | 4.70 |
| 17-Nov-17 | 1.10 | | | 1.10 | 1.10 | | | | 4.40 | 4.40 |
| 9-Jan-18 | | 0.29 | | 0.29 | 0.29 | | | | 2.40 | 2.40 |
| 15-Feb-18 | | 0.16 | | 0.16 | 0.16 | | | | 2.50 | 2.50 |
| 16-Mar-18 | | 0.14 | | 0.14 | 0.14 | | | | 3.00 | 3.00 |
| 7-Apr-18 | | BDL | | BDL | BDL | | | | 1.00 | 1.00 |
| 20-Apr-18 | | 0.30 | | 0.30 | 0.30 | | | | 2.50 | 2.50 |
| 30-Apr-18 | | 0.23 | | 0.23 | 0.23 | | | | 2.40 | 2.40 |
| 3-May-18 | | 0.12 | | 0.12 | 0.12 | | | | 0.80 | 0.80 |
| 11-May-18 | | 0.04 | | 0.04 | 0.04 | | | | 1.40 | 1.40 |
| 22-Aug-18 | | 0.07 | | 0.07 | 0.07 | | | | 1.60 | 1.60 |
| 3-Oct-18 | | 0.18 | | 0.18 | 0.18 | | | | 2.50 | 2.50 |
| 10-Oct-18 | | 0.52 | | 0.52 | 0.52 | | | | 2.10 | 2.10 |
| 30-Nov-18 | | 0.06 | | 0.06 | 0.06 | | | | 0.70 | 0.70 |
| 18-Jan-19 | | 0.16 | | 0.16 | 0.16 | | | | 0.80 | 0.80 |
| 6-Mar-19 | | 0.44 | | 0.44 | 0.44 | 0.06 | | | BDL | BDL |
| 29-Mar-19 | | 0.15 | | 0.15 | 0.15 | 0.02 | | | 0.60 | 0.60 |
| 21-Apr-19 | 1.20 | | | 1.20 | 1.20 | 0.36 | | | 1.50 | 1.50 |
| 7-May-19 | | 0.18 | | 0.18 | 0.18 | 0.01 | | | 0.50 | 0.50 |
| 21-May-19 | | 0.06 | | 0.06 | 0.06 | 0.05 | | | 1.30 | 1.30 |
| 21-Jun-19 | | 0.08 | | 0.08 | 0.08 | 0.05 | | | 1.00 | 1.00 |
| 1-Aug-19 | | 0.61 | | 0.61 | 0.61 | 0.03 | | | 0.90 | 0.90 |
| 9-Aug-19 | 1.8 | | | 1.80 | 1.80 | 1.10 | | | 4.10 | 4.10 |
| 11-Sep-19 | 8.9 | | 8.9 | | 8.90 | | | 22.2 | | |
| 20-Nov-19 | | 0.27 | | 0.27 | 0.27 | 0.22 | | | 2.10 | 2.10 |
| 16-Jan-20 | | 0.18 | | 0.18 | 0.18 | 0.06 | | | 1.60 | 1.60 |
| 23-Jan-20 | | 0.05 | | 0.05 | 0.05 | 0.01 | | | 1.10 | 1.10 |
| 13-Mar-20 | | 0.05 | | 0.05 | 0.05 | 0.03 | | | 2.70 | 2.70 |
| 25-Mar-20 | | 0.12 | | 0.12 | 0.12 | 0.05 | | | 1.20 | 1.20 |
| 23-May-20 | | 0.04 | | 0.04 | 0.04 | 0.06 | | | 0.40 | 0.40 |
| 8-Jun-20 | | 0.58 | | 0.58 | 0.58 | 0.40 | | | 2.90 | 2.90 |
| | | 0.26 | | 0.26 | 0.26 | 0.16 | | | 1.80 | 1.80 |
| | | | | | | | | | | |
| | 7 | 38 | 1 | 44 | 45 | 16 | | 0 | 43 | 43 |
| averages | 2.486 | 0.217 | 8.900 | 0.381 | 0.570 | 0.167 | | #DIV/0! | 2.029 | 2.029 |
| summer (Apr-Se | 3.020 | 0.256 | 8.900 | 0.455 | 0.768 | 0.253 | | #DIV/0! | 2.225 | 2.225 |
| 1.150 | | | | | | | | | | |
| winter (Oct-Mar | | 0.163 | #DIV/0! | 0.273 | 0.273 | 0.081 | | #DIV/0! | 1.756 | 1.756 |
| 5 | | | | | | | | | | |
| summer count | | 22 | 1 | 26 | 27 | 8 | | 0 | 25 | 25 |
| 2 | | | | | | | | | | |
| winter count | | 16 | 0 | 18 | 18 | 8 | | 0 | 18 | 18 |

**Table 8. Entire record of total and ortho-P and DIN in bulk deposition samples from the Mosida site (From Miller 2021)**

| too | Date | TP>1 | | Total Phos | TP>5 | Total Phos | Total Phos | OrthoPhos | TN>10 | Total Nitro | Total Nitro |
|---|---|---|---|---|---|---|---|---|---|---|---|
| big | | outliers | (mg/l) | outliers | (mg/l) | (mg/l) | mg/l | | outliers | (mg/l) | (mg/l) |
| | | | w/o outlrs | | w/o outlrs | all data | all data | | | w/o outlrs | all data |
| | 10-Feb-17 | | | | | | | | | | |
| | 22-Feb-17 | | 0.10 | none | 0.10 | 0.10 | | | | 1.38 | 1.38 |
| | 27-Feb-17 | | 0.07 | | 0.07 | 0.07 | | | | 1.24 | 1.24 |
| | 5-Mar-17 | | 0.09 | | 0.09 | 0.09 | | | | 2.28 | 2.28 |
| | 23-Mar-17 | | 0.13 | | 0.13 | 0.13 | | | | 2.63 | 2.63 |
| | 27-Mar-17 | | 0.21 | | 0.21 | 0.21 | | | | 1.61 | 1.61 |
| | 30-Mar-17 | | 0.15 | | 0.15 | 0.15 | | | | 2.23 | 2.23 |
| | 8-Apr-17 | | 0.16 | | 0.16 | 0.16 | | | | 2.14 | 2.14 |
| | 19-Apr-17 | 1.66 | | | 1.66 | 1.66 | | | | 7.24 | 7.24 |
| | 21-Apr-17 | | 0.20 | | 0.20 | 0.20 | | | | 1.75 | 1.75 |
| | 25-Apr-17 | | 0.10 | | 0.10 | 0.10 | | | | 1.81 | 1.81 |
| | 6-May-17 | | 0.90 | | 0.90 | 0.90 | | | | 1.50 | 1.50 |
| | 17-May-17 | 4.00 | | | 4.00 | 4.00 | | | | 4.80 | 4.80 |
| | 21-May-17 | | 0.42 | | 0.42 | 0.42 | | | | 1.90 | 1.90 |
| | 25-Jul-17 | 2.60 | | | 2.60 | 2.60 | | | | 2.70 | 2.70 |
| | 15-Sep-17 | 4.60 | | | 4.60 | 4.60 | | | | BDL | BDL |
| | 24-Sep-17 | | 0.55 | | 0.55 | 0.55 | | | | 1.20 | 1.20 |
| | 17-Nov-17 | | 0.75 | | 0.75 | 0.75 | | | | 2.60 | 2.60 |
| | 9-Jan-18 | | 0.86 | | 0.86 | 0.86 | | | | 3.80 | 3.80 |
| | 16-Mar-18 | 1.50 | | | 1.50 | 1.50 | | | | 7.20 | 7.20 |
| | 7-Apr-18 | | 0.16 | | 0.16 | 0.16 | | | | 1.70 | 1.70 |
| | 30-Apr-18 | | 0.21 | | 0.21 | 0.21 | | | | 1.00 | 1.00 |
| | 3-May-18 | | 0.45 | | 0.45 | 0.45 | | | | 1.40 | 1.40 |
| | 11-May-18 | | 0.10 | | 0.10 | 0.10 | | | | 1.90 | 1.90 |
| | 22-Aug-18 | | 0.04 | | 0.04 | 0.04 | | | | 0.90 | 0.90 |
| | 3-Oct-18 | 4.90 | | | 4.90 | 4.90 | | | 49.30 | | 49.30 |
| 34 | 10-Oct-18 | | | | | | | | 35.70 | | 35.70 |
| | 7-Mar-19 | | 0.58 | | 0.58 | 0.58 | | | | 5.00 | 5.00 |
| | 29-Mar-19 | | 0.38 | | 0.38 | 0.38 | 0.32 | | | BDL | BDL |
| | 10-Apr-19 | | 0.04 | | 0.04 | 0.04 | 0.03 | | | 0.80 | 0.80 |
| | 7-May-19 | 1.80 | | | 1.80 | 1.80 | BDL | | | 2.8 | 2.80 |
| | 21-May-19 | | 0.77 | | 0.77 | 0.77 | 0.52 | | | 2.90 | 2.90 |
| | 21-Jun-19 | | 0.05 | | 0.05 | 0.05 | 0.02 | | | 0.70 | 0.70 |
| | 1-Aug-19 | 3.1 | | | 3.10 | 3.10 | 1.90 | | 10.30 | | 10.30 |
| | 9-Aug-19 | 2 | | | 2.00 | 2.00 | 1.50 | | | 6.40 | 6.40 |
| | 11-Sep-19 | 2.5 | | | 2.50 | 2.50 | 2.20 | | 10.10 | | 10.10 |
| | 23-Jan-20 | 1.3 | | | 1.30 | 1.30 | 1.10 | | | 3.70 | 3.70 |
| | 8-Feb-20 | | 0.13 | | 0.13 | 0.13 | 0.02 | | | 1.30 | 1.30 |
| | 25-Mar-20 | | 0.05 | | 0.05 | 0.05 | BDL | | | 0.80 | 0.80 |
| | 23-May-20 | | 0.40 | | 0.40 | 0.40 | 0.20 | | | 0.20 | 0.20 |
| 11 | 8-Jun-20 | | | | | | | | 33.4 | | 33.40 |
| | | | 0.52 | | 0.52 | 0.52 | 0.41 | | | 3.20 | 3.20 |
| | | | | | | | | | | | |
| | | 11 | 28 | 0 | 39 | 39 | 11 | | 5 | 34 | 39 |
| | averages | | | | | | | | | | |
| | | 2.724 | 0.306 | #DIV/0! | 0.988 | 0.988 | 0.747 | | 27.760 | 2.491 | 5.731 |
| | | | | | | | | | | | |
| | | 2.846 | | | | | | | | | |
| summer (Apr-S | | 0.389 | #DIV/0! | 1.457 | 1.457 | 1.093 | | 25.775 | 2.653 | 6.674 | |
| | | 1.500 | | | | | | | | | |
| winter (Oct-Mar | | | 0.234 | #DIV/0! | 0.313 | 0.313 | 0.143 | | 35.700 | 2.287 | 4.376 |
| | | 10 | | | | | | | | | |
| summer count | | | 13 | 0 | 23 | 23 | 7 | | 4 | 19 | 23 |
| | | 1 | | | | | | | | | |
| winter count | | | 15 | 0 | 16 | 16 | 4 | | 1 | 15 | 16 |

## Precipitation-Weighted AD estimates

As mentioned above, we sought the expertise of Dr. David Gay, (current Director of the NADP) in evaluating this three-year summary of AD. Because of the seasonality of precipitation (greater precipitation in winter and early spring and drier in late spring and summer), Dr. Gay suggested that weighting the data based on precipitation would be a more accurate way of analyzing the data with respect to the isolated rain events. In this procedure, Dr. Miller first determined that there were too many weeks without sampling data to apply this method for each year. However, when all 3 years were combined, there were only 11 weeks without samples. So, he adjusted the 39 (50 - 11) values of the 3-yr average actual TP concentrations using the precipitation-weighted method. The 2017-2019 3-yr average annual precipitation at Utah Lake was 11.7 inches. The average weekly precipitation was 11.7 / 52 = 0.225 inches. He divided each actual weekly precipitation by this average weekly value of 0.225 to determine the weighting factor. He multiplied the weekly TP concentrations by the weighting factors to determine the precipitation weighted concentrations. For example, the 3rd week "TP all data" 3-yr average precipitation was 0.857 inches and the weighting factor is 0.857 / 0.225 = 3.809. The 3rd week actual TP concentration is 0.185 mg/l and when multiplied by the weighting factor of 3.809, the precipitation-weighted TP concentration is 0.705 mg/l, about 4 times higher. This procedure gives 39 of the 50 weeks with precipitation weighted TP concentration values which are used to determine the 39 weekly load rates (Table 2C). Note that the precipitation -weighted averages are about the same as the non-weighted data. However, when the weekly precipitation values are high, the resulting weighting factor is high. Finally, the 39-week average was used to populate the weeks that had precipitation, but which sample collection was not performed. Table 1D provides the final data where all 50 weeks when precipitation occurred have appropriate data entered.

Dr. Miller also performed an analysis based on weighting the data by number of samples. An example of this is shown in Table 1E). As noted by Dr. Miller, many of the weeks during summer were not sampled and many other weeks during summer were sampled fewer than other seasons of the year. Unfortunately, because summer months experienced nearly twice as much nutrient deposition, this led to an underestimation of annual deposition as compared to the precipitation-weighted estimates. Therefore, the precipitation-weighted data is considered the most accurate estimate of atmospheric deposition.

Table 9. Precipitation weighted adding 39-week average to populate other 50 weeks where precipitation occurred.

| week | 3-yr avg all data number samples per week | 3-yr avg TP < 5 number samples per week | TP <= 1 number samples per week | Utah Lake avg precip (in) weekly | monthly lake area (acre) weekly | all data TP conc (mg/l) | precip weighted TP < 5 conc (mg/l) | all data TP <= 1 conc (mg/l) | TP < 5 load x1.133E-4 (T/yr) | TP <=1 load x1.133E-4 (T/yr) | load x1.133E-4 (T/yr) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | | | 0.243 | 84290 | 0.851 | 0.546 | 0.272 | 1.975 | 1.267 | 0.631 |
| 2 | 10 | 10 | 9 | 0.467 | 84290 | 0.635 | 0.635 | 0.358 | 2.831 | 2.831 | 1.596 |
| 3 | 13 | 13 | 13 | 0.857 | 84290 | 0.707 | 0.707 | 0.707 | 5.783 | 5.783 | 5.783 |
| 4 | 8 | 8 | 8 | 0.093 | 84290 | 0.065 | 0.065 | 0.065 | 0.057 | 0.057 | 0.057 |
| 5 | | | | 0.093 | 85722 | 0.851 | 0.546 | 0.272 | 0.769 | 0.493 | 0.246 |
| 6 | 13 | 13 | 13 | 0.360 | 85722 | 0.093 | 0.093 | 0.093 | 0.325 | 0.325 | 0.325 |
| 7 | 8 | 7 | 7 | 0.190 | 85722 | 0.804 | 0.108 | 0.108 | 1.483 | 0.198 | 0.198 |
| 8 | 10 | 10 | 9 | 0.360 | 85722 | 0.398 | 0.398 | 0.093 | 1.391 | 1.391 | 0.325 |
| 9 | 7 | 7 | 7 | 0.127 | 86916 | 0.040 | 0.040 | 0.040 | 0.050 | 0.050 | 0.050 |
| 10 | 12 | 12 | 12 | 0.297 | 86916 | 0.229 | 0.229 | 0.229 | 0.670 | 0.670 | 0.670 |
| 11 | 16 | 16 | 14 | 0.333 | 86916 | 0.528 | 0.528 | 0.243 | 1.732 | 1.732 | 0.798 |
| 12 | 24 | 24 | 22 | 0.633 | 86916 | 0.956 | 0.956 | 0.516 | 5.961 | 5.961 | 3.218 |
| 13 | 24 | 24 | 23 | 0.343 | 86916 | 0.217 | 0.217 | 0.147 | 0.733 | 0.733 | 0.496 |
| 14 | 17 | 17 | 15 | 0.227 | 88108 | 0.352 | 0.352 | 0.179 | 0.798 | 0.798 | 0.406 |
| 15 | 7 | 7 | 5 | 0.490 | 88108 | 0.985 | 0.985 | 0.496 | 4.817 | 4.817 | 2.425 |
| 16 | 28 | 28 | 27 | 0.360 | 88108 | 0.406 | 0.406 | 0.313 | 1.459 | 1.459 | 1.124 |
| 17 | 8 | 7 | 7 | 0.213 | 88108 | 1.346 | 0.181 | 0.181 | 2.862 | 0.386 | 0.386 |
| 18 | 22 | 22 | 19 | 0.337 | 89258 | 1.059 | 1.059 | 0.451 | 3.608 | 3.608 | 1.536 |
| 19 | 16 | 16 | 14 | 0.313 | 89258 | 0.569 | 0.569 | 0.332 | 1.801 | 1.801 | 1.051 |
| 20 | 8 | 7 | 6 | 0.317 | 89258 | 2.317 | 0.852 | 0.381 | 7.427 | 2.731 | 1.223 |
| 21 | 23 | 22 | 19 | 0.527 | 89258 | 2.137 | 1.186 | 0.733 | 11.390 | 6.321 | 3.905 |
| 22 | | | | 0.140 | 89258 | 0.851 | 0.546 | 0.272 | 1.205 | 0.773 | 0.385 |
| 23 | 9 | 9 | 8 | 0.117 | 89675 | 0.286 | 0.286 | 0.140 | 0.340 | 0.340 | 0.166 |
| 24 | 3 | 3 | 1 | 0.017 | 89675 | 0.107 | 0.107 | 0.026 | 0.018 | 0.018 | 0.004 |
| 25 | 8 | 7 | 4 | 0.063 | 89675 | 0.703 | 0.703 | 0.185 | 0.450 | 0.450 | 0.118 |
| 26 | | | | 0.000 | 89675 | | | | | | |
| 27 | | | | 0.007 | 88589 | 0.851 | 0.546 | 0.272 | 0.060 | 0.038 | 0.019 |
| 28 | | | | 0.013 | 88589 | 0.851 | 0.546 | 0.272 | 0.111 | 0.071 | 0.035 |
| 29 | 3 | 2 | 2 | 0.117 | 88589 | 1.531 | 0.263 | 0.263 | 1.798 | 0.309 | 0.309 |
| 30 | 8 | 5 | 3 | 0.377 | 88589 | 6.072 | 2.725 | 0.845 | 22.976 | 10.312 | 3.198 |
| 31 | 6 | 6 | 3 | 0.077 | 85869 | 0.474 | 0.474 | 0.089 | 0.355 | 0.355 | 0.067 |
| 32 | 14 | 13 | 9 | 0.227 | 85869 | 1.319 | 0.728 | 0.287 | 2.913 | 1.609 | 0.635 |
| 33 | | | | 0.027 | 85869 | 0.851 | 0.546 | 0.272 | 0.224 | 0.143 | 0.071 |
| 34 | 11 | 9 | 6 | 0.223 | 85869 | 2.015 | 1.105 | 0.283 | 4.373 | 2.398 | 0.614 |
| 35 | | | | 0.000 | 85869 | | | | | | |
| 36 | | 1 | | 0.160 | 84478 | 1.640 | 1.640 | 0.000 | 2.512 | 2.512 | 0.000 |
| 37 | 17 | 16 | 13 | 0.323 | 84478 | 1.291 | 0.671 | 0.348 | 3.992 | 2.074 | 1.077 |
| 38 | 1 | 1 | 1 | 0.203 | 84478 | 0.425 | 0.425 | 0.425 | 0.826 | 0.826 | 0.826 |
| 39 | 7 | 7 | 6 | 0.323 | 84478 | 0.590 | 0.590 | 0.377 | 1.825 | 1.825 | 1.166 |
| 40 | 7 | 6 | 5 | 0.303 | 83893 | 1.757 | 0.857 | 0.732 | 5.060 | 2.470 | 2.108 |
| 41 | 9 | 9 | 9 | 0.257 | 83893 | 0.129 | 0.129 | 0.129 | 0.316 | 0.316 | 0.316 |
| 42 | | | | 0.067 | 83893 | 0.851 | 0.546 | 0.272 | 0.542 | 0.348 | 0.173 |
| 43 | | | | 0.033 | 83893 | 0.851 | 0.546 | 0.272 | 0.267 | 0.171 | 0.085 |
| 44 | | 1 | | 0.023 | 84975 | 0.003 | 0.003 | 0.003 | 0.001 | 0.001 | 0.001 |
| 45 | 6 | 6 | 4 | 0.013 | 84975 | 0.048 | 0.048 | 0.039 | 0.006 | 0.006 | 0.005 |
| 46 | 9 | 9 | 7 | 0.103 | 84975 | 0.307 | 0.307 | 0.125 | 0.304 | 0.304 | 0.124 |
| 47 | 9 | 9 | 9 | 0.320 | 84975 | 0.366 | 0.366 | 0.366 | 1.129 | 1.129 | 1.129 |
| 48 | 10 | 10 | 10 | 0.350 | 84975 | 0.236 | 0.236 | 0.236 | 0.794 | 0.794 | 0.794 |
| 49 | | | | 0.323 | 85476 | 0.851 | 0.546 | 0.272 | 2.662 | 1.708 | 0.851 |
| 50 | 3 | 3 | 3 | 0.110 | 85476 | 0.055 | 0.055 | 0.055 | 0.059 | 0.059 | 0.059 |
| 51 | | | | 0.003 | 85476 | 0.851 | 0.546 | 0.272 | 0.025 | 0.016 | 0.008 |
| 52 | | | | 0.170 | 85476 | 0.851 | 0.546 | 0.272 | 1.401 | 0.899 | 0.448 |
| totals | 416 | 402 | 353 | 11.669 | 86462 | 0.851 | 0.546 | 0.272 | 114.467 | 75.687 | 41.242 |

**TABLE 10. Results obtained by weighting the data by "number of samples"**

*# samples weighted*

| week | number samples per week | number samples per week | number samples per week | avg precip (in) weekly | lake area (acre) weekly | all data TP cone (mg/l) | TP < 5 cone (mg/l) | TP <= 1 cone 4 (mg/l) | all data load x1.133E-4 (T/yr) | TP < 5 load x1.133E-4 (T/yr) | TP <= 1 load x1.133E-4 (T/yr) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | | | 0.243 | 84290 | | | | | | | |
| 2 | 10 | 10 | 9 | 0.467 | 84290 | 0.286 | 0.296 | 0.167 | 0.000 | 0.000 | 0.000 | |
| 3 | 13 | 13 | 13 | 0.857 | 84290 | 0.225 | 0.233 | 0.259 | 1.275 | 1.320 | 0.743 | |
| 4 | 8 | 8 | 8 | 0.093 | 84290 | 0.117 | 0.121 | 0.134 | 1.845 | 1.910 | 2.119 | |
| 5 | | | | [illegible] | [illegible] | | | | 0.104 | 0.108 | 0.119 | |
| 6 | 13 | 13 | 13 | 0.360 | 85722 | 0.071 | 0.073 | 0.081 | 0.247 | 0.256 | 0.284 | |
| 7 | 8 | 7 | 7 | 0.190 | 85722 | 0.712 | 0.086 | 0.096 | 1.313 | 0.159 | 0.177 | |
| 8 | 10 | 10 | 9 | 0.360 | 85722 | 0.233 | 0.241 | 0.056 | 0.813 | 0.841 | 0.196 | |
| 9 | 7 | 7 | 7 | 0.127 | 86916 | 0.047 | 0.048 | 0.054 | 0.058 | 0.060 | 0.067 | |
| 10 | 12 | 12 | 12 | 0.297 | 86916 | 0.195 | 0.201 | 0.223 | 0.569 | | 0.589 | 0.654 |
| 11 | 16 | 16 | 14 | 0.333 | 86916 | 0.534 | 0.553 | 0.247 | 1.751 | | 1.812 | 0.811 |
| 12 | 24 | 24 | 22 | 0.633 | 86916 | 0.763 | 0.789 | 0.433 | 4.755 | 4.920 | 2.702 | |
| 13 | 24 | 24 | 23 | 0.343 | 86916 | 0.320 | 0.331 | 0.238 | 1.079 | 1.117 | 0.803 | |
| 14 | 17 | 17 | 15 | 0.227 | 88108 | 0.555 | 0.574 | 0.286 | 1.257 | 1.301 | 0.648 | |
| 15 | 7 | 7 | 5 | 0.490 | 88108 | 0.296 | 0.306 | 0.122 | 1.448 | 1.498 | 0.598 | |
| 16 | 28 | 28 | 27 | 0.360 | 88108 | 0.664 | 0.687 | 0.567 | 2.387 | 2.470 | 2.037 | |
| 17 | 8 | 7 | 7 | 0.213 | 88108 | 1.064 | 0.130 | 0.144 | 2.261 | 0.276 | 0.306 | |
| 18 | 22 | 22 | 19 | 0.337 | 89258 | 1.454 | 1.505 | 0.614 | 4.956 | 5.128 | 2.091 | |
| 19 | 16 | 16 | 14 | 0.313 | 89258 | 0.612 | 0.633 | 0.359 | 1.937 | 2.005 | 1.135 | |
| 20 | 8 | 7 | 6 | 0.317 | 89258 | 1.230 | 0.410 | 0.174 | 3.943 | 1.313 | 0.559 | |
| 21 | 23 | 22 | 19 | 0.527 | 89258 | 1.962 | 1.078 | 0.638 | 10.458 | 5.745 | 3.401 | |
| 22 | | | | 0.140 | 89258 | | | | | | | |
| 23 | 9 | 9 | 8 | 0.117 | 89675 | 0.463 | 0.479 | 0.231 | 0.551 | 0.570 | 0.274 | |
| 24 | 3 | 3 | 1 | 0.017 | 89675 | 0.397 | 0.411 | 0.037 | 0.069 | 0.071 | 0.006 | |
| 25 | 8 | 7 | 4 | 0.063 | 89675 | 1.878 | 1.700 | 0.283 | 1.202 | 1.089 | 0.181 | |
| 26 | | | | 0.000 | 89675 | | | | | | | |
| 27 | | | | 0.007 | 88589 | | | | | | | |
| 28 | | | | 0.013 | 88589 | | | | | | | |
| 29 | 3 | 2 | 2 | 0.117 | 88589 | 0.826 | 0.098 | 0.109 | 0.970 | 0.115 | 0.128 | |
| 30 | 8 | 5 | 3 | 0.377 | 88589 | 2.711 | 0.787 | 0.162 | 10.257 | 2.977 | 0.615 | |
| 31 | 6 | 6 | 3 | 0.077 | 85869 | 0.776 | 0.803 | 0.084 | 0.582 | 0.602 | 0.063 | |
| 32 | 14 | 13 | 9 | 0.227 | 85869 | 1.712 | 0.908 | 0.275 | 3.780 | 2.006 | 0.608 | |
| 33 | | | | 0.027 | 85869 | | | | | | | |
| 34 | 11 | 9 | 6 | 0.223 | 85869 | 2.091 | 0.971 | 0.184 | 4.538 | 2.107 | 0.399 | |
| 35 | | | | 0.000 | 85869 | | | | | | | |
| 36 | | 1 | | 0.160 | 84478 | 0.216 | 0.223 | 0.000 | 0.330 | 0.342 | 0.000 | |
| 37 | 17 | 16 | 13 | 0.323 | 84478 | 1.430 | 0.723 | 0.339 | 4.420 | 2.236 | 1.047 | |
| 38 | 1 | 1 | 1 | 0.203 | 84478 | 0.044 | 0.046 | 0.051 | 0.086 | 0.089 | 0.098 | |
| 39 | 7 | 7 | 6 | 0.323 | 84478 | 0.269 | 0.278 | 0.169 | 0.832 | 0.861 | 0.523 | |
| 40 | 7 | 6 | 5 | 0.303 | 83893 | 0.854 | 0.370 | 0.292 | 2.459 | 1.065 | 0.840 | |
| 41 | 9 | 9 | 9 | 0.257 | 83893 | 0.095 | 0.099 | 0.109 | 0.233 | 0.241 | 0.267 | |
| 42 | | | | 0.067 | 83893 | | | | | | | |
| 43 | | | | 0.033 | 83893 | | | | | | | |
| 44 | | 1 | | 0.023 | 84975 | 0.003 | 0.003 | 0.003 | 0.001 | 0.001 | 0.001 | |
| 45 | 6 | 6 | 4 | 0.013 | 84975 | 0.461 | 0.477 | 0.293 | 0.058 | 0.060 | 0.037 | |
| 46 | 9 | 9 | 7 | 0.103 | 84975 | 0.564 | 0.583 | 0.206 | 0.559 | 0.578 | 0.204 | |
| 47 | 9 | 9 | 9 | 0.320 | 84975 | 0.217 | 0.224 | 0.249 | 0.668 | 0.691 | 0.767 | |
| 48 | 10 | 10 | 10 | 0.350 | 84975 | 0.142 | 0.146 | 0.163 | 0.477 | 0.494 | 0.548 | |
| 49 | | | | 0.323 | 85476 | | | | | | | |
| 50 | 3 | 3 | 3 | 0.110 | 85476 | 0.032 | 0.033 | 0.036 | 0.034 | 0.035 | 0.039 | |
| 51 | | | | 0.003 | 85476 | | | | | | | |
| 52 | | | | 0.170 | 85476 | | | | | | | |
| total/avg | 416 | 402 | 353 | 11.669 | 86462 | 0.680 | 0.453 | 0.209 | **74.563** | **49.055** | **26.096** | |

## The 2021 Season for Bulk Deposition

This report also includes the first 9 months of 2021. As the drought continued, there were again, several weeks when no precipitation occurred and therefore no samples were collected. Consequently, as was previously described for the first three years, virtually all the outliers occurred following an extended interval between rain events (See table 12; Data from the individual sites are "pictures" of the original data tables and therefore not in numerical order with the other report tables). These tables include the raw data from seven of the eight sites in Utah County and were extracted as pictures from Miller (2021). Table 11 includes the first 10 months of 2021. Average measurements for the last three months of the year may vary from the current data. It was anticipated that the persistent smoke from the long summer of California fires would add substantially to measured deposition of nutrients on Utah Lake. However, this did not appear to be the case. Some sites had a 25 to 30% higher average (Lehi, Pelican Point, Lincoln Point and Mosida), while a couple were a little lower or the same (Genola and Orem). While summer values were consistently about 2X those of winter, year to year average values were notably quite similar Also, as with the earlier data, nearly all the outliers occurred after an extended interval (2-5 weeks) between rain/sampling events. Most notable, this large data set also includes measurements of ortho-P. Throughout all the sample sites and the sampling period, the proportion of ortho-P ranges from 41 to 62% of the total P (see inserted "pictures" of data tables). An unexpected large amount of the total P is biologically available.

**Table 11.** Comparison of 2021 average concentration (mg/L) of deposited of Total P at selected sites around Utah Lake with three-year average from 2017-2020.

| **2021** | **Lehi (UL outlet)** | **Pelican Pnt** | **Lincoln Pnt** | **Mosida** | **Genola** | **Orem** |
|---|---|---|---|---|---|---|
| Summer | 1.50 | 1.13 | 2.18 | 1.49 | 1.64 | 0.80 |
| Winter | 0.56 | 0.66 | 0.63 | 0.66 | 0.31 | 0.35 |
| Average | 1.04 | 0.89 | 1.38 | 1.09 | 1.01 | 0.60 |
| **2017-2020 3-year Averages** | | | | | | |
| Summer | 1.17 | 0.747 | 1.617 | 1.093 | 1.925 | 0.768 |
| Winter | 0.35 | 0.742 | 0.446 | 0.143 | 0.200 | 0.273 |
| Average | 0.79 | 0.745 | 1.043 | 0.747 | 1.206 | 0.570 |

Table 12. The following records are photographs of nutrient deposition for 2021 for each of the bulk deposition sampling sites. Each table is a picture of the data record. Note that most outliers occur following an extended period between precipitation events.

**Table 3. Lincoln Point**

| Sampling Date | TP>1 outliers | Total Phos (mg/l) w/o outlrs | TP>5 outliers | Total Phos (mg/l) w/o outlrs | Total Phos (mg/l) all data | OrthoP mg/l all data | OP < 1 | OP > 1 | TN>10 outliers | Total Nitro (mg/l) w/o outlrs | Total Nitro (mg/l) all data | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 13-Mar-21 | | 0.25 | | 0.25 | 0.25 | 0.20 | 0.20 | | | 1.40 | 1.40 | |
| 20-Mar-21 | | 0.10 | | 0.10 | 0.10 | 0.10 | 0.10 | | | BDL | BDL | |
| 26-Mar-21 | | 0.16 | | 0.16 | 0.16 | 0.12 | 0.12 | | | 1.10 | 1.10 | |
| 15-Apr-21 | | 0.66 | | 0.66 | 0.66 | 0.24 | 0.24 | | | 2.00 | 2.00 | |
| 26-Apr-21 | | 0.46 | | 0.46 | 0.46 | 0.25 | 0.25 | | | 1.20 | 1.20 | |
| 23-May-21 | 1.30 | | | 1.30 | 1.30 | 0.88 | 0.88 | | | 5.10 | 5.10 | |
| 24-Jun-21 | 3.70 | | | 3.70 | 3.70 | 2.60 | | 2.60 | | 2.30 | 2.30 | |
| 18-Jul-21 | 14.70 | | 14.70 | | 14.70 ??? | | | | 27.20 | | 27.20 | 27.20 |
| 22-Jul-21 | 2.70 | | | 2.70 | 2.70 | 1.90 | | 1.90 | | 6.50 | 6.50 | |
| 30-Jul-21 | 7.90 | | 7.90 | | 7.90 | 6.90 | | 6.90 | 18.90 | | 18.90 | 18.90 |
| 1-Aug-21 | | 0.90 | | 0.90 | 0.90 | 0.71 | 0.71 | | | 4.60 | 4.60 | |
| 17-Aug-21 | 1.10 | | | 1.10 | 1.10 | 0.58 | 0.58 | | | 3.20 | 3.20 | |
| 11-Sep-21 | | | | | | | | | | | | |
| 28-Sep-21 | 3.20 | | | 3.20 | 3.20 | 2.10 | | 2.10 | | 3.60 | 3.60 | |
| 8-Oct-21 | | 0.70 | | 0.70 | 0.70 | 0.48 | 0.48 | | | 2.20 | 2.20 | |
| 19-Oct-21 | | 0.09 | | 0.09 | 0.09 | 0.03 | 0.03 | | | 0.20 | 0.20 | |
| 26-Oct-21 | | 0.05 | | 0.05 | 0.05 | 0.02 | 0.02 | | | 0.20 | 0.20 | |
| 2-Nov-21 | | 0.20 | | 0.20 | 0.20 | 0.23 | 0.23 | | | BDL | BDL | |
| 9-Nov-21 | | | | | | | | | | | | |
| count | 23 | 52 | 6 | 69 | 75 | 39 | 31 | 8 | 8 | 60 | 68 | 2 |
| averages | 3.89 | 0.27 | 8.65 | 0.74 | 1.38 | 0.70 | 0.26 | 2.41 | 22.01 | 2.24 | 4.57 | 23.05 |
| ıer (Apr-Sep | 4.41 | 0.40 | 9.32 | 1.03 | 2.18 | 1.24 | 0.38 | 2.59 | 23.22 | 2.79 | 6.11 | 23.05 |
| · (Oct-Mar) a | 2.68 | 0.18 | 5.30 | 0.51 | 0.63 | 0.24 | 0.19 | 1.20 | 18.40 | 1.65 | 2.73 | |
| ıer count | 16 | 20 | 5 | 31 | 36 | 18 | 11 | 7 | 6 | 31 | 37 | 2 |
| · count | 7 | 32 | 1 | 38 | 39 | 21 | 20 | 1 | 2 | 29 | 31 | 0 |
| are FB avg | 4.94 | 0.36 | 11.30 | 1.04 | 2.25 | 1.08 | 0.32 | 3.38 | 23.05 | 2.58 | 5.31 | 23.05 |
| count | 7 | 10 | 2 | 15 | 17 | 16 | 12 | 4 | 2 | 13 | 15 | 2 |
| are summer | 4.94 | 0.67 | 11.30 | 1.75 | 3.66 | 1.80 | 0.53 | 3.38 | 23.05 | 3.56 | 7.46 | 23.05 |
| are winter | | 0.22 | | 0.22 | 0.22 | 0.17 | 0.17 | | | 1.02 | 1.02 | |
| ıer count | 7 | 3 | 2 | 8 | 10 | 9 | 5 | 4 | 2 | 8 | 10 | 2 |
| · count | 0 | 7 | 0 | 7 | 7 | 7 | 7 | 0 | 0 | 5 | 5 | 0 |

Table 12, Cont.

**Table 4. Pelican Point**

| Sampling Date | TP>1 outliers | Total Phos (mg/l) w/o outlrs | TP>5 outliers | Total Phos (mg/l) w/o outlrs | Total Phos (mg/l) all data | OrthoP mg/l all data | OP <1 | OP >1 | too big | TN>10 outliers | Total Nitro (mg/l) w/o outlrs | Total Nitro (mg/l) all data | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 13-Mar-21 | | 0.09 | | 0.09 | 0.09 | 0.05 | 0.05 | | | | 0.70 | 0.70 | |
| 20-Mar-21 | | 0.04 | | 0.04 | 0.04 | 0.06 | 0.06 | | | | 0.20 | 0.20 | |
| 26-Mar-21 | | 0.08 | | 0.08 | 0.08 | 0.05 | 0.05 | | | | 0.80 | 0.80 | |
| 6-Apr-21 | 1.70 | | | 1.70 | 1.70 | 0.26 | 0.26 | | | | BDL | BDL | |
| 15-Apr-21 | | 0.16 | | 0.16 | 0.16 | 0.05 | 0.05 | | | | 0.90 | 0.90 | |
| 26-Apr-21 | 1.10 | | | 1.10 | 1.10 | 1.00 | 1.00 | | | | 1.50 | 1.50 | |
| 23-May-21 | | 0.43 | | 0.43 | 0.43 | 0.24 | 0.24 | | | | 3.50 | 3.50 | |
| 24-Jun-21 | | 0.82 | | 0.82 | 0.82 | 0.54 | 0.54 | | | | 3.70 | 3.70 | |
| 18-Jul-21 | | | | | | | | | | 18.5 | | 18.50 | |
| 1-Aug-21 | 6.30 | | 6.3 | | 6.30 | 3.80 | | 3.8 | | 17.4 | | 17.40 | |
| 17-Aug-21 | 3.9 | | | 3.90 | 3.90 | 2.40 | | 2.40 | | | 4.50 | 4.50 | |
| 11-Sep-21 | | | | | | | | | | | | | |
| 28-Sep-21 | 3.20 | | | 3.2 | 3.20 | 1.90 | | 1.9 | | | 3.3 | 3.30 | |
| 8-Oct-21 | | 0.3 | | 0.3 | 0.30 | 0.08 | 0.08 | | | | 0.9 | 0.90 | |
| 19-Oct-21 | | 0.3 | | 0.3 | 0.30 | 0.14 | 0.14 | | | | 1.6 | 1.60 | |
| 26-Oct-21 | | 0.04 | | 0.04 | 0.04 | 0.06 | 0.06 | | | | 0.7 | 0.70 | |
| 2-Nov-21 | | 0.20 | | 0.2 | 0.20 | 0.41 | 0.41 | | | | 4.5 | 4.50 | |
| 9-Nov-21 | | | | | | | | | | | | | |
| count | 13 | 50 | 3 | 60 | 63 | 32 | 29 | 3 | | 3 | 58 | 61 | |
| averages | 3.36 | 0.24 | 6.93 | 0.58 | 0.89 | 0.41 | 0.17 | 2.70 | | 15.37 | 2.17 | 2.82 | |
| ıer avgs | 3.17 | 0.26 | 7.05 | 0.71 | 1.13 | 0.83 | 0.27 | 2.70 | | 17.95 | 2.45 | 3.52 | 79.20 |
| r avgs | 3.80 | 0.23 | 6.70 | 0.47 | 0.66 | 0.12 | 0.12 | | | 10.20 | 1.93 | 2.19 | |
| ıer count | 9 | 21 | 2 | 28 | 30 | 13 | 10 | 3 | 1 | 2 | 27 | 29 | 1 |
| r count | 4 | 29 | 1 | 32 | 33 | 19 | 19 | 0 | 0 | 1 | 31 | 32 | 0 |
| areFBavg | 3.24 | 0.25 | 6.30 | 0.88 | 1.24 | 0.74 | 0.25 | 2.70 | | 17.95 | 2.06 | 4.18 | |
| count | 5 | 10 | 1 | 14 | 15 | 15 | 12 | 3 | 0 | 2 | 13 | 15 | 0 |
| are summer | 3.24 | 0.47 | 6.30 | 1.62 | 2.20 | 1.27 | 0.42 | 2.70 | | 17.95 | 2.90 | 6.66 | |
| are winter | | 0.15 | | 0.15 | 0.15 | 0.12 | 0.12 | | | | 1.34 | 1.34 | |
| ıer count | 5 | 3 | 1 | 7 | 8 | 8 | 5 | 3 | 0 | 2 | 6 | 8 | 0 |
| r count | 0 | 7 | 0 | 7 | 7 | 7 | 7 | 0 | 0 | 0 | 7 | 7 | 0 |

Table 12. Cont.

**Table 5. Genola**

| Sampling Date | TP>1 outliers | Total Phos (mg/l) w/o outlrs | TP>5 outliers | Total Phos (mg/l) w/o outlrs | Total Phos (mg/l) all data | OrthoP mg/l all data | OP <1 | OP >1 | TN>10 outliers | Total Nitro (mg/l) w/o outlrs | Total Nitro (mg/l) all data | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 13-Mar-21 | | 0.18 | | 0.18 | 0.18 | 0.06 | 0.06 | | | 0.40 | 0.40 | |
| 20-Mar-21 | | 0.03 | | 0.03 | 0.03 | 0.05 | 0.05 | | | BDL | BDL | |
| 26-Mar-21 | | 0.18 | | 0.18 | 0.18 | 0.13 | 0.13 | | | 0.90 | 0.90 | |
| 14-Apr-21 | | 0.32 | | 0.32 | 0.32 | 0.16 | 0.16 | | | 1.80 | 1.80 | |
| 70 26-Apr-21 | | 0.19 | | 0.19 | 0.19 | 0.12 | 0.12 | | | 0.70 | 0.70 | |
| 10-May-21 | 2.20 | | | 2.20 | 2.20 | 0.69 | 0.69 | | | BDL | BDL | |
| 23-May-21 | | 1.00 | | 1.00 | 1.00 | 0.15 | 0.15 | | | 2.60 | 2.60 | |
| 24-Jun-21 | | 0.80 | | 0.80 | 0.80 | 0.57 | 0.57 | | | 3.40 | 3.40 | |
| 18-Jul-21 | 1.50 | | | 1.50 | 1.50 | 0.95 | 0.95 | | | 5.50 | 5.50 | |
| 22-Jul-21 | | 0.50 | | 0.50 | 0.50 | 0.20 | 0.20 | | | 3.10 | 3.10 | |
| 30-Jul-21 | 1.10 | | | 1.10 | 1.10 | 0.64 | 0.64 | | | 3.00 | 3.00 | |
| 1-Aug-21 | | 0.10 | | 0.10 | 0.10 | 0.10 | 0.10 | | | 0.80 | 0.80 | |
| 17-Aug-21 | | 0.09 | | 0.09 | 0.09 | 0.10 | 0.10 | | | 1.30 | 1.30 | |
| 11-Sep-21 | 3.20 | | | 3.20 | 3.20 | 1.40 | | 1.40 | | 4.40 | 4.40 | |
| 28-Sep-21 | | 0.50 | | 0.50 | 0.50 | 0.22 | 0.22 | | | 1.30 | 1.30 | |
| 8-Oct-21 | | 0.20 | | 0.20 | 0.20 | 0.10 | 0.10 | | | 1.20 | 1.20 | |
| 19-Oct-21 | | 0.08 | | 0.08 | 0.08 | 0.06 | 0.06 | | | 0.80 | 0.80 | |
| 26-Oct-21 | | 0.05 | | 0.05 | 0.05 | 0.04 | 0.04 | | | 0.50 | 0.50 | |
| 2-Nov-21 | | 0.10 | | 0.10 | 0.10 | 0.10 | 0.10 | | | 0.40 | 0.40 | |
| 9-Nov-21 | | | | | | | | | | | | |
| count | 15 | 60 | 5 | 70 | 75 | 37 | 35 | 2 | 1 | 63 | 64 | |
| averages | 4.10 | 0.24 | 7.78 | 0.53 | 1.02 | 0.22 | 0.16 | 1.25 | 11.80 | 1.68 | 1.84 | |
| summer avgs | 4.11 | 0.30 | 7.78 | 0.76 | 1.64 | 0.33 | 0.23 | 1.25 | 11.80 | 2.27 | 2.54 | |
| winter avgs | 4.00 | 0.20 | | 0.31 | 0.31 | 0.08 | 0.08 | | | 0.94 | 0.94 | |
| summer count | 14 | 26 | 5 | 35 | 40 | 20 | 18 | 2 | 1 | 35 | 36 | |
| winter count | 1 | 34 | 0 | 35 | 35 | 17 | 17 | 0 | 0 | 28 | 28 | |
| compareFBavg | 2.00 | 0.29 | | 0.65 | 0.65 | 0.31 | 0.25 | 1.40 | | 1.89 | 1.89 | |
| count | 4 | 15 | 0 | 19 | 19 | 19 | 18 | 1 | 0 | 17 | 17 | |
| compare summ | 2.00 | 0.44 | | 0.96 | 0.96 | 0.44 | 0.35 | 1.40 | | 2.54 | 2.54 | |
| compare winter | | 0.12 | | 0.12 | 0.12 | 0.08 | 0.08 | | | 0.70 | 0.70 | |
| summer count | 4 | 8 | 0 | 12 | 12 | 12 | 11 | 1 | 0 | 11 | 11 | 0 |
| winter count | 0 | 7 | 0 | 7 | 7 | 7 | 7 | 0 | 0 | 6 | 6 | 0 |

Table 12. Cont.

Table 12. Cont.

**Table 7. Mosida**

| too big | Sampling Date | TP>1 outliers | Total Phos (mg/l) w/o outlrs | TP>5 outliers | Total Phos (mg/l) w/o outlrs | Total Phos (mg/l) all data | OrthoP mg/l all data | OP <1 | OP >1 | TN>1( outliers | Total Nitro (mg/l) w/o outlrs | Total Nitro (mg/l) all data |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 13-Mar-21 | | 0.33 | | 0.33 | 0.33 | 0.18 | 0.18 | | | 1.70 | 1.70 |
| | 20-Mar-21 | | 0.10 | | 0.10 | 0.10 | 0.10 | 0.10 | | | BDL | BDL |
| | 26-Mar-21 | | 0.14 | | 0.14 | 0.14 | 0.03 | 0.03 | | | BDL | BDL |
| | 15-Apr-21 | | 0.22 | | 0.22 | 0.22 | 0.07 | 0.07 | | | 1.30 | 1.30 |
| | 25-Apr-21 | | 0.13 | | 0.13 | 0.13 | 0.10 | 0.10 | | | 1.00 | 1.00 |
| | 23-May-21 | 1.7 | | | 1.70 | 1.70 | 1.60 | | 1.60 | | 6.40 | 6.40 |
| | 24-Jun-21 | | 0.48 | | 0.48 | 0.48 | 0.29 | 0.29 | | | 2.70 | 2.70 |
| | 22-Jul-21 | 1.8 | | | 1.80 | 1.80 | 1.30 | | 1.30 | | 3.80 | 3.80 |
| | 30-Jul-21 | 4 | | | 4.00 | 4.00 | 2.00 | | 2.00 | | 5.10 | 5.10 |
| | 1-Aug-21 | 2.8 | | | 2.80 | 2.80 | 1.60 | | 1.60 | | 4.30 | 4.30 |
| | 17-Aug-21 | | 0.70 | | 0.70 | 0.70 | 0.56 | 0.56 | | | 2.60 | 2.60 |
| 22.( | 11-Sep-21 | | | | | | | | | | | |
| | 28-Sep-21 | 2.2 | | | 2.20 | 2.20 | 1.20 | | 1.20 | | 5.30 | 5.30 |
| | 8-Oct-21 | | 0.60 | | 0.60 | 0.60 | 0.31 | 0.31 | | | 3.50 | 3.50 |
| | 19-Oct-21 | | 0.50 | | 0.50 | 0.50 | 0.36 | 0.36 | | | 2.10 | 2.10 |
| | 26-Oct-21 | | 0.10 | | 0.10 | 0.10 | 0.21 | 0.21 | | | 0.20 | 0.20 |
| | 2-Nov-21 | | 0.70 | | 0.70 | 0.70 | 0.59 | 0.59 | | | 1.10 | 1.10 |
| | 9-Nov-21 | | | | | | | | | | | |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| count | 21 | 41 | 1 | 61 | 62 | 33 | 23 | 10 | 5 | 55 | 60 | |
| averages | 2.59 | 0.32 | 5.20 | 1.02 | 1.09 | 0.68 | 0.27 | 1.61 | 27.76 | 2.49 | 4.60 | |
| summer avgs | 2.73 | 0.39 | | 1.49 | 1.49 | 1.02 | 0.28 | 1.60 | 25.78 | 2.96 | 5.81 | |
| winter avgs | 2.23 | 0.27 | 5.20 | 0.51 | 0.66 | 0.35 | 0.27 | 1.70 | 35.70 | 2.01 | 3.21 | |
| summer count | 15 | 17 | 0 | 32 | 32 | 16 | 7 | 9 | 4 | 28 | 32 | 0 |
| winter count | 6 | 24 | 1 | 29 | 30 | 17 | 16 | 1 | 1 | 27 | 28 | 0 |
| compareFBavg | 2.50 | 0.36 | | 1.03 | 1.03 | 0.66 | 0.25 | 1.54 | | 2.94 | 2.94 | |
| count | 5 | 11 | 0 | 16 | 16 | 16 | 11 | 5 | 0 | 14 | 14 | 0 |
| compare summ | 2.50 | 0.38 | | 1.56 | 1.56 | 0.97 | 0.26 | 1.54 | | 3.61 | 3.61 | |
| compare winter | | 0.35 | | 0.35 | 0.35 | 0.25 | 0.25 | | | 1.72 | 1.72 | |
| summer count | 5 | 4 | 0 | 9 | 9 | 9 | 4 | 5 | 0 | 9 | 9 | 0 |
| winter count | 0 | 7 | 0 | 7 | 7 | 7 | 7 | 0 | 0 | 5 | 5 | 0 |

Table 12. Cont.

**Table 8. Lehi**

| | Sampling Date | TP>1 outliers | Total Phos (mg/l) w/o outlrs | TP>5 outliers | Total Phos (mg/l) w/o outlrs | Total Phos (mg/l) all data | OrthoP mg/l all data | OP <1 | OP >1 | TN>10 outliers | Total Nitro (mg/l) w/o outlrs | Total Nitro (mg/l) all data | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 13-Mar-21 | | 0.39 | | 0.39 | 0.39 | 0.22 | 0.22 | | | 2.50 | 2.50 | |
| 57 | 20-Mar-21 | | 0.36 | | 0.36 | 0.36 | 0.09 | 0.09 | | | BDL | BDL | |
| | 26-Mar-21 | | 0.19 | | 0.19 | 0.19 | 0.09 | 0.09 | | | 2.30 | 2.30 | |
| | 6-Apr-21 | | 0.07 | | 0.07 | 0.07 | 0.05 | 0.05 | | | 1.60 | 1.60 | |
| | 15-Apr-21 | 2.5 | | | 2.50 | 2.50 | 1.30 | | 1.30 | | 4.50 | 4.50 | |
| | 26-Apr-21 | 1.3 | | | 1.30 | 1.30 | 0.45 | 0.45 | | | BDL | BDL | |
| | 10-May-21 | 2.1 | | | 2.10 | 2.10 | 0.36 | 0.36 | | | 0.90 | 0.90 | |
| | 23-May-21 | | 0.16 | | 0.16 | 0.16 | 0.03 | 0.03 | | | BDL | BDL | |
| ? | 24-Jun-21 | 9.2 | | 9.2 | | 9.20 | 4.00 | | 4.00 | | 2.50 | 2.50 | |
| | 22-Jul-21 | 7.4 | | 7.4 | | 7.40 | 3.50 | | 3.50 | 11.70 | | 11.70 | |
| | 30-Jul-21 | | 0.5 | | 0.50 | 0.50 | 0.33 | 0.33 | | | 1.80 | 1.80 | |
| | 1-Aug-21 | | 0.3 | | 0.30 | 0.30 | 0.19 | 0.19 | | | 2.20 | 2.20 | |
| | 17-Aug-21 | | 0.02 | | 0.02 | 0.02 | 0.03 | 0.03 | | | 1.80 | 1.80 | |
| | 11-Sep-21 | 1.8 | | | 1.80 | 1.80 | 1.20 | | 1.20 | | 5.40 | 5.40 | |
| | 28-Sep-21 | 2.1 | | | 2.10 | 2.10 | 0.96 | 0.96 | | | BDL | BDL | |
| | 8-Oct-21 | | 0.6 | | 0.60 | 0.60 | 0.29 | 0.29 | | | 1.40 | 1.40 | |
| | 19-Oct-21 | | 0.04 | | 0.04 | 0.04 | 0.04 | 0.04 | | | 1.50 | 1.50 | |
| | 26-Oct-21 | | 0.04 | | 0.04 | 0.04 | 0.01 | 0.01 | | | 1.20 | 1.20 | |
| | 2-Nov-21 | | 0.3 | | 0.30 | 0.30 | 0.35 | 0.35 | | | 4.30 | 4.30 | |
| | 9-Nov-21 | | | | | | | | | | | | |
| | count | 20 | 58 | 4 | 74 | 78 | 38 | 32 | 6 | 1 | 67 | 68 | 1 |
| | averages | 3.40 | 0.23 | 8.58 | 0.64 | 1.04 | 0.54 | 0.18 | 2.47 | 11.70 | 2.45 | 2.59 | 17.00 |
| | summer avgs | 3.79 | 0.27 | 8.58 | 0.72 | 1.50 | 0.79 | 0.24 | 2.46 | 11.70 | 3.16 | 3.42 | 17.00 |
| | winter avgs | 2.48 | 0.20 | | 0.56 | 0.56 | 0.27 | 0.14 | 2.50 | | 1.76 | 1.76 | |
| | summer count | 14 | 26 | 4 | 36 | 40 | 20 | 15 | 5 | 1 | 33 | 34 | 1 |
| | winter count | 6 | 32 | 0 | 38 | 38 | 18 | 17 | 1 | 0 | 34 | 34 | 0 |
| | compareFBavg | 3.77 | 0.25 | 8.30 | 0.75 | 1.55 | 0.71 | 0.23 | 2.50 | 11.70 | 2.42 | 3.04 | |
| | count | 7 | 12 | 2 | 17 | 19 | 19 | 15 | 4 | 1 | 14 | 15 | 0 |
| | compare summ | 3.77 | 0.21 | 8.30 | 1.09 | 2.29 | 1.03 | 0.30 | 2.50 | 11.70 | 2.59 | 3.60 | |
| | compare winter | | 0.27 | | 0.27 | 0.27 | 0.16 | 0.16 | | | 2.20 | 2.20 | |
| | summer count | 7 | 5 | 2 | 10 | 12 | 12 | 8 | 4 | 1 | 8 | 9 | 0 |
| | winter count | 0 | 7 | 0 | 7 | 7 | 7 | 7 | 0 | 0 | 6 | 6 | 0 |

Table 12. Cont.

**Table 9. Orem**

| Sampling Date | TP>1 outliers | Total Phos (mg/l) w/o outlrs | TP>5 outliers | Total Phos (mg/l) w/o outlrs | Total Phos (mg/l) all data | OrthoP mg/l all data | OP <1 | OP >1 | TN>10 outliers | Total Nitro (mg/l) w/o outlrs | Total Nitro (mg/l) all data | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 13-Mar-21 | | 0.22 | | 0.22 | 0.22 | 0.16 | 0.16 | | | 2.10 | 2.10 | |
| 20-Mar-21 | | 0.13 | | 0.13 | 0.13 | 0.08 | 0.08 | | | 1.00 | 1.00 | |
| 26-Mar-21 | | 0.17 | | 0.17 | 0.17 | 0.1 | 0.1 | | | 2.00 | 2.00 | |
| 15-Apr-21 | | 0.32 | | 0.32 | 0.32 | 0.08 | 0.08 | | | 2.10 | 2.10 | |
| 26-Apr-21 | | 0.22 | | 0.22 | 0.22 | 0.13 | 0.13 | | | 2.10 | 2.10 | |
| 23-May-21 | | 0.46 | | 0.46 | 0.46 | 0.24 | 0.24 | | | 2.60 | 2.60 | |
| 24-Jun-21 | | 1.00 | | 1.00 | 1.00 | 0.51 | 0.51 | | | 4.30 | 4.30 | |
| 18-Jul-21 | 2.9 | | | 2.90 | 2.90 | 2 | | 2 | | 8.20 | 8.20 | |
| 22-Jul-21 | | 0.20 | | 0.20 | 0.20 | 0.11 | 0.11 | | | 2.30 | 2.30 | |
| 30-Jul-21 | 2.5 | | | 2.50 | 2.50 | 2.1 | | 2.1 | | 2.40 | 2.40 | |
| 1-Aug-21 | | 0.40 | | 0.40 | 0.40 | 0.26 | 0.26 | | | 2.10 | 2.10 | |
| 17-Aug-21 | | 0.09 | | 0.09 | 0.09 | 0.1 | 0.1 | | | 1.80 | 1.80 | |
| 11-Sep-21 | | 0.80 | | 0.80 | 0.80 | 0.28 | 0.28 | | | 1.10 | 1.10 | |
| 28-Sep-21 | | 0.90 | | 0.90 | 0.90 | 0.04 | 0.04 | | | 1.10 | 1.10 | |
| 8-Oct-21 | | 0.30 | | 0.30 | 0.30 | 0.09 | 0.09 | | | 2.20 | 2.20 | |
| 19-Oct-21 | | 0.10 | | 0.10 | 0.10 | 0.04 | 0.04 | | | 0.60 | 0.60 | |
| 26-Oct-21 | | 0.04 | | 0.04 | 0.04 | 0.07 | 0.07 | | | 1.20 | 1.20 | |
| 2-Nov-21 | | 0.10 | | 0.10 | 0.10 | 0.24 | 0.24 | | | 5.20 | 5.20 | |
| 9-Nov-21 | | | | | | | | | | | | |
| count | 11 | 58.00 | 1 | 68 | 69 | 39 | 36 | 3 | 2 | 67 | 69 | |
| averages | 2.41 | 0.25 | 8.90 | 0.48 | 0.60 | 0.25 | 0.13 | 1.73 | 16.80 | 2.18 | 2.60 | |
| summer avgs | 2.93 | 0.32 | 8.90 | 0.58 | 0.80 | 0.41 | 0.17 | 1.73 | 16.80 | 2.38 | 3.14 | |
| winter avgs | 1.50 | 0.17 | | 0.35 | 0.35 | 0.09 | 0.09 | | | 1.94 | 1.94 | |
| summer count | 7 | 31 | 1 | 37 | 38 | 19 | 16 | 3 | 2 | 36 | 38 | 0 |
| winter count | 4 | 27 | 0 | 31 | 31 | 20 | 20 | 0 | 0 | 31 | 31 | 0 |
| compareFBavg | 2.70 | 0.34 | | 0.60 | 0.60 | 0.37 | 0.16 | 2.05 | | 2.47 | 2.47 | |
| count | 2 | 16 | 0 | 18 | 18 | 18 | 16 | 2 | 0 | 18 | 18 | 0 |
| compare summ | 2.70 | 0.49 | | 0.89 | 0.89 | 0.53 | 0.19 | 2.05 | | 2.74 | 2.74 | |
| compare winter | | 0.15 | | 0.15 | 0.15 | 0.11 | 0.11 | | | 2.04 | 2.04 | |
| summer count | 2 | 9 | 0 | 11 | 11 | 11 | 9 | 2 | 0 | 11 | 11 | 0 |
| winter count | 0 | 7 | 0 | 7 | 7 | 7 | 7 | 0 | 0 | 7 | 7 | 0 |

## Wet and Dry Atmospheric Deposition Samples

Wet and dry deposition samplers were constructed and deployed in 2017 in an effort to accurately measure the actual deposition on the Utah Lake surface rather than to utilized regional NADP sites that were located several hundred miles to the east and southeast and at remote and elevated sites relative to Utah Lake. To review, Utah Lake is a remnant of ancient Lake Bonneville that once covered the majority of northern Utah and some of eastern Nevada. Much of the lakebed of Lake Bonneville is currently playa, and mostly remains dry due to the continuing megadrought and the continued diversion of major and minor tributaries. Significant local sources of mobilized nutrients include the west desert (salt flats) and the Severe lakebed in Iron County. Other local sources include agricultural activities in and near Utah Valley and the urbanized and urbanizing portions of Utah County that surround the lake. While it has been argued by some members of the Science Panel that some of these urban sources are inappropriately applied to the AD contribution to the lake, it should be noted that these disturbances have been ongoing for decades and only continue to intensify, becoming a continuous supply of dust and aerosols to the lake, including during year-around inversions over the lake with an entrapped urban plume that descends downslope to the lake surface (See Miller and Barrus SAP, 2019; Appendix A).

Each year of monitoring produced a Master's thesis ( Olsen 2018, Riedhead 2019, Barrus 2021) and these results of three of the last four years were published in peer-reviewed journals (Olsen et al. 2018 and Barrus et al. 2021).

Data from the first two theses were analyzed similarly. TP and DIN unit deposition rates were arranged to create spatial models of nutrient distribution patterns on the lake. To calculate total deposition during 2017, a total lake surface area of 354 km$^2$ (88,000 acres) was used, which was the average lake area during the sampling period. At that time, we hypothesized that deposition near the shoreline is most likely higher than deposition in the interior of the lake as near-shore local soil dust would be important, but perhaps not so pervasive across the lake.

Most atmospheric deposition studies, however, including the NADP, are not interested this type of local transport and deposition. Rather, they focus on deposition rates from long-range nutrient transport [NADP 2014, Mahowald, 2008] and therefore, such long-range sources and transport may be less important than local sources from disturbed landscapes and dry playas. However, there may not be such a clear distinction between local and long-range transport. Goodman et al. (2019) described the similarity between playa dust from the remnant playas of Lake Bonneville, urban aerosols and snowpack dust, documenting the distribution of playa dusts into areas high in the Wasatch Mountains. They also noted that urban aerosols contribute substantial amounts of anthropogenic trace elements which are soluble and readily available in the environment. This confirmed our initial hypothesis and observations that large quantities of dust are transported from the Sevier Lake and the west desert playas and deposited locally, including on the Utah Lake surface. Similar observations and subsequent atmospheric deposition measurements were performed by Jassby et al. (1994). They investigated atmospheric deposition on Lake Tahoe and described the storm systems that approach from the west, across the California Central Valley and the south, from the deserts of southern California and Nevada. Jassby et al. (1994) also found that these particles travelled much further than in studies that described merely the transport of large particles from immediately adjacent road dust (Van Curen 2012).

Nevertheless, in our early studies, we assumed transport similar to Van Curen (2012) and chose to conservatively estimate total deposition rates across Utah Lake.

Using Kriging methods, six “dummy” sample points along the center of the lake were created (blue squares in Figure 3) and assigned background deposition values for TP and DIN of 0.019 mg TP $m^{-2}$ $week^{-1}$ (Mahowald, et al. 2008) and 0.112 mg DIN $m^{-2}$ $week^{-1}$ (NADP 2014), respectively (Olsen 2018).

These values are at least two orders of magnitude lower than the local deposition rates measured at the lake shore. Dr. Gay modified this observation, stating “My deposition values for wet deposition are much higher and agree with your local deposition measured rates. And we measure wet deposition versus your bulk measurements, which should be higher.” This suggests that long-range transport, at least for nitrogen contribute significantly to local deposition. Nevertheless, in order to provide the most conservative (least controversial) estimate, we used these low background levels for the interior of the lake. Figure 4 shows the data locations used to create the spatial model. The red stars along the shore are local sample locations: Lake Shore, Mosida, Saratoga Springs, Pump Station, and at the Orem WWTP. Background deposition rates were assigned as described above to the six blue squares in the center of the lake (Figure 4).

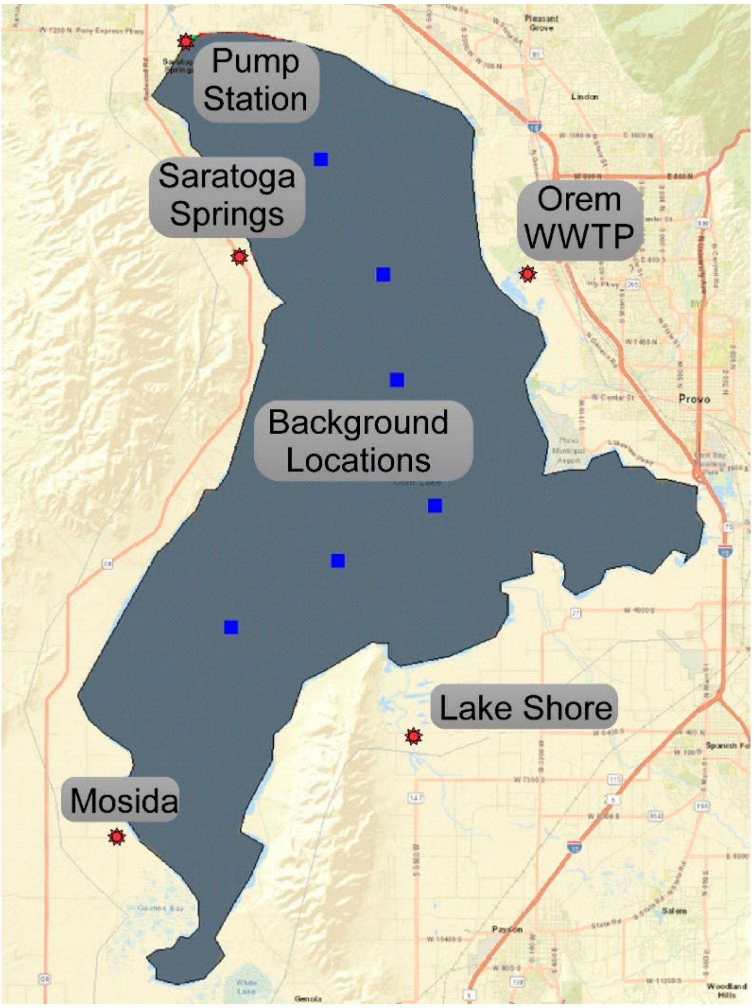



Figure 4. Utah Lake coverage showing the eleven points used in interpolation. The red stars show locations of lakeside samplers. The Blue squares show the locations used for the interpolation analysis using Kriging techniques. See text for more details.

Olsen et al. (2018) used the Groundwater Modeling System (GMS) geostatistical software developed by AQUAVEO (2018) for computation and to create the spatial distribution maps. To interpolate between the sample points simple kriging was used with an exponential variogram that had a range of 1000 m to represent the decrease in the deposition rate as distance increased from the shoreline (Cole et al. 1990, Gomolka 1975). Data were interpolated from the sample points, both measured and background (mid lake), onto a 2D grid with 3398 cells which represents the lake surface. Each of the cells had an area of 101,722 m2 with dimensions approximately 381 m by 267 m (1250 feet by 875 feet). This approach means that the estimated deposition rates tend toward the average deposition rate for cells away from the sample points. In this case the average rate would be the average of the six lake surface points (long-range background) and the five shoreline sample points, this would result in data closer to the long-range background deposition rates, significantly lower than any rates measured at the shoreline stations. In other words, using Kriging in this manner, put more weight on the background estimates acquired from locations hundreds of miles away, such as estimated by Brahney (2019), rather than actual measured values acquired from five lakeside samplers.

Table 13. Summary for total phosphorous (TP) concentration and load data from May 2017 through December 2017.

| Site | No. of Data | Mean TP Concentrations (mg/L) | | Rain | Total TP Load Rate (mg $m^{-2}$ $day^{-1}$) | | |
|---|---|---|---|---|---|---|---|
| | | Wet | Dry | cm(in)/Week | Mean | S.D. | Skewness |
| Lake Shore | 41 | 0.68 | 0.38 | 0.64(0.25) | 1.33 | 1.95 | 0.82 |
| Mosida | 38 | 0.22 | 1.10 | 0.30(0.12) | 2.77 | 5.63 | 2.55 |
| Saratoga Springs | 44 | 0.60 | 5.15 | 0.43(0.17) | 31.38 | 88.73 | 2.14 |
| Pump Station | 38 | 0.59 | 0.85 | 0.41(0.16) | 3.78 | 20.14 | 4.68 |
| Orem WWTP [1] | 27 | 1.62 | 0.39 | 0.28(0.11) | 1.26 | 2.65 | 3.33 |
| Average | 38 | 0.74 | 1.57 | 0.41(0.16) | 8.10 | 23.82 | 2.70 |

[1]Waste Water Treatment Plant (WTTP) property.

Nitrogen loads were estimated similar to the P calculations (Table 14).

Table 14. Summary for dissolved inorganic nitrogen (DIN) deposition data from May 2017 through December 2017

| Site | No. of Data | Mean DIN Concentrations (mg/L) | | Rain | Total DIN Load Rate (mg $m^{-2}$ $day^{-1}$) | | |
|---|---|---|---|---|---|---|---|
| | | Wet | Dry | cm(in)/Week | Mean | S.D. | Skewness |
| Lake Shore | 41 | 4.30 | 1.15 | 0.64(0.25) | 4.09 | 4.06 | 0.47 |
| Mosida | 38 | 2.29 | 1.50 | 0.30(0.12) | 4.17 | 4.74 | 1.21 |
| Saratoga Springs | 44 | 4.86 | 6.00 | 0.43(0.17) | 36.06 | 124.62 | 3.31 |
| Pump Station | 38 | 4.29 | 0.38 | 0.41(0.16) | 1.59 | 2.33 | 2.31 |
| Orem WWTP | 27 | 7.55 | 1.33 | 0.28(0.11) | 5.23 | 4.60 | 3.04 |
| Average | 38 | 4.66 | 2.07 | 0.41(0.16) | 10.23 | 28.07 | 2.07 |

Much discussion occurred among the authors and reviewers as to the best manner to report the data and particularly how to report the data from Saratoga Springs. It was suggested that this site was close to considerable anthropogenic activity, including a gravel pit and experienced aberrant contributions from a local population of bees during the early summer. While it was ultimately decided to display both the results from 1) samples where no visible particles were present whatsoever (even excluding any single particle of dust or mud), and 2) where all sample data were included, including when visible particles or bees were present. These values represent the extremes of sample collection and data use. For example, members of the Science Panel criticized the fact that insects or even muddy or dirty samples should not be included in the sample set. An additional response to this criticism is discussed below. Excluding samples where visible particles or dust were present assumes that no material, whether from natural wind-born dust storms or plant material is not "natural" and would never reach the lake. Alternatively, nearly the entire 160 miles of Utah Lake shoreline is lined with several 10s to hundreds of meters of phragmites or cattails and it is well known that dust particles can travel large distances and be deposited across lake surfaces (e.g., Jassby et al. 1994) and high-elevation mountain snowpack (e.g., Lawrence et al. 2010, Goodman et al. 2019) in relatively high amounts. Notably, elevated deposition occurs at all sites during summer as has been documented for four years by Dr. Wood Miller (see above) and this is typical of AD data from arid regions (see the Miller and Barrus SAP 2019).

Olsen et al. (2018) suggested that because most of the storms in this region approach from a westerly direction, first arriving on the western shore (perhaps represented by the Saratoga Springs site, Mosida, or even at the pump station), these dust particles are naturally sourced. In turn, the Orem WWTP site is on the eastern shore and local dust clouds generated during these storms need to cross the 10-km-wide lake before reaching the Orem WWTP site. This site has the minimum average TP loading measured during the study of 1.26 mg $m^{-2}$ $day^{-1}$. They argued that it is likely then, that TP deposition rates decrease across the lake in some fashion from 31.38 to 1.26 mg $m^{-2}$ $day^{-1}$ measured at Saratoga Springs and Orem WWTP, respectively. However, while this seems like an appropriate approximation of dust attenuation across the lake surface, this is actually a much faster attenuation rate than measured across much larger Lake Tahoe (Jassby et al. 1994). This discrepancy is likely due to the closer proximity of dust sources to Utah Lake and hence delivers larger particles that settle sooner/closer than those measured across Lake Tahoe.

However, concerning the Saratoga Springs site, while it is assumed to be subject to exceptional exposure to human activities and seasonal insect "contamination", it would logically be assumed that the wet samples should also be elevated, as rain would be expected to capture dust particles as well. However, the concentration of wet samples lies slightly lower than the wet sample mean in Table 13. Therefore, with these (terrestrial insect) only temporally (4-6 weeks) entering this dry-side bucked, perhaps the dry side data should not be so readily discarded as outlier data (see discussion on insect-based nutrient contribution to lakes below).

One alternative to resolving this discrepancy and still utilize the data is to replace the Saratoga mean dry sample with the mean of the other five sites (similar to Dr. Miller's treatment of the weeks that are absent wet deposition in his bulk sampling study). Along with the background regional deposition rates used at the 6 sites established in the middle of the lake, the resultant estimate of annual deposition on Utah Lake becomes 135 metric tons of total P and 654 metric tons for total inorganic N using Olsen et al. (2018) data.

## A Review and Discussion of the Brahney (2019) Proposed AD on Utah Lake and Critique of Olsen et al. (2018) Methods and Data

Following release of the Olsen thesis and subsequent publication (Olsen et al. 2018), UDWQ asked Dr. Brahney of Utah State University to provide a critique of the Olsen thesis and develop her own estimate of atmospheric deposition on Utah lake. Because of the paucity of local data (which the Council was committed to develop), Brahney used global, regional, and urban deposition data from various sources and sampling media. While this produced a noteworthy document, several questions remain concerning use of data collected great distances from Utah Lake that sampled various media using various types of samplers. Here I provide a detailed evaluation of the applicability of the data and in relation to our efforts to collect site-specific data while adhering to NADP protocols as closely as possible. We also include a response to criticisms of our sampling methods.

Brahney (2019) criticized the Olsen thesis mostly based on contamination and particularly at one of the sample sites that captured high levels of dust throughout the sampling period and insects for about 6 weeks, although the ensuing Utah Lake Science Panel discussion mostly focused on emergent midges rather than the terrestrial bees that were the actual culprit and likely originating from a cultivated field about 600 m upwind. Brahney (2019) was also critical about the lack of carefully adhering to NADP recommended protocols – and particularly that we placed our samplers at the shoreline. Dr. Brahney also criticized the presence of other particles and even dust captured by rain droplets. In place, she used NADP wet deposition data from the four regional sites in eastern Utah, all but three of which are at least 4000 feet higher in elevation and all were on the other side of the 12,000 ft Wasatch Mountains and at least 150 miles east and southeast of Utah Lake – likely providing very low probability for representing dust inputs from local sources surrounding Utah Lake; In addition, Brahney (2019) used dust data from locations from hundreds to thousands of miles from Utah Lake (from Logan, UT to Singapore, China) to estimate P content of "urban dust", and the limited amount of data from snowpack dust in the Wasatch Range. In short, there were several separate data sets and several different sampling methods of different media from distant locations used to develop estimates that were assumed to be more applicable to Utah Lake and hypothetically, more-so than our five lake side samplers. However, data from the wet/dry samplers are now backed up by more than five hundred bulk samples in Dr. Wood Miller's database (see above) and a growing data base of more than 500 wet/dry samples under the direction of Dr. Wood Miller and the Council.

Measurements of total vs dissolved vs SRP/ortho-P are well known to be different – depending on whether the sample material is weathered bedrock (eastern Uintas) vs Lake Bonneville sediments vs urban sources. Yet, Brahney (2019) made the statement that "as has been demonstrated elsewhere, local sources are not expected to contribute significantly beyond the shoreline of Utah Lake (Cole et al. 1990, Dolislager et al. 2012, VanCuren et al. 2012a, 2012b) whereas regional sources, such as the semi-arid and arid regions of the Colorado Plateau, are assumed to contribute uniformly to the lake."

This statement is inaccurate on two counts: first, Brahney (2019) failed to include a much more comprehensive multiyear study by Jassby et al. (1994) investigating the movement and deposition of dusts across Lake Tahoe – with *insignificant reductions* in P deposition at a buoy site near the middle of the lake, 20 km from the western shore (see figures below). Secondly, Brahney (2019) failed to recognize the fact that prevailing winds and all storms arrive from the west, SW, or NW - making Colorado Plateau dusts virtually impossible to travel 200 miles to the northwest to Utah Lake. The significant sources of dust from the large playas in Utah's west desert and the playa of Sevier Lake, southwest of, and directly upwind (from the daily prevailing winds) from Utah Lake and primary direction of summer thunderstorms; (e.g., see windrose from Mosida and Delta below) to Utah Lake (Abu-Hmeidan, 2018, Carling et al. 2017, Goodman et al. 2019).

In addition, the number of days of inversions that Salt Lake, Cache and Utah Counties experience is much higher than Brahney's (2019) estimate of 25 days. For example, there has been at least 75 days of inversions since November, 2021 and the time of this writing February, 2022, trapping urban aerosols in the bottom of Utah's Valleys and overlying Utah Lake. Brahney (2019) states that data on inversions are not available but then claims that inversions occur 3 to 7 % of time. In reality, inversions occur nearly nightly, including during summer, because of the cool downslope winds that come off the Wasatch Mountains (particularly Spanish fork Canyon; as depicted in the windrose in Brahney (2019), across the cities of Spanish Fork, Payson and Provo and out across the lake. Thus, much of the significant sources of AD have been discounted or nearly completely unaccounted for in the Brahney (2019) report.

Nevertheless, because of these inaccuracies and criticisms of the Olsen (2018) thesis, two additional sampling seasons were performed for the purposes of gathering multiyear data, excluding the Saratoga sampling site, and carefully adhering to every NADP siting recommendation wherever possible (see below). These included raising sampling equipment to a height of 2 m, moving the solar panel to 5 m from the sampler, moving a sampler to adhere to prescribed distances from roads and driveways and highways (including accounting for vehicle use), buildings, etc. In addition to NADP recommended protocols, we added screens with 500-micron mesh to the dry-side buckets to prevent large particles such as insects and plant material from entering the sample. We also added a matting material (Miner's Moss®) to the top of the lid to prevent splash from raindrops from bouncing off the lid and entering the wet-side bucket during a rain event. Perhaps most importantly, we added a sampling station in the south-central interior portion of the lake, at Bird Island in 2020 to more accurately estimate AD across the lake surface relative to the shoreline sites. These additions and changes are discussed in greater detail below.

Additional discussion, with specific reference to the statements/assumptions in the Brahney (2019) paper and our response follows.

Brahney (2021) states: "Approximately 56.6 km of the Utah Lake perimeter is bordered by urban or agricultural regions. To determine the lake area potentially influenced by urban activities, we applied a first order decay equation mimicking similar observations at Lake Tahoe where urban influence had diminished to 10% by 200m (VanCuren et al. 2012b). Because there is no current data on the attenuation of urban atmospheric deposition onto Utah Lake, I apply three different attenuation equations. The Lake Tahoe study indicated that the zone of influence diminished to 10% at 200m. I applied first order rate decay equation that mimicked that observed at Lake Tahoe. In an attempt to calculate the maximum deposition to Utah Lake, and because there is only one example from a large lake, we apply first order rate decay equations where the urban influence would extend to 2 and 4x that observed at Lake Tahoe, i.e., 10% of the urban deposition rate at 400 and 600m."

This statement is misapplied. As mentioned above, a particularly important paper addressing AD on Lake Tahoe was published by Jassby et al. (1994). This multi-year study included two sampling sites on the west side of the lake and four buoy stations on the lake. Three buoys were in a west-east transect in line with the two sites on the west side of the lake (Figure 5). Figure 6 displays the relative difference in deposition rates between the West Lake site (WL) and southern lake site (SOU) relative to the Mid-lake site (MID). In other words, SRP AD declined about 20% over the 20 km distance from WL to MID. In addition, this was not a statistically significant drop for SRP measured at the shoreline. Surprisingly, the differences for nitrate and ammonia were statistically significant – but in an opposite pattern. This is contrary to the Lake Tahoe data reported by VanCuren et al (2006). I suggest the difference is likely due to the close proximity of the VanCuren et al. (2006) samples to a lakeside gravel road on the south side of Lake Tahoe with sampling likely conducted during only a mild southern breeze. Clearly, larger particles were generated by passing vehicles which provided the observed rapid attenuation pattern.

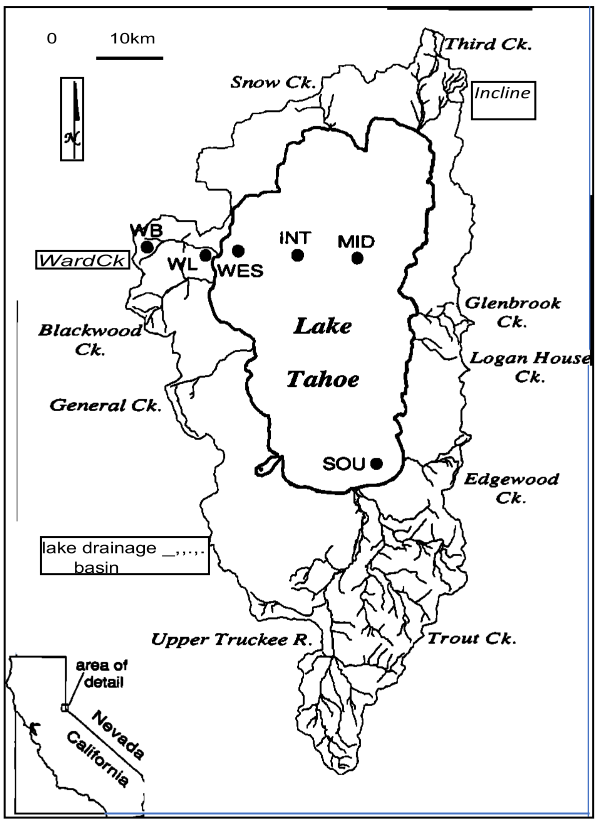



Figure 5. Map of Lake Tahoe showing locations of sample sites. (From Jassby et al. 1994)

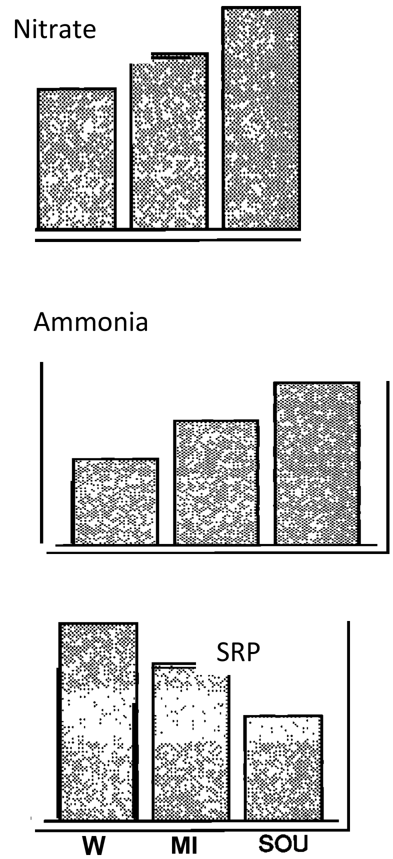



Figure 6. Relative deposition rates of nitrate, ammonia and SRP on Lake Tahoe as measured with buoy buckets (MID and SOU) compared to the shoreline sampler (WL). WL, Ward Lake Level; MID, Mid Lake; SOU, South Lake. From Jassby et al. (1994).

Alternatively, the Jassby et al. (1994) paper attributed the AD source to wind-born agricultural dusts from California's Central Valley or the Mohave desert in southern Nevada and southern California. Either way these dust sources are between 60 and 100 miles (90 to 160 km) downwind from the Central Valley source and these dusts need to travel from about 100 ft elevation to over the ~7000 ft+ Sierra Nevada Range in order to settle in the Lake Tahoe basin. While the particles were likely much smaller in mass, these samples demonstrated that Lake Tahoe receives about 18 tons of SRP per year, equivalent to about 12 tons of SRP to Utah Lake. Jassby et al. (1994) attributed the increase in nitrate and ammonia deposition rates with distance across the lake to different source(s) for the DIN than for SRP and perhaps were from local forest sources. Sadly, this uncontrollable AD is the primary source of nutrients contributing to the slow eutrophication of Lake Tahoe (Jassby et al. 1994).

Notably, this is a similar distance to travel from the west desert or the Sevier Lake playa to Utah Lake- only the main difference between Lake Tahoe and Utah Lake is that the mountain range separating the west desert from Utah Lake requires that the dust travels up and over about 3000 ft elevation (compared to 7000 ft rise before reaching the Lake Tahoe basin) and more importantly, there is only about a 100 ft (30m) elevation change between the Sevier Lake playa near Delta and Utah Lake. In short, there is much less resistance for dust and particularly for larger particles from the SW to be transported by prevailing winds and storm events to Utah Lake. Such was the conclusion suggested by Cole et al. (1990).

Considering the Jassby et al. (1994) paper, the comparison of the VanCuren et al. (2010) data and calculation to the Utah Lake geography and placement of our samplers is unfounded and use of its calculation is inappropriately applied to Utah Lake.

In addition, Brahney (2019) applied the NADP data as follows:

> "Regional wet phosphorus deposition rates are determined as an average of the four NADP locations in remote locations. Logan was not included due to the proximity to urban and agricultural locations. Because 65% of the 16 measurements were below detection, I use half the detection limit (3 $\mu$g $PO4^{3-}$ $L^{-1}$) in these instances. The mean concentration was 10.9 $\mu$g P $L^{-1}$. Deposition rates ranged from 2 to 4.1 mg P $m^{-2}$ $yr^{-1}$, with a mean of 2.9 mg P $m^{-2}$ $yr^{-1}$)."

As mentioned above, the locations of three of these four sites are 150 miles south and southeast of Utah Lake, while East McKee Mountain is located about 140 miles east of UL in the eastern Uinta Mountains and all of these sites, except the Green River site are between 7000 and 8000 ft above sea level and one large mountain range away. While these sites are thought to represent regional high-elevation wet deposition for the western US, they are not in line with the typical west and southwest prevailing winds that move from the much closer Sevier Lake Playa (about 100 km) toward Utah Lake (see Figure 7, Vernal windrose; and Figure 8, Delta windrose).

Just the fact that 65% of the 16 samples were below detection indicates that these are high altitude, pristine sites with minimal ground disturbance. Alternatively, much of central and western Utah is bare playa, subject to continued drying by drought and tributary diversions – exposing nutrient-rich sediments or is disturbed by agriculture or by urban development or is subject to ever-increasing

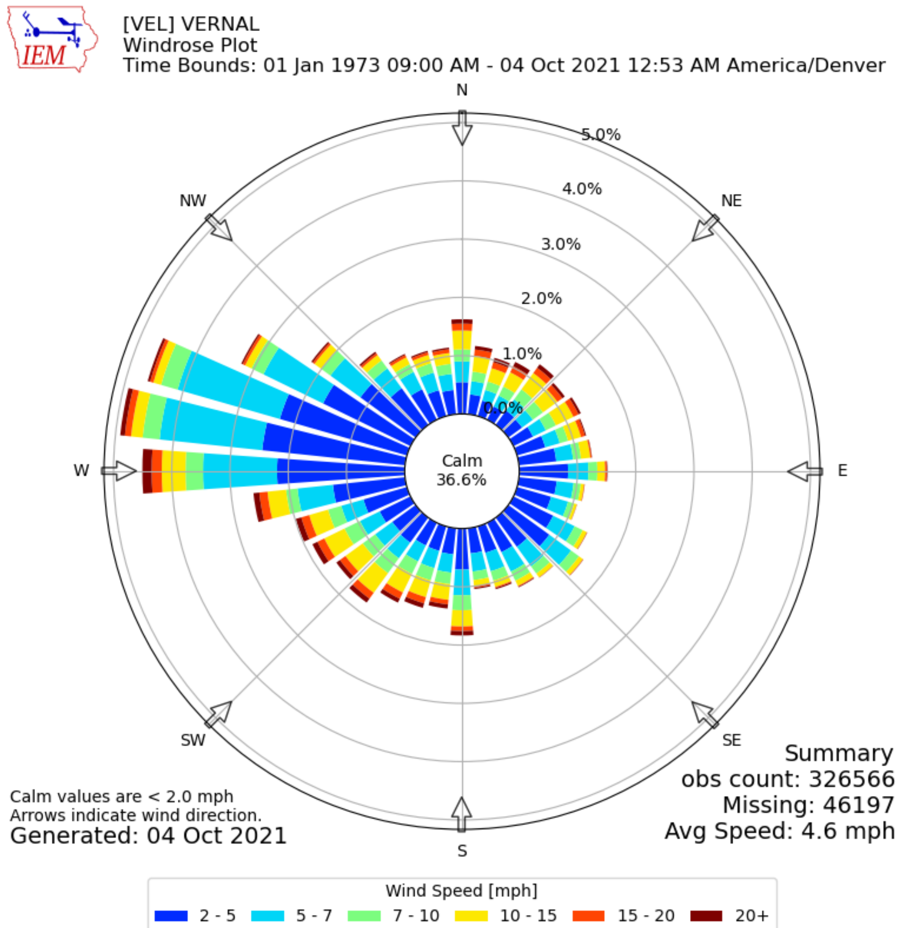



Figure 7. Windrose recorded at the Vernal, Utah airport. The prevailing wind approaches from the west/northwest with occasional high velocity winds from the southwest and northeast.

frequency and intensity of inversions due to urbanization in confined valleys, all of which, affect Utah Lake.

While these samplers are dependable in collecting rainwater samples, their location, >220 km (140 miles) east and southeast of Utah Lake and their high elevation, does not represent the conditions around Utah Lake. At best, Utah Lake is about 1/2 the distance from the west and southwest desert dust sources than the NADP sites, and Utah Lake is directly downwind from these sources. This provides a much higher probability of receiving more deposition from these sources – for both wet and dry samples.

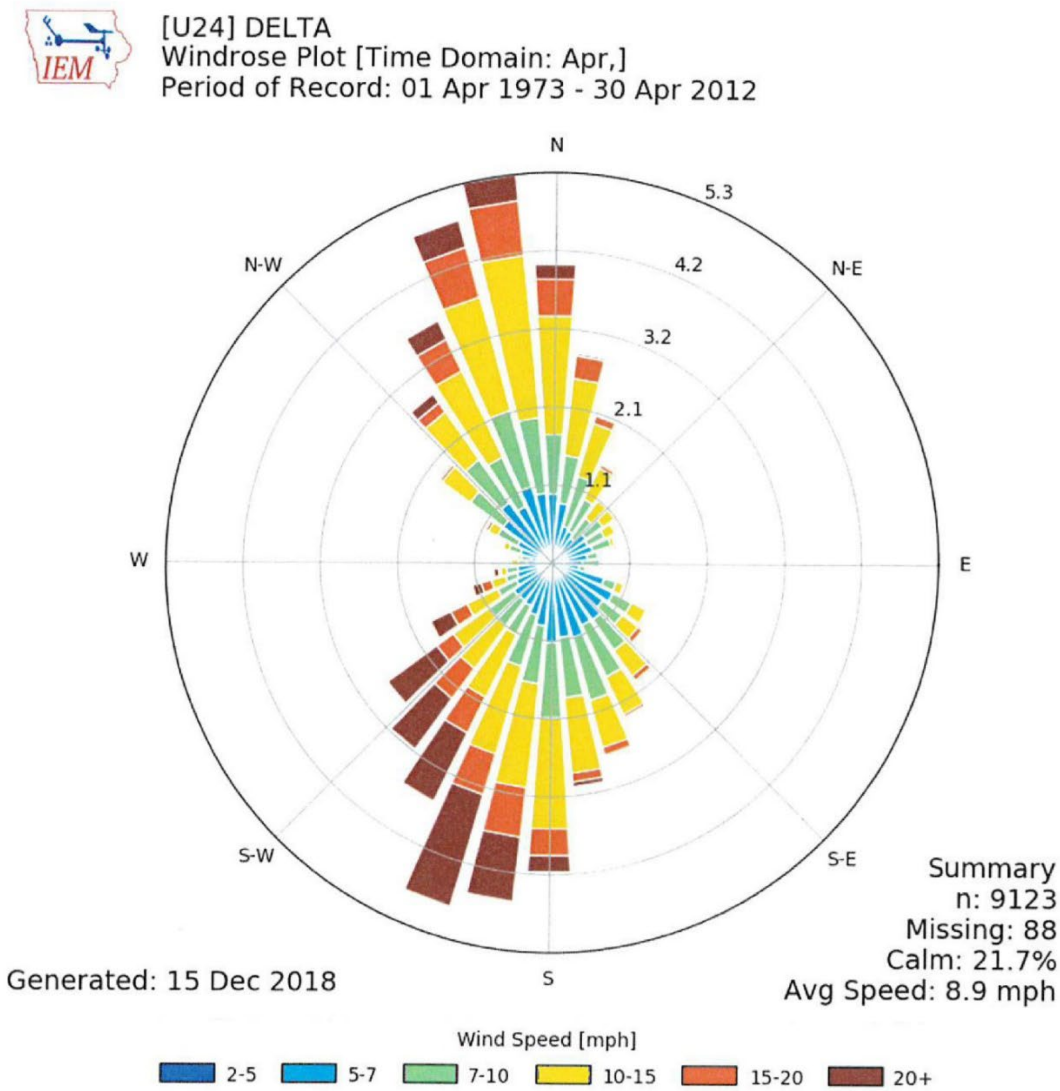



Figure 8. Windrose from the Delta airport, located in the wide-open valley (minimal restrictions from mountain ranges. Data from the Iowa Environmental Mesonet (IEM).

Table 15. Wet phosphorus deposition rates from remote locations around Utah as measured by the NADP. From Brahney (2019)

| NADP site | Site Name | Class | $PO_4^{3-}$ µg/L | total ppt (mm) | mg $PO_4^{3-}$ $m^{-2}$ $yr^{-1}$ |
|---|---|---|---|---|---|
| UT98 | Green River | Rural | 13.5 | 996.2 | 2.7 |
| UT09 | Canyonland | National Park | 9.5 | 1073.9 | 2.0 |
| UT99 | Bryce | National Park | 6.0 | 2432.2 | 2.9 |
| UT95 | East McKee | Mountain | 14.5 | 280.3 | 4.1 |
| *Average* | | | *10.9* | | *2.9* |

Other concerns with the Brahney (2019) white paper include the minimal measurements of dry deposition samples and the lack of use of wet samples that contain any visible dust; e.g. " Note that if the dust mediated transfer of nutrients to Utah Lake is determined by the total mass flux of dust and mean P concentrations, rain contaminated by dusts should not be used to establish a wet deposition rate since dust deposition is independently accounted for. Since rain effectively scrubs the atmosphere of particles, this method is recommended instead measuring wet and dry particulate deposition separately."

These last two sentences are contradictory. i.e., "rain scrubs the atmosphere of particles and therefore this method is recommended." Yet, it is suggested not to use wet deposition samples that contain dust. Following this suggestion results in excluding the very important wind-driven dusty summer thunderstorms that disperse across the lake – as was done to obtain the "low" AD values by Olsen et al. (2018) (See Table 1). Because it is scrubbed by rain droplets and is carried to the surface of the earth, it is certainly wet and needs to be measured – no matter how muddy – as was done to obtain the "high values in Olsen et al. (2018).

Moreover, this is contrary to current understanding that in arid regions dry deposition is much greater than wet deposition (e.g. Jassby et al. 1994; Rafael Morales-Baquero, et al. 2013. Loye-Pilot and Martin 1996; Reheis et al. 1995, and as observed in W. Millers data set).

Further, while NADP samples were using wet deposition methods only, the Brahney (2019) citations for local urban samples were identified as only dust samples (i.e., bulk marble, or dust-on-snow samples) – with virtually no explanation of the method(s) used for sample collection except "bulk marble". For example, the frequency of sampling is unknown as well as the exact location of the sampler. With the severe criticism of not using NADP standard samplers and protocols in our studies, it is curious as to why bulk marble sampler data and rain-on-snow data were used in the Brahney (2019) report. These include far more variability in source, composition, sampling frequency and duration than used in our study.

In addition, it appears that there is no legitimate reason for removing the high Uinta data from the calculation of mean phosphate concentrations shown Table 5 in Brahney (2019). For example, three of the locations are near the ridge line at >11,000 ft elevation and about 5,000 ft higher than the phosphorus mine and are from about 25 to 100 km northwest of the mine. Munroe (2014) mentions that the prevailing winds in the Uinta Mountains approach from the south or southwest. A windrose recorded at the Vernal, Utah airport, in the Uinta Basin is displayed in Figure 7. The least common winds are from the southeast – the direction needed to carry dust northwest to the Munroe et al. (2014) samplers.

The source of the dust is more likely the disturbance from oil and gas development in the Uinta Basin to the southwest, including hundreds of miles of well-travelled gravel roads. This area is still 50 km away from the samplers and about 5500 ft lower, suggesting that this is a case of long-term, perhaps mid-range-distance transport – a very similar distance from the sources of dust from the playas of the west and southwest playas of Utah, to Utah Lake.

Also, Brahney (2019) states: “Assuming minimum to maximum and mean deposition rates observed regionally (1.4 - 15.6, mean 6.2 g $m^{-2}$ $yr^{-1}$) and phosphorus concentrations as measured in these dusts (0.56 – 1.15, mean 0.78 mg/g), total phosphorus deposition can be expected to range from 0.78 to 17.9 mg TP $m^{-2}$ $yr^{-1}$, with an average deposition rate of 4.8 mg TP $m^{-2}$ $yr^{-1}$.”

A key point here is that Brahney (2019) cited values of Mahowald et al. (2008) for TP concentrations in the fine fraction (<2.5 $\mu$m) which is 1% for coal, oil boiler, gasoline and diesel engines, and incinerator sources of dusts and 0.5% TP for the coarse (>10 $\mu$m) fraction of the same. There are no coal-fired plants, oil boilers or incinerators (the most P-concentrated particles), in Utah Valley, and there are no data displayed for gasoline and diesel engines (Therefore, Mahowald et al. (2008) suggested that P in these emissions is insignificant). This suggests that the source of P is likely mineral aerosols and dust, such as described by Carling et al. (2017) and Abu-Hmeidan, et al. (2018) where it was found that about 90% of dusts deposited in Wasatch Front mountains had the chemical signature of west desert and southwest desert playa dust. Clearly, these dusts would have to travel across urban zones before being lofted to 8000 ft in the Wasatch Mountains. As such, the percentage of P concentration in the local and surrounding dusts is much less – ranging from 0.007% to a high of about 0.018% (700 to 1800 mg/kg; Carling et al. 2017), notably in the range of P in the earth’s crust).

Nevertheless, this suggests that particles from the playas are drifting across the lake before they get to the urban or mountain environments. Thus, if we carry the most accurate local urban dust number, (in Provo; 189.6 mg $m^{-2}$ $yr^{-1}$, cited in Table 2 of Brahney (2019), through the deposition calculations, and project this number across Utah Lake, there would be a much higher value for P deposition on Utah Lake, at about 67 metric tons per year. This number is in the range of values reported in the bulk deposition samples by Dr. Wood Miller (see above) and which is closer to the range of hundreds of sample values reported for multiple years from multiple sites surrounding Utah Lake from the wet/dry samplers. The reasons why this is nearly an order of magnitude higher than Brahney’s (2019) final number is that the Provo number is “diluted” with a rural/urban number from Logan (more than 160 km away; 88.9 mg $m^{-2}$ $yr^{-1}$ ) that is less than ½ the Provo number (resulting in 139.3 mg $m^{-2}$ $yr^{-1}$) and then further reduced to 93.6 mg $m^{-2}$ $yr^{-1}$ based on a non-referenced estimate of P composition in "local" dusts. The more direct use of this important Provo number would provide a much more accurate number than "diluting" it with a rural number from Cache Valley and other unknown manipulations.

It appears that all the data in Tables 5 and 6 of Brahney (2019) were dust-on-snow samples (i.e., Zhang et al. 2018, Monroe 2014, Reynolds et al. 2024). Reynolds (2014) described the source of dust samples being from the Colorado Plateau located in western Utah and eastern Colorado with all their sampling sites located in the high mountains of Colorado and additional points on the plains east of the Rockies. Notably, being dust on snow samples, these samples were collected during spring as melting snow concentrates dust so that ample quantity can be collected for analysis. The problem, however, is that "leachable" P has already been leached out of the dust through repeated melt freeze cycles and the general acidification of precipitation (circa pH 6.0). Thus, soluble, and weakly-bound P has likely been leached from these samples. With an average of 40 to 60% of P occurring as SRP in great basin sediment/dust, bulk samples (Miller 2021) and wet/dry samples (Barrus et al. 2021), it is possible that 50% of the P has already been leached from the concentrated dust sitting on the surface of the snowpack. Hence, the actual total P concentrations could be 2X higher than reported.

Finally, there is further discounting of the AD deposition number on Utah Lake by assuming there is a 90% reduction in dusts by the time they reach 200, 400 and 600 m ranges from the shoreline (based on VanCuren et al. 2010). At 600 m from the shoreline, about 80% of the lake surface is assumed to have the same deposition rate as the NADP sites in the pristine national parks. Based on the discussion above and our mid-lake sample data (see below) – this condition is not likely to occur.

Brahney (2019) also stated: "I estimate urban wet P deposition rates by taking an average of the few measurements that have been made globally. The one site near Logan, UT is not an urban site. It is admittedly in rural Cache Valley. But it is the only site sampled in Utah."

Only one wet deposition site in Utah, located 140 miles north of Utah Lake, in an agricultural zone in rural Cache Valley likely provides a poor estimation of wet deposition on Utah Lake. The only other wet deposition sampling site used was in Singapore, China with 5.6 million residents and several thousand miles from Utah Lake and there is no reference as to the equipment or method(s) used for these samples, but it was not likely NADP certified. In short, data in Table 8 in Brahney (2019) are from multiple types of samplers, from multiple sources and then multiplied by the average *expected* fraction of P, from various sources, with no connection to Utah Lake or Utah Valley. This does not represent the composition of sedimentary dust mobilized from the west and southwest deserts of Utah that are transported across our urban zones and still deposited thousands of feet higher in the Wasatch Range (e.g., Carling et al. 2017) that many of our local scientists have characterized and continue to investigate. Because of these common wind movements (i.e., prevailing SW winds; e.g., the Delta and Mosida windrose (Figures 8 and 9), it is likely that all urban wet and dry dusts contain substantial amounts of parent material from nearby playas.

Alternative to Brahney's (2019) approach, our wet-side samplers are based on the original NADP design and are completely covered until rain falls on the moisture sensor. When the moisture sensor dries, within a few minutes following the rain event, the lid closes once more, preserving the wet sample. There is very slim probability that the wet side sampler is exposed to aberrant contamination, although, as described above, summer rain events commonly include dust particles in raindrops (part of the precipitation process). Data from our sampler located at the Orem POTW is located with an urban environment and would be much more representative of urban wet deposition. And that data (like the Provo dust sample), was available at the time of Brahney's (2019) writing.

Brahney (2019) also states: "Several studies have examined the exchangeable/leachable and or organic phosphorus concentrations in regional dusts from the intermountain west."

However, none of the examples referred to were sourced in the Great Basin or the Lake Bonneville footprint. Alternatively, recent samples reveal P-rich sediments that now occupy thousands of square miles of exposed playa. More than 100 samples collected from the Lake Bonneville footprint indicate that TP ranges from 700 to 1700 $mg \cdot kg^{-1}$ (Abu-Hmeidan, 2018, Carling et al. 2017). Moreover, 40–60% of this phosphorous is in the water soluble, salt extractable, or iron-bound phases, all of which can easily release bioavailable phosphorous to the water column (Abu-Hmeidan, 2018, Carling et al. 2017, Randall et al 2017, W. Miller 2021). Notably, Brahney's (2019) estimate of bioavailable P is similar to values reported for local dusts, although literature estimates from dust on snow are as low as 3.7% (Brahney 2019). Further, trace element sourcing and mass balance calculations concluded that 90% of dust that is delivered to the Wasatch Front is from the playas of the Utah west desert (Abu-Hmeidan, 2018, Carling et al. 2017), suggesting that these are the primary sources of deposition on local waterbodies as well.

As discussed above, this low percentage of SRP within the total P is likely due to the dust-on-snow-type of sampling, where it is very likely that most of the leachable P has already been leached from the dust due to the melting of acidic snow and spring-time rain-on-snow events.

For this present study, our goal has been to measure all nutrient loads from all sources to the lake surface, especially during the algal-growing season. This includes adjacent landscapes, even if they are disturbed, because so much of Utah County is currently being disturbed, and nutrients from these sources reach the lake surface and beyond (see data from Bird Island sampler below).

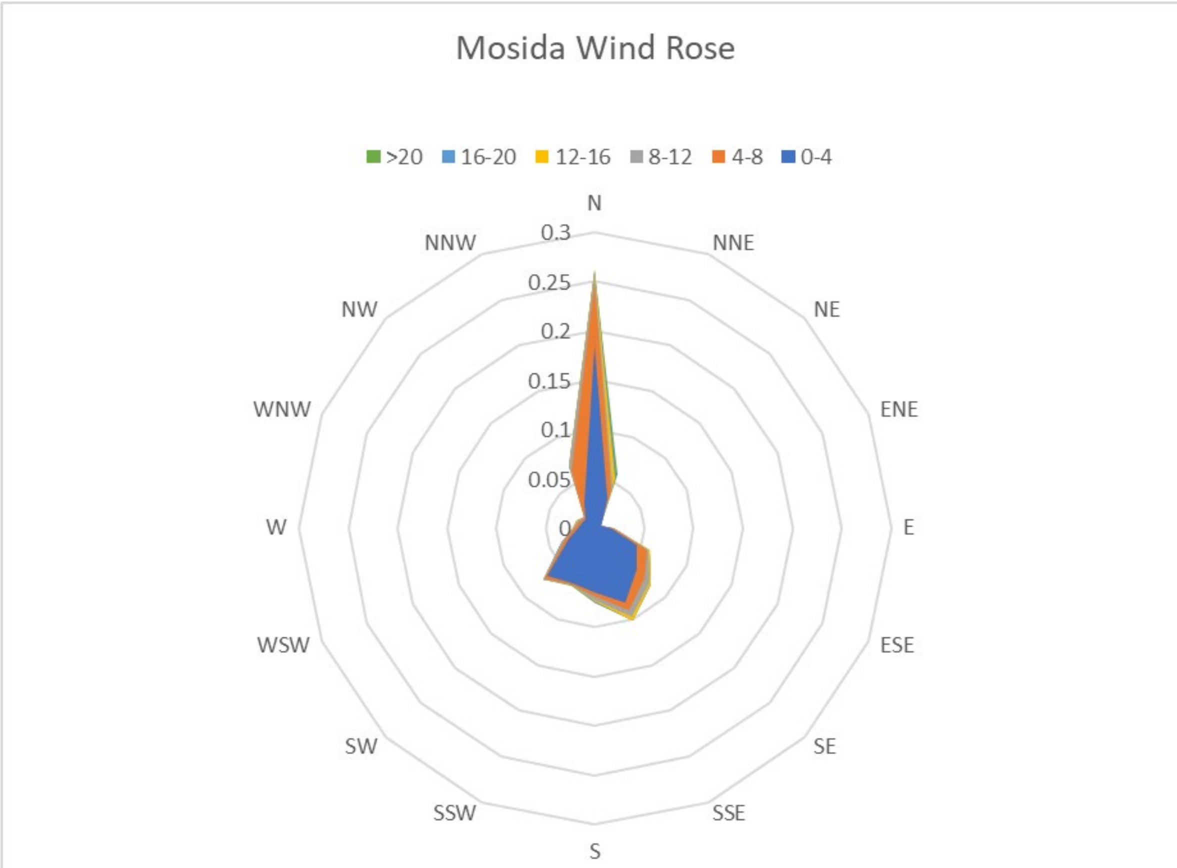



Figure 9. Wind-rose diagram generated from the Hobo weather station located at the Mosida sampling site for the dates. Note that the station was inadvertently set up exactly 180 degrees opposite of the compass reading, indicating that the true wind direction is from the south.

These differences in the goals and scope of our studies, compared to the Brahney (2019) report, which included bringing in other estimates from long distances, that used multiple sampling methods and frequencies, relaxed selection of sample sites, reporting methods and data. These regional studies have different objectives and can perhaps represent AD on high-elevation lakes; although I suggest that local samples are still best for estimating AD on a specific lake, such as Lake Tahoe (Jassby 1994). For our study, trying to characterize nutrient loads to a lake in the bottom of Utah Valley, frequent measurements of various natural (exposed playas) and anthropogenic (agricultural, urbanization) disturbances, including frequent inversions, should be treated as legitimate nutrient sources because they are daily reality, and they clearly are transported to the lake shoreline and beyond. Even though many of our samplers were set near the shoreline, all site and sampler design were adjusted to follow NADP recommended protocols. These are discussed below.

## 2018 Sampling Program

Reidhead (2019) continued the atmospheric deposition program for 2018 (Olsen et al. 2019). While sample sites and field methods remained similar to Olsen, (2018); i.e., top of sample buckets were set 1.2 m above the ground, wet and dry samples were collected each week, etc.) However, the method of estimating AD across the surface of Utah Lake was even more conservative than that of Olsen (2018). In essence, a triangle was created with distance between two of the lake-side sample sites functioning as the base and the sides extended to a single point at the center of the lake at which zero deposition was assumed to occur (Figure 10). Sample handling and preparation in the lab were slightly different. All large particles were removed. Aliquots were then collected for nitrate and $NH^4$ analysis. Additional aliquots for P analysis were directly analyzed for TP or filtered through a 0.45 micro filter and analyzed for SRP according to Gavlak (2005).

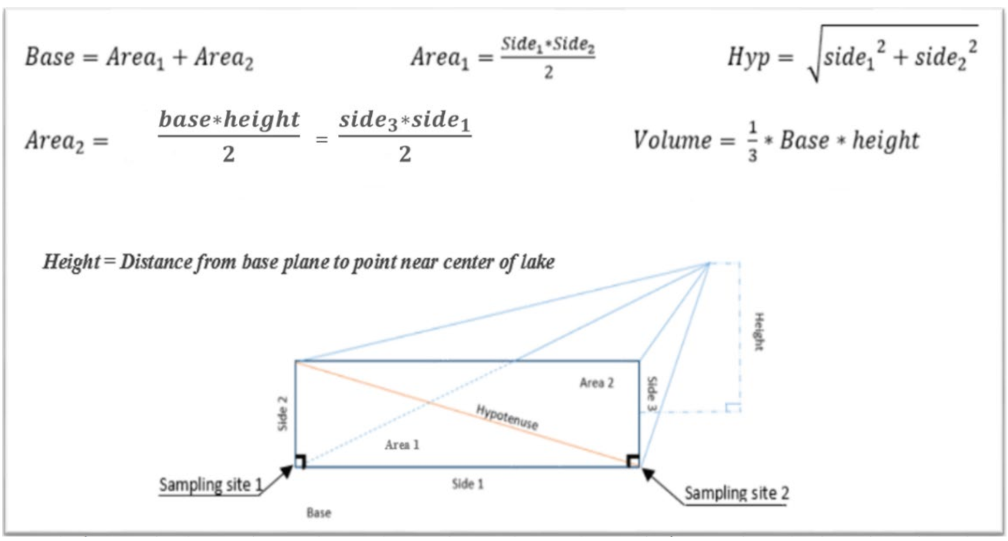



Figure 10. Relatively conservative basic mathematical equations developed to interpolate atmospheric deposition data across Utah Lake.

Figure 11 shows the weekly means of SRP values measured by Reidhead (2019) and Olsen (2018). Figure 11a does not include 2017 data for Saratoga Springs to provide a more accurate comparison between sample sites. (b) includes 2017 to demonstrate how much higher the Saratoga Springs value was compared to the other sites. Also note, the extremely high values measured at Saratoga Springs only occurred during the 2017 sampling season.

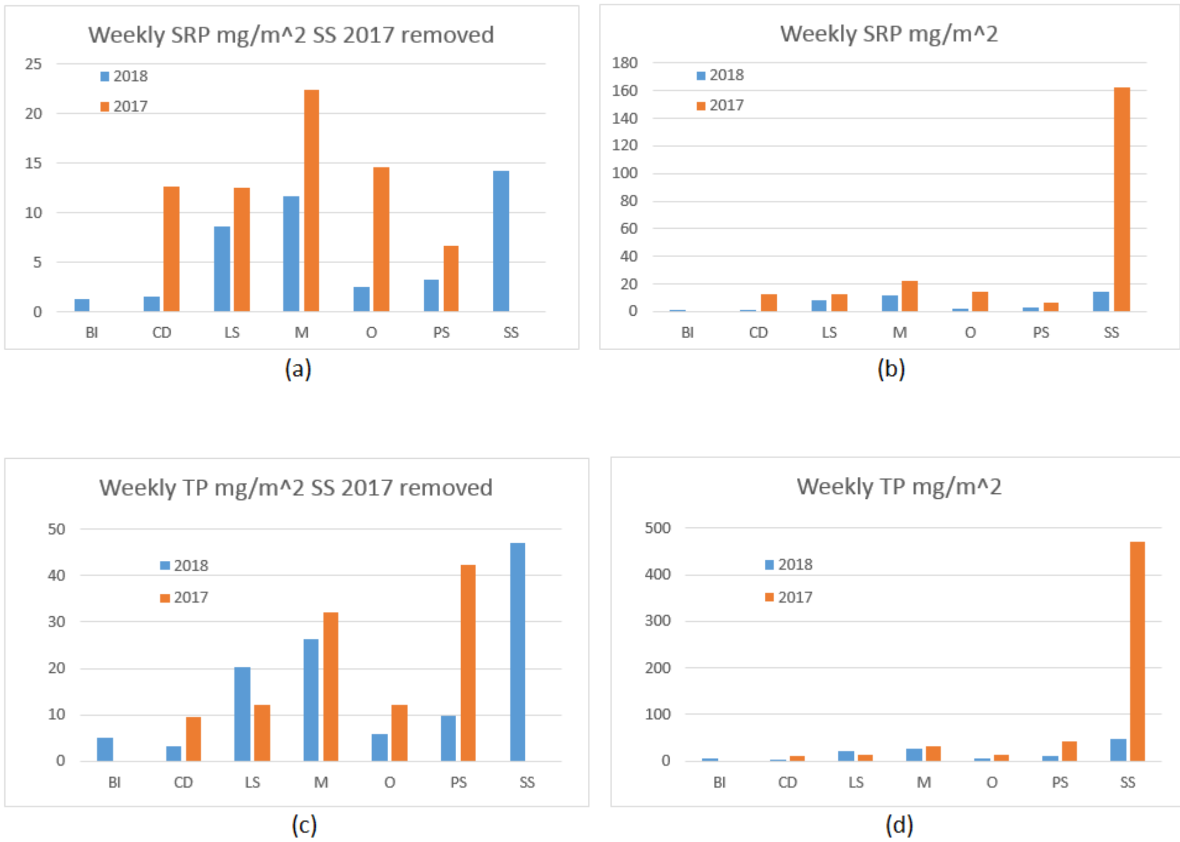
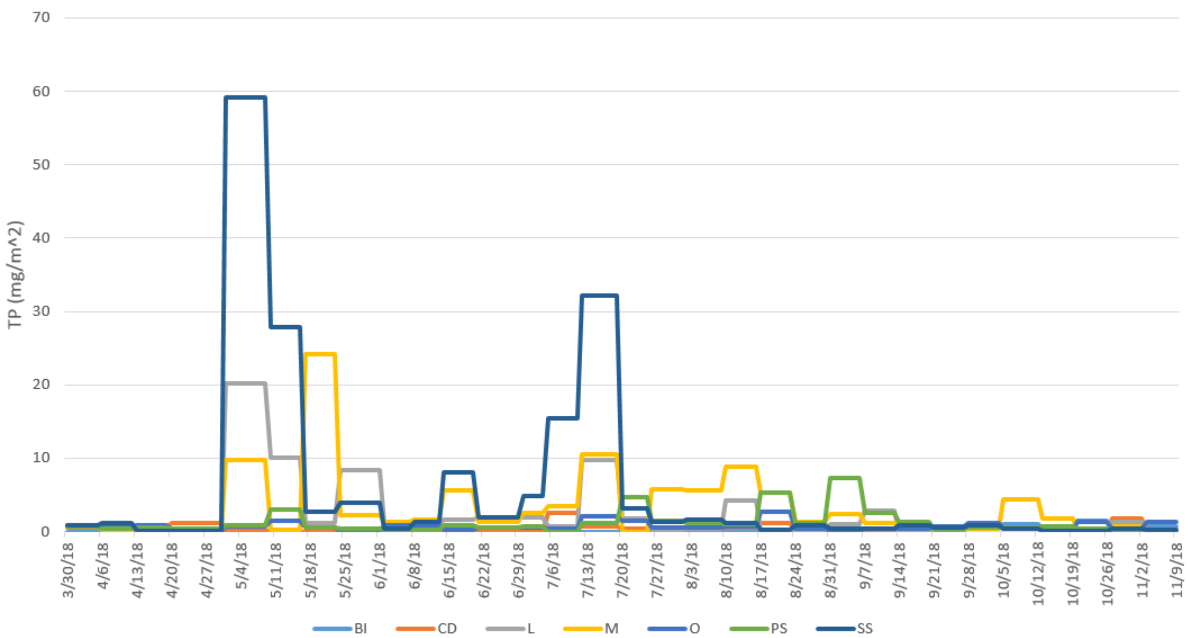
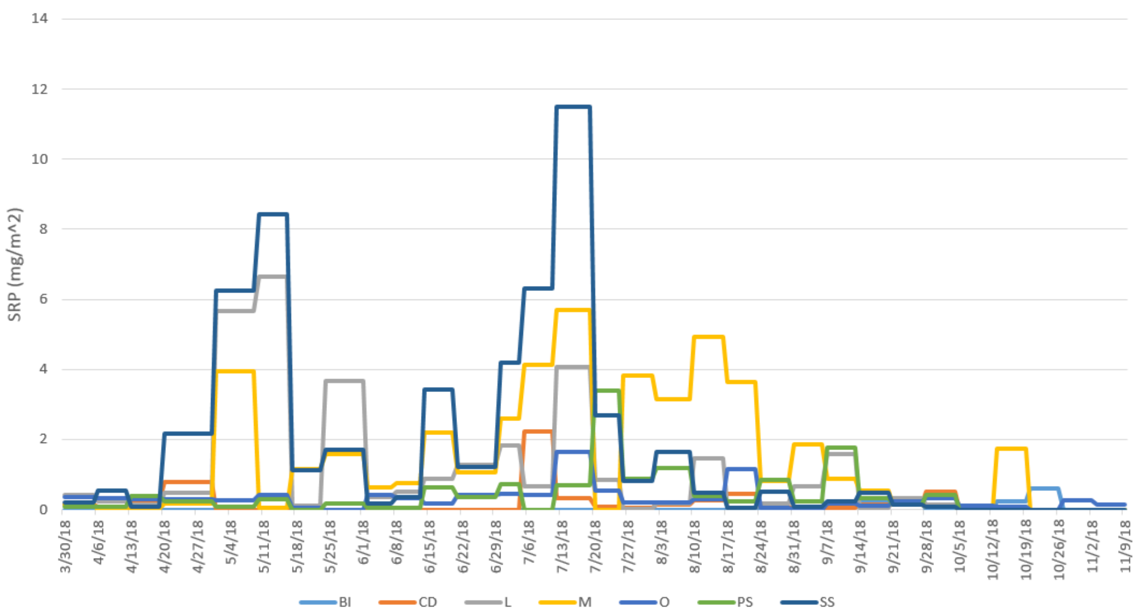



Figure 11. Mean of weekly samples for SRP (a) and (b) and TP (c) and (d). Samples were collected between May and October, 2018 and May through November, 2017.

Results of weekly measurements for individual sites are shown in Figure 12. This information is important on two counts. First, there are two pronounced peeks for some of the sites, one that occurs in May that may be associated with appearance of the terrestrial bees at the Saratoga Springs site although the Mosida and Orem sites also have spikes, and one that includes a large spike in July at Saratoga Springs as well as other smaller spikes at the other sites. Reidhead (2019) related that summer thunderstorms, including wind and dust events prior to the weekly sample collection is the cause of the spikes. Another important observation includes to relative increase in TP in summer samples as compared to earlier in the spring and the fall samples – a phenomenon also observed by W. Miller (2020 and 2021).




A




B

Figure 12. Results of each of the weekly samples for total P (A) and SRP (B) for the entire 2018 sampling season. The sampling period included from the end of April to early October.

Table 16 lists the 2018 results for Total P and SRP and for ammonia and nitrate deposition on Utah Lake. This is based on the mean values using the geometrical obtuse triangle with the base measured between each set of two sites and the sides converging to the same single point near the middle of the lake. In this analysis, the calculation was performed on a linear scale. Also, Table 16 includes only the total for 7.5 months of measurement. Therefore, between assuming zero deposition at the midpoint of the lake and only listing the total deposition for 7.5 months, the actual annual nutrient deposition is much greater than the values listed. Extrapolations to annual deposition rate were provided in the addendum, and in this version (7) of the full report, including an addition of approximately 25% to the 7.5 month total deposition. This was based on the weekly averages calculated from W. Millers multiyear data set (described above). Thus, ¾ of the annual AD falls in the 7.5 to 8-month period of spring, summer and fall.

Table 16. Total AD results applied to the entire lake for the 7.5 month sampling period of 2018 (from Reidhead 2019).

| | |
|---|---|
| **Soluble Reactive Phosphorus** | **57.9 Tons** |
| **Total Phosphorus** | **153.0 Tons** |
| **Nitrate-Nitrogen** | **118.3 Tons** |
| **Ammonium-Nitrogen** | **386.9 Tons** |

Reidhead (2018) also characterized P speciation in several surface soil samples from multiple locations around the lake (Figure 13). A total of 49 sites were sampled although samples from seven sites on the eastern side of the lake were removed from the sample set because they were considered duplicates or were from organic boggy sites that he felt did not represent mobile sediments or dusts. Extraction followed the method of (Moore and Coale, 2009) and included total digestion with nitric acid. Samples were analyzed using ICP- OES. Total P ranged from 1014 and 1730 mg P $kg^{-1}$, a range commonly found by other researchers sampling the west and southwest deserts of Utah (Abu-Hmeidan 2019, Carling 2017).

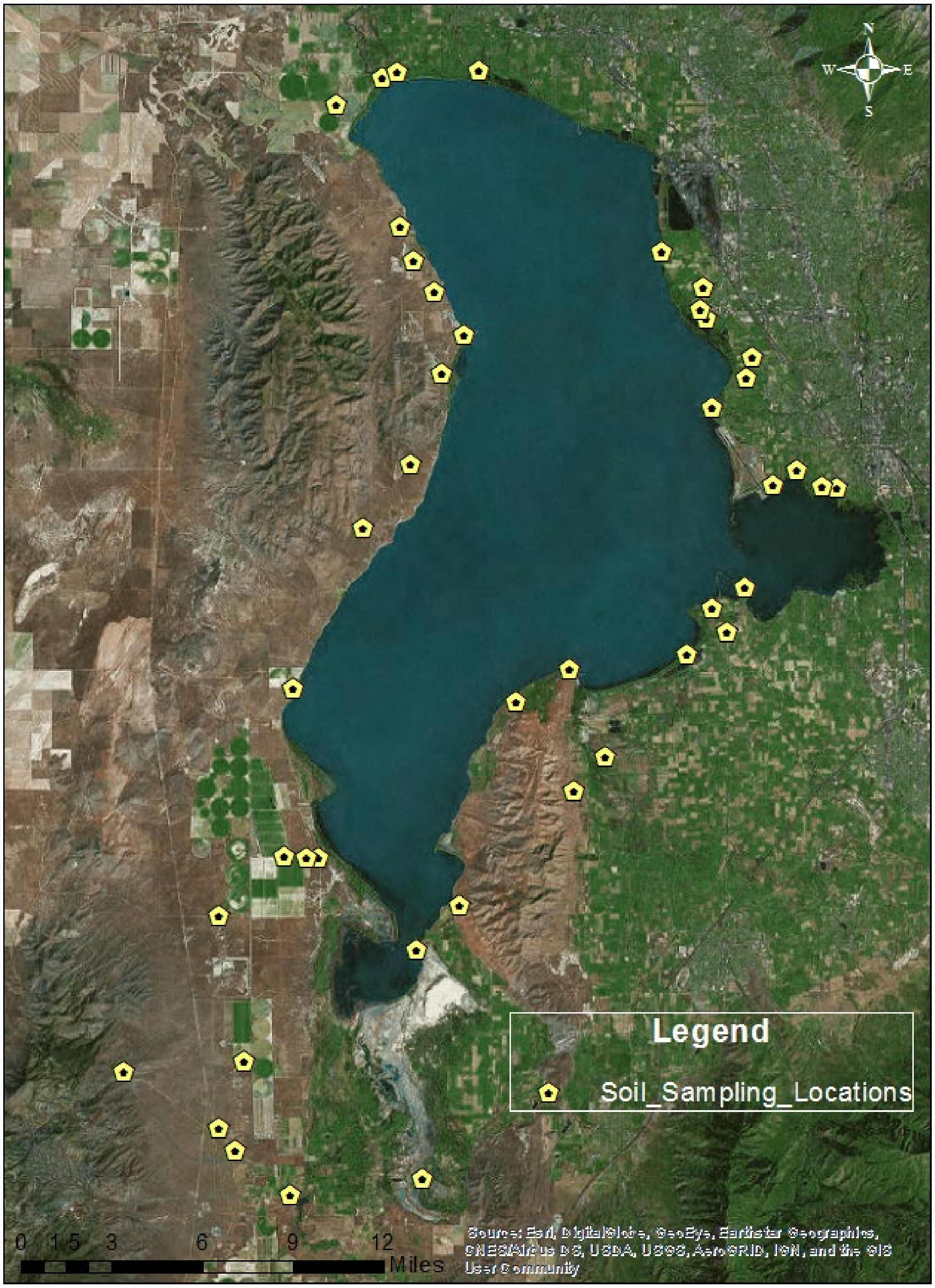



Figure 13. Location of sites around Utah Lake where Readhead (2019) collected surface soil samples for P extraction and analysis.

## 2019-2020 Sampling Program

As a result of consultation with Dr. David Gay, Director of the NADP and suggestions by the Utah Lake Science Panel, several changes were implemented in the AD program starting in 2019. These changes are described in detail in the AD SAP written and updated for this project (Miller and Barrus 2020). Briefly these changes include:

1) The legs on the sampling table were extended so that the top of the sampling buckets was 2 m above the ground.
2) Screens with 500-micron nylon mesh were placed in the dry side buckets to prevent insect or plant parts from entering the bucket and getting caught in the water sample.
3) The solar panel for each system was moved to a distance 5 m away from the sample table to prevent any splash or deflected particles off the panel from reaching the sample buckets.
4) Miner's moss®, the commercial name for a matting material thicker than artificial grass, that was designed for sluice boxes, was attached to the lid that moves back and forth between the wet and dry buckets. This was intended to eliminate the potential splash and deflection of rain droplets from the lid to the wet bucket during a rain event. We performed a simple experiment to judge the effectiveness of the miner's moss. We simulated heavy rainfall by pouring approximately 4 liters of dyed water on the lid when it was situated on the dry side. Only a few tiny droplets (microliters) reached the wet side bucket, this visually confirmed that the Miners Moss absorbed the energy of raindrop impact and eliminated droplet splash or bounce that previously could have entered the wet sample buckets.

After the Saratoga Springs equipment was destroyed by new owners of the property, this site was abandoned for the wet/dry samplers because of the criticism by Science Panel members. However, a bulk sampler was installed by Dr. Wood Miller near Saratoga Springs and continues to be maintained.

After considerable debate concerning the appropriate method to estimate nutrient deposition in the center, an additional sampling device was designed and installed near Bird Island in the south-central portion of the lake (Figure 14) and a photo of the sampler is shown in Figure 15. The table surface was situated about 5 m above the lake surface and the solar panel was mounted on a bar so that it was situated lower than the buckets and about 2.5 m from the table.

In addition, two new wet/dry AD samplers were purchased from N-CON Systems Company, Inc. in Georgia. N-CON is the only company in the US which builds wet/dry samplers according to NADP specifications. These samplers were placed approximately 5 m from our newly modified samplers at the Orem and Central Davis sites. In addition, at these same sites the original wet/dry samplers were retained as well. In this manner we were able to:

1) Determine the influence of the different heights of the sample tables
2) Compare results of our sample design with NADP sampler results
3) Compare the effect of screens (our samplers) vs non screened (NADP samplers) on dry side

These results are discussed below.

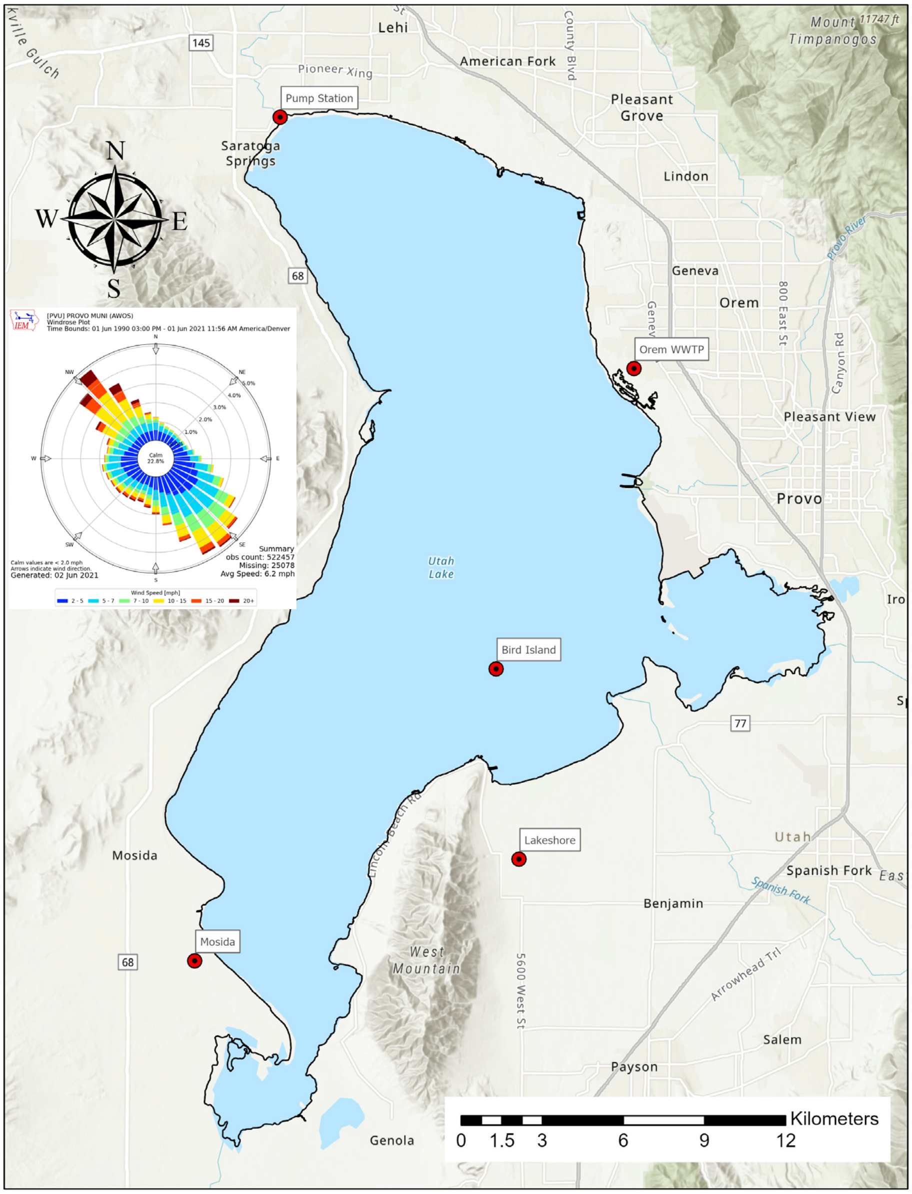



Figure 14. AD sampling sites around and in Utah Lake for 2020. Note location of interior sampling station at Bird Island. Also note a wind-rose diagram showing the wind direction at the Provo Municipal Airport based on data from June 1990 to June 2021, generated by Iowa Environmental Mesonet (IEM), Iowa State University generated June 2, 2021. See text for discussion concerning this windrose site.

Also, for clarification of any discrepancies between NADP guidelines we listed the site characteristics for each of our sampling sites for the 2017 season (Table 16). In summary, discrepancies include; 1) location of the solar panel was about 2 m from the buckets. Being stainless steel and glass, this was not likely a source of contamination; 2) The access road at Lakeshore was a driveway to the landowner's fields – traveled < 6 times per day; 3) The access road to the Saratoga springs site was estimated to have < 6 vehicles per day; 4) The parking lot at Orem WWTP always had < 6 vehicles per day. The horse coral had one horse (not an AFO or CAFO). The only other issue was the gravel pit located about 2.5 km away from the sampler (see Figure 17 below below for clarification in relation to distance from the gravel pit to the shoreline).

**Table 17.** Site information and compliance of each site with NAPD site selection protocols during the 2017 sampling year. Not all protocols were followed as we are interested in the total contribution from local transport in addition to long-range transport. As such it was important to set the samplers as near to the shoreline as possible while representing the entire lake shoreline. While the guidelines do not specify the distance from irrigation sources (only specifying "no impact"), we identified this distance for clarification for the reader. Clearly, if there was impact from the sources identified, they would be poorly operated irrigation systems.

| Issue | Lake Shore | Mosida | Saratoga Springs | Pump Station | Orem WWTP |
|---|---|---|---|---|---|
| Latitude | −111.787781 | −111.927626 | −111.868827 | −111.895347 | −111.735528 |
| Longitude | 40.11229 | 40.076452 | 40.283815 | 40.359414 | 40.276158 |
| Irrigation sources | Compliant | Central Pivot irrigation 380 m from collector | Compliant | Central Pivot irrigation 500 m from collector | Wheel line irrigation 500 m from site |
| ≥5 m from Equipment | Solar Panel | Solar Panel | Solar Panel | Solar Panel | Solar Panel |
| ≥5 m from Collector | 3 m from collector | Compliant | Compliant | Compliant | Compliant |
| ≥10 m from Collector | Access road is 7 m from collector | Compliant | Compliant | Compliant | Compliant |
| ≥20 m from Collector | Horse corral 10 m from collector | Compliant | Compliant | Compliant | Compliant |
| ≥30 m from Collector | Farm Shed 15 m from collector | Compliant | Small gravel driveway 25 m from collector | Compliant | Compliant |
| ≥100 m from Collector | Compliant | Compliant | Compliant | Compliant | Parking lot 60 m from collector |
| ≥500 m from Collector | Compliant | Compliant | Compliant | Compliant | Compliant |
| ≥1 km from Collector | Compliant | Compliant | Compliant | Compliant | Compliant |
| NAPD Site Classification | R | I | S | S | U |

Figure 15. Photo of AD sampler installed at Bird Island in the south-central part of Utah Lake. The table was about 5 m above the water surface. The solar panel was mounted on a stainless-steel bar extending from the table surface to about 2.5 m from the sample buckets to prevent splash from reaching the sample buckets. The sampler was secured by guywires and weights extending approximately 50 m from each corner.

Note that the Saratoga Springs sampler was removed/destroyed. Also note the windrose depicting the wind direction (inset in Figure 14). This windrose, was generated by the weather station at Provo airport which is located immediately north of Provo Bay. However, this location does not provide representative wind direction and speed across most of Utah Lake. Rather, it is well known that the dominant winds at this location are the local down-canyon winds from Spanish Fork Canyon, located east/southeast of the town of Spanish Fork (bottom right portion of the map). In addition, the daily prevailing winds known to come from the south/southwest and blow across the lake from the south/southwest. In short, West Mountain, the north/south range located at the bottom of the map, deflects these prevailing winds to the north and prevents them from reaching the Provo airport as indicated by the windrose generated from the weather station at our Mosida (Figure 8). The wind apparently is being funneled between the local mountain ranges to the east and west and extending south from Goshen Bay. On close inspection, this weather station was originally oriented 180 degrees opposite magnetic north, so the data indicates a northerly source. This has since been corrected. We also included a windrose from the Delta Airport (Figure 9), located in a broad agricultural valley (no nearby mountains to redirect the wind), approximately 100 km SW of Utah Lake and located near the Sevier Lake playa. The windrose shows the dominant wind direction and velocity are directing any airborne particles directly to Utah Valley.

I have also included Table 17 prepared by Dr. W. Miller summarizing wind velocities and direction of three small towns located west and southwest of Utah Lake for the 10 days prior to a rain event. These values clearly show the direction of the prevailing wind at points surrounding Utah Lake.

These different windrose diagrams and the table explain the confusion between different observations and beliefs of weather patterns occurring on the lake. Also, this explains how thunderstorms generally run from south-southwest to north, carrying large loads of dust from the Sevier Lake playa and extending north toward Utah Lake.

We wanted to determine if table height affected sample results by situating the sample buckets at 2 m above the ground vs the 1 m above the ground used during the previous two years. We evaluated the data from the two locations with side-by-side tables (Figure 16). These tables were installed at the Central Davis Wastewater Treatment Plant location and within the Ambassador Duck Club. Both sites are located near Farmington Bay part of Great Salt Lake. The general climate and landcover is like that around Utah Lake although the samplers located near Central Davis were closer to an urban environment than the samplers located in open upland rangeland of Ambassador Duck Club. This also provides data from an area different from Utah Lake to support generalizing the findings. Figure 1 is reproduced here for convenience.

Figure 16. High (~2-meter) sample table on the left and the low (~1-meter) sample table on the right. The solar panels were mounted on T-posts located 5 m from the tables. Note green miner's moss attached to the surface of the lid covering the wet-side buckets.

Table 18. Wind speed and direction from several small towns south and west of Utah Lake. Values Included the previous 10 days prior to a rain event. Note the prevailing wind can be strong and nearly always comes from the southwest and occasionally from the northwest.

| | date | Eureka avg (mph) | previous 10 day avgof avgs | Eureka max (mph) | previous 10 day avgof maxs | Winddirec tion at Eureka | Vernon avg (mph) | previous 10 day avgof avgs | Vernon max (mph) | previous 10 day avgof maxs | Vernon Wind direction | Tickville avg (mph) | previous 10 day avgof avgs | Tickville max (mph) | previous 10 day avgof maxs | Tickville Wind direction |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 22-Feb-17 | 20 | 10 | 42 | 29 | | 5 | 9 | 48 | 27 | | 4 | 6 | 42 | 22 | |
| 2 | 8-Apr-17 | 18 | 12 | 52 | 32 | | 12 | 11 | 48 | 32 | | 11 | 9 | 45 | 28 | |
| 3 | 25-Apr-17 | 10 | 8 | 37 | 31 | | 8 | 7 | 41 | 28 | | 7 | 7 | 33 | 25 | |
| 4 | 6-May-17 | 8 | 9 | 55 | 28 | 213 | 11 | 8 | 51 | 28 | 146 | 8 | 8 | 38 | 25 | 42 |
| 5 | 17-May-17 | 10 | 10 | 46 | 34 | 234 | 8 | 8 | 40 | 31 | 242 | 9 | 9 | 37 | 26 | 352 |
| 6 | 21-May-17 | 9 | 10 | 24 | 33 | 345 | 6 | 8 | 25 | 30 | 32 | 5 | 8 | 17 | 25 | 347 |
| 7 | 13-Jun-17 | 18 | 13 | 49 | 38 | 214 | 15 | 11 | 48 | 33 | 226 | 14 | 10 | 48 | 32 | 214 |
| 8 | 20-Jun-17 | 8 | 10 | 51 | 32 | 292 | 6 | 8 | 44 | 29 | 214 | 6 | 8 | 25 | 26 | 16 |
| 9 | 17-Jul-17 | 7 | 7 | 40 | 29 | | 6 | 0.6 | 30 | 26 | | 6 | 6 | 31 | 23 | |
| 10 | 25-Jul-17 | 8 | 7 | 30 | 27 | 225 | 6 | 6 | 36 | 29 | 209 | 6 | 6 | 28 | 24 | 60 |
| 11 | 10-Aug-17 | 7 | 7 | 55 | 33 | 329 | 5 | 6 | 39 | 31 | 200 | 5 | 6 | 41 | 23 | 350 |
| 12 | 15-Sep-17 | 8 | 7 | 45 | 29 | | 7 | 7 | 42 | 29 | | 6 | 7 | 30 | 24 | |
| 13 | 24-Sep-17 | 6 | 9 | 23 | 27 | | 5 | 8 | 34 | 28 | | 5 | 8 | 25 | 25 | |
| 14 | 5-Nov-17 | 14 | 10 | 41 | 26 | 240 | 12 | 7 | 45 | 25 | 197 | 8 | 6 | 31 | 21 | 185 |
| 15 | 17-Nov-17 | 17 | 9 | 42 | 25 | 273 | 20 | 8 | 44 | 24 | 196 | 11 | 7 | 42 | 21 | 182 |
| 16 | 9-Jan-18 | 6 | 6 | 28 | 18 | | 11 | 5 | 38 | 16 | | 4 | 4 | 24 | 14 | |
| 17 | 15-Feb-18 | 10 | 8 | 33 | 26 | | 7 | 6 | 27 | 22 | | 7 | 7 | 31 | 21 | |
| 18 | 16-Mar-18 | 7 | 6 | 49 | 22 | | 11 | 6 | 38 | 22 | | 7 | 6 | 31 | 21 | |
| 19 | 23-Mar-18 | 9 | 8 | 52 | 31 | | 8 | 9 | 48 | 33 | | 8 | 7 | 41 | 28 | |
| 20 | 7-Apr-18 | 7 | 7 | 39 | 29 | | 5 | 6 | 38 | 26 | | 4 | 7 | 29 | 22 | |
| 21 | 20-Apr-18 | 5 | 11 | 29 | 28 | | 8 | 10 | 30 | 36 | | 6 | 10 | 25 | 29 | |
| 22 | 30-Apr-18 | 6 | 9 | 41 | 28 | | 8 | 7 | 41 | 27 | | 11 | 8 | 39 | 25 | |
| 23 | 3-May-18 | 4 | 8 | 24 | 25 | | 6 | 7 | 24 | 26 | | 6 | 8 | 21 | 23 | |
| 24 | 11-May-18 | 10 | 7 | 27 | 22 | 332 | 8 | 6 | 29 | 22 | 67 | 10 | 7 | 32 | 22 | 4 |
| 25 | 22-Aug-18 | 11 | 8 | 36 | 33 | 200 | 10 | 7 | 36 | 29 | 168 | 6 | 6 | 24 | 23 | 120 |
| 26 | 3-Dct-18 | 8 | 9 | 37 | 28 | 204 | 10 | 8 | 40 | 28 | 186 | 6 | 7 | 28 | 23 | 136 |
| 27 | 29-Mar-19 | 8 | 7 | 38 | 28 | | 6 | 7 | 33 | 24 | | 8 | 7 | 38 | 23 | |
| 28 | 10-Apr-19 | 10 | 8 | 41 | 27 | | 11 | 8 | 36 | 24 | | 12 | 7 | 40 | 23 | |
| 29 | 21-Jun-19 | 13 | 7 | 47 | 31 | 312 | 11 | 7 | 38 | 27 | 355 | 12 | 7 | 39 | 24 | 312 |
| 30 | 1-Aug-19 | 8 | 7 | 30 | 27 | 210 | 9 | 6 | 37 | 26 | 194 | 5 | 6 | 26 | 22 | 352 |
| 31 | 9-Aug-19 | 7 | 7 | 51 | 29 | 273 | 6 | 6 | 47 | 27 | 213 | 6 | 5 | 31 | 23 | 344 |
| 32 | 28-Aug-19 | 8 | 8 | 37 | 29 | | 6 | 7 | 22 | 23 | | 7 | 8 | 32 | 25 | |
| 33 | 11-Sep-19 | 13 | 8 | 41 | 30 | 209 | 12 | 7 | 52 | 28 | 205 | 9 | 7 | 45 | 25 | 320 |
| 34 | 13-Mar-20 | 11 | 7 | 28 | 25 | 251 | 6 | 6 | 28 | 24 | 163 | 5 | 6 | 28 | 21 | 140 |
| 35 | 23-May-20 | 6 | 11 | 47 | 33 | 230 | 6 | 9 | 58 | 34 | 290 | 5 | 9 | 46 | 30 | 312 |
| 36 | 8-Jun-20 | 11 | 9 | 32 | 37 | 323 | 8 | 10 | 45 | 40 | 322 | 8 | 8 | 37 | 30 | 343 |
| avgs | averages | 9.0 | 8.3 | 39.0 | 28.7 | | 8.5 | 7.1 | 38.3 | 27.5 | | 7.3 | 7.2 | 32.7 | 24.0 | |

Our program received criticism for the "contamination" of our dry-side samples by insects. Taxonomic identification revealed that these were terrestrial bees from a nearby farm. In response, I suggested that insects from terrestrial and aquatic sources fall on lakes and streams. Nevertheless, we went to great lengths, including adding screens on the dry-side buckets to prevent such contamination by insects and plant materials during the 2020 year. In retrospect and after further literature review, I offer this discussion, as reported by Wurtsbaugh (2007).

Norlin (1964, 1967) suggested that most insects falling onto lake surfaces are not derived from the shoreline vegetation but rather are from ''aerial plankton'' that drift considerable distances from the terrestrial landscape and are deposited evenly over the lake surface in downdrafts. In large lakes, this diffuse input of ''aerial plankton'' trapped on the lake surface can be concentrated in downwelling zones near the shore where fish can feed on them (Norlin 1967). Consequently, terrestrial insects can be very important to fish even in large lakes. This occurs in Bear Lake, which is 280 $km^2$ and is located in northeast Utah and southeast Idaho in the arid western United States, where terrestrial insects constitute 60% of the summer diet of juvenile cutthroat trout (*Salmo clarki utah*; Ruzycki et al. 2001). In another study, juvenile rainbow trout (*Oncorhynchus mykiss*) captured close to shore in a 0.2-$km^2$ lake ate only 15% terrestrial food, whereas larger trout that inhabited the entire lake ate 49% terrestrial insects (Wurtsbaugh et al. 1975). Mehner et al. (2005) found that terrestrial insects contributed 73% of the diet of bleak in a small, 0.12-$km^2$ German lake. While Mehner et al. (2005) suggested that this may represent a 2.1% contribution to the nutrient budget of the lake, Wurtsbaugh (2007) cautioned that this is likely a large overestimation of such contributions mostly because of the complications in estimating P excretion in comparison to the rapid turnover (hours to days) of particulate P.

Therefore, terrestrial insects captured in our sample likely represent a small, if measurable contribution to the nutrient budget of Utah Lake. Nevertheless, I believe a more frequent (monthly to weekly) Kriging analysis of lake loading would allow the use of these samples while avoiding the issues of small-mesh screens than literally filter out "legitimate" dust and aerosol, as well as insect and plant material from the sample (see results below).

Thus, neither small lake sizes nor forested shorelines are necessary for terrestrial insects to be an important food source for fish. Therefore, while terrestrial insects may not contribute a large percentage to a lake's nutrient budget, they have clearly been identified as present and contributing nutrients to lakes of different sizes and regardless of whether these lakes are in forested areas or not. Notably, since our sampling only captured the terrestrial bees at one location and located near the shoreline, I similarly suggest that while the added contribution is likely small, it is a logical contribution to Utah Lake.

The suggestion by Brahney (2019) to exclude the sample at Saratoga Springs because of dust "contamination" can also be debated. The sampler was placed about 100 m from the shoreline and about 2600 m from of the gravel pit. Therefore, about 6000 m of the Utah Lake shoreline was closer to the gravel pit than was our sampler (Figure 17). It is also likely that a greater amount of dust that reached the sampler, reached the lake surface – particularly when the most direct path to the lake from the gravel pit is only 1200 m (less than half the distance of that to our sampler). Regardless of its human source, this dust is undoubtedly reaching the lake, and compared to the distance to the sampler, is being distributed at least 1000 m across the surface of the lake and probably at greater concentrations than what reached the sampler.


Figure 17. Image of the gravel pit near Saratoga Springs in relation to Utah Lake and the location of our AD sampler. The distance from the gravel pit to the sampler is approximately 2600 m. The distance to the shoreline is about 1200 m. See text for additional detail.

# Results of 2019 and 2020 Studies

## High vs Low Tables Comparison

We collected 38 pairs of data from the high-low table pairs over 8 months. This included 21 and 17 pairs from the Central Davis and the Ambassador site, respectively.

Figure 18 shows that visually, there is no effect of table height on sample concentration. However, at the Central Davis location the low table seems to have slightly higher values during low deposition periods and higher values during high deposition periods. In contrast the plot of the data from the Ambassador site seems to exhibit the opposite trend. But these patterns are not consistent even at a single site.

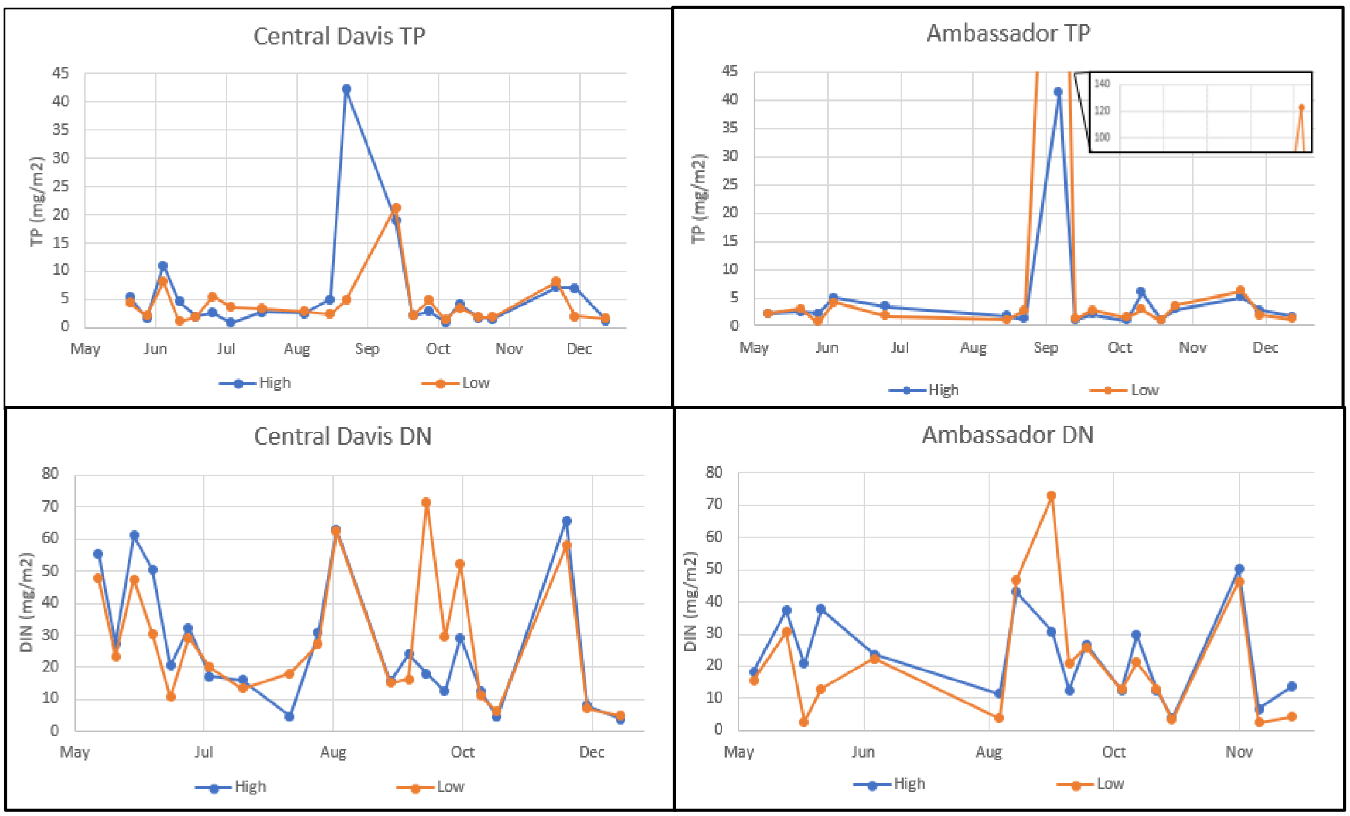



Figure 18. A graphical comparison of TP data (top panel) and DIN data (bottom panel) collected over 8 months from paired high and low tables at two different sites, Central Davis and Ambassador, in the left and right panels, respectively. Note that (timing) of sample collection was not always aligned between Central Davis and Ambassador Duck Club. Also note that the pattern for DN did not well align with the pattern for TP, suggesting that there are probably some different sources between N and P. We performed a paired t-test on these data pairs (Table 19), which demonstrated no significant difference between the high and low table sets.

Table 19. Student t-test results comparing measurements from the collectors with high tables and low table. At $\alpha = 0.05$, there is no significant difference between the high-table and low-table data sets.

| Variable | N | Low-Table Mean (mg/m²) | High-Table Mean (mg/m²) | Mean Diff. (mg/m²) | Prob > \|t\| | Prob > t | Prob .7 < t |
|---|---|---|---|---|---|---|---|
| P | 34 | 2.88 | 3.11 | 0.24 | 0.41 | 0.68 | 0.32 |
| DIN | 37 | 25.29 | 25.39 | 0.10 | 0.97 | 0.52 | 0.48 |

We graphically evaluated that data using both time-history and box-and-whisker plots shown in Figures 19 and 20, respectively for P and DIN measurements. In the plot the line within the box represents the median sample value or the 50th quartile. The box ends represent the 25th and 75th data quartiles also expressed as the 1st and 3rd quartile, respectively. The diamond represents the mean and the upper and lower 95% of the mean as the center and left and right ends of the triangle, respectively. The size of the diamond is a visual representation of the size of the confidence interval. If the 50th quartile line is not in the center of the box or if the diamond is not centered on the 50th quartile line, the data are skewed. The "whiskers" extend to the outermost data point that falls within: the 1st quartile - 1.5*(interquartile range) and the 3rd quartile + 1.5*(interquartile range). If the data points do not reach these computed ranges, then the whiskers end at the upper and lower data point values (not including outliers). The red bracket outside the box identifies the shortest half, which is the densest 50% of the observations.

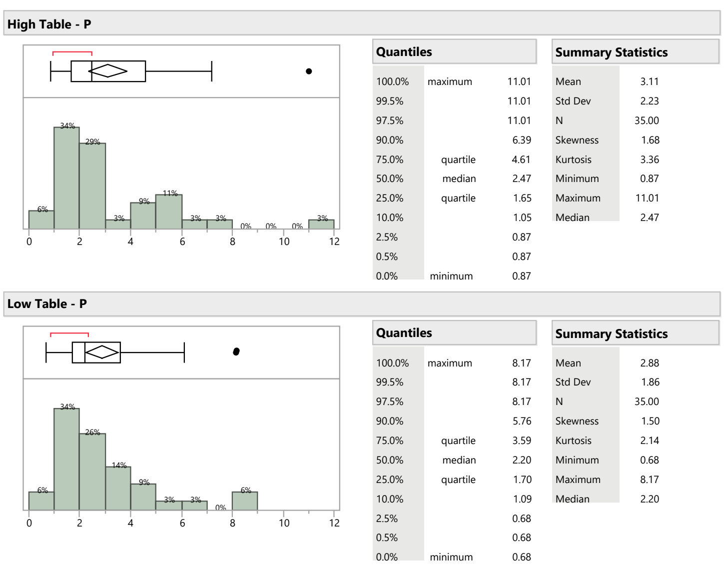
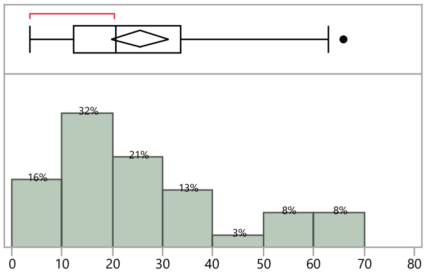



Figure 19. Distributions and statistics of P data collected from the high table (top panel) and low table (bottom panel). Each panel includes a box-and-whisker plot (top left corner) a histogram (bottom left corner) and descriptive statistics (right side) for paired samples collected using a high or low table in the top and bottom panels, respectively. The distributions are skewed but have similar means and medians. Three outliers were removed. If the data points did not reach these computed ranges, then the whiskers end at the upper and lower data point values (not including outliers). The red bracket outside the box identifies the shortest half, which is the densest 50% of the observations. Data units are mg $m^{-2}$.

**High Table - DIN**



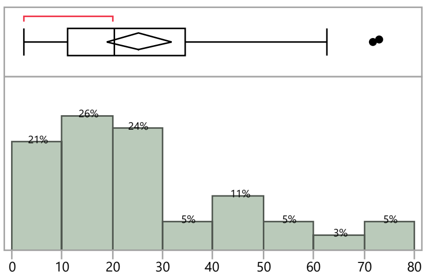

**Quantiles**

| | | |
|---|---|---|
| 100.0% | maximum | 65.88 |
| 99.5% | | 65.88 |
| 97.5% | | 65.88 |
| 90.0% | | 56.13 |
| 75.0% | quartile | 33.60 |
| 50.0% | median | 20.56 |
| 25.0% | quartile | 12.45 |
| 10.0% | | 4.64 |
| 2.5% | | 3.75 |
| 0.5% | | 3.75 |
| 0.0% | minimum | 3.75 |

**Summary Statistics**

| | |
|---|---|
| Mean | 25.39 |
| Std Dev | 17.44 |
| N | 38.00 |
| Skewness | 0.89 |
| Kurtosis | -0.07 |
| Minimum | 3.75 |
| Maximum | 65.88 |
| Median | 20.56 |
| Interquartile Range | 21.15 |

**Low Table - DIN**




**Quantiles**

| | | |
|---|---|---|
| 100.0% | maximum | 72.97 |
| 99.5% | | 72.97 |
| 97.5% | | 72.97 |
| 90.0% | | 58.44 |
| 75.0% | quartile | 34.53 |
| 50.0% | median | 20.45 |
| 25.0% | quartile | 11.08 |
| 10.0% | | 3.85 |
| 2.5% | | 2.49 |
| 0.5% | | 2.49 |
| 0.0% | minimum | 2.49 |

**Summary Statistics**

| | |
|---|---|
| Mean | 25.29 |
| Std Dev | 19.83 |
| N | 38.00 |
| Skewness | 0.97 |
| Kurtosis | 0.05 |
| Minimum | 2.49 |
| Maximum | 72.97 |
| Median | 20.45 |
| Interquartile Range | 23.45 |

Figure 20. Distributions and statistics describing DIN data collected from the high table (top panel) and low table (bottom panel). Data analysis as described for Figure 17. The distributions are skewed but have similar means and medians. No outliers were removed. Data units are $mg/m^2$.

We also performed a one-way ANOVA, (test results not shown) which also indicated no significant difference between the high and low tables. In addition, because the data were skewed ( See Figures 17 and 18), we performed the nonparametric Wilcoxon/Kruskal-Wallis test (Test results not shown). Again, there were no statistically significant differences for TP or DIN between the high and low table sets.

## Screens and Outlier Data

As discussed above we previously addressed the issue of “contamination” by removing outliers in the data (Olsen et al. 2018), resulting in the “low” data set. This was determined by excluding data for any sample that had any visible debris, dirt, or mud. The “high” data set had no outliers removed. This led to a range in values for P and N deposition between 8 tons when only the “low” data set was used (omitting about 1/3 of all samples), to 350 Mg (tons; including all samples) of TP and 46 to 460 tons of DIN during this period. Discussions among the Utah Lake Science Panel members focused on the impact of insects and to a lesser extent, plant parts falling into the dry side bucket and captured in the water. We sought to resolve this debate by adding 500-micron mesh nylon screens to each dry-side bucket. Notably however, manufacturer’s specs included the fact that only about 40% of the screen area is actually open for passage of particles or aerosols. We were therefore concerned that, even though they could physically fit through the screen mesh, particles and aerosols themselves might settle on the screen filament surfaces rather than pass through and contribute to the sample. Moreover, these particles could be remobilized and transported out of the sample bucket with subsequent breezes and gusts.

Therefore, we decided to compare the dry-side bucket data from the NADP sampler with our screened dry-side bucket. NADP does not use screens in the dry side or wet side buckets (even though some debris often occurs – even in the wet side bucket). Rather, the protocol is simply to note the presence of debris to the associated meta data so that the data user can decide whether the sample is appropriate-according to individual data objectives by the user. Notably, the NADP samplers for this test were located at the Central Davis Property and the Orem plant property – rather than the two sites (Mosida and Saratoga Springs) that were known to have the occasional presence of insects during spring or account for the dust from an adjacent gravel pit. Therefore, only very rarely were insects or plant debris noted in either sampler type.

Screens were added to the sample buckets in May of 2020. Thus, 2019 data were all collected without screens, while approximately 7 months of 2020 data were collected with screens in place. This importantly, included spring and summer months when insects are present. We compared samples collected in 2019 and 2020 with and without outliers removed to better characterize the impact of outliers on AD concentrations. Historically and for this work, we considered a measurement an outlier if the concentration was greater than 1 mg/l for TP or 8 mg/l for DIN; these values are approximately 3 standard deviations above the mean for TP and DIN, respectively. Table 21 presents the number of outliers and average weekly concentration with and without the outliers for 2019 and 2020. Most outliers occurred at the Mosida site and were generally associated with the small terrestrial bees (as compared to the Saratoga Springs containing insects for 2017). A number of samples were muddy to various degrees and were identified as being collected following dust storms.

Installing screens made a large difference in sample results (Table 20). For TP samples at all sites in 2019 and 2020 there were 13 and 6 TP outliers, respectively. Of the 6 outlier samples in 2020, 3 occurred before screen installation.

Table 20. A comparison of all the data with and without outliers removed from 2019 and 2020. This includes four and five stations for 2019 and 2020, respectively.

| **Location** | **N** | **TP** | **(mg/l)** | | **DIN** | **(mg/l)** | |
|---|---|---|---|---|---|---|---|
| **2019** | | **Avg w/ Outliers** | **Avg w/o outliers** | **# outliers** | **Avg w/ outliers** | **Avg w/o Outliers** | **# outliers** |
| Lakeshore | 35 | 0.219 | 0.137 | 2 | 2.070 | 0.590 | 2 |
| Mosida | 35 | 3.130 | 0.129 | 9 | 10.097 | 0.489 | 3 |
| Pump Station | 36 | 0.155 | 0.155 | 0 | 1.134 | 0.432 | 2 |
| Orem | 36 | 0.265 | 0.154 | 2 | 1.572 | 0.575 | 2 |
| 2020 (with screens) | | | | | | | |
| Lakeshore | 35 | 0.181 | 0.120 | 2 | 0.785 | 0.451 | 2 |
| Mosida | 39 | 0.532 | 0.088 | 2 | 1.935 | 0.458 | 3 |
| Pump Station | 40 | 0.120 | 0.120 | 0 | 0.398 | 0.320 | 1 |
| Orem | 32 | 0.150 | 0.113 | 1 | 0.553 | 0.352 | 1 |
| Bird Island | 18 | 0.376 | 0.255 | 1 | 0.820 | 0.642 | 1 |

The remaining 3 outliers were collected after high-wind days with large amounts of visible dust in the sample. This was also the case for earlier samples in 2017 and 2018 (Olsen, personal communication). The majority of samples that had insects occurred in late May and June, with much fewer insects present later in summer or fall. Yet, several wind and thunderstorm events occurred throughout late spring and summer during all sampling years, as is typical during the summer monsoon season. For the DIN samples, all the sites in 2019 and 2020 had outliers. This includes the 2020 DIN data collected after screen installation (Table 19). As mentioned above, this suggests that there are likely various sources for DIN as compared to that for P. While it is generally accepted that the primary source of inorganic N to the atmosphere is the combustion fossil fuels (combining O or H to atmospheric N under high temperature), we made certain that all our samplers were at least 1000 m from highways. It is possible that some dusts, coming from agricultural or playa landscapes may have different concentrations of inorganic N. For the 2019 data for both TP and DIN, the mean concentrations for data with the outliers removed is approximately 15% lower than concentration with the outliers included in the mean calculation. For 2020 data for both TP and DIN, the mean concentrations for data with the outliers removed is approximately 50% lower than concentration with the outliers included in the mean calculation (Table 21).

Table 21. Comparison of the mean TP and DIN concentrations with and without outliers removed for the years 2019 and 2020. For most of 2020 screens were installed on the sample buckets.

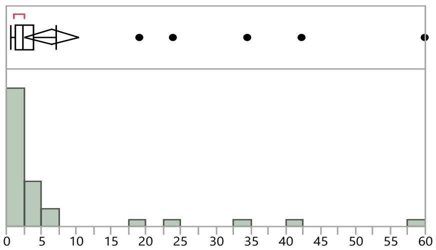
| Year | TP w/ (mg/l) | TP w/o (mg/l) | % Diff | DIN w/ (mg/l) | DIN w/o (mg/l) | % Diff |
|---|---|---|---|---|---|---|
| 2019 | 0.942 | 0.144 | 15% | 3.718 | 0.522 | 14% |
| 2020 | 0.271 | 0.139 | 51% | 0.898 | 0.445 | 49% |

We collected these data side-by-side over 6 months in 2020 at the Central Davis and Orem sites. Both the screened and unscreened samples were taken on 2-meter tables. Between these two sites, there were 41 different pairs of samples collected, with 17 and 24 samples taken at the Central Davis and Orem sites, respectively.

The unscreened data generally had higher nutrient concentrations than the screened data. There are a few times when that was not the case; for example, in the largest discrepancy, the TP results from 10/29/2020 showed the screened Orem data to be 34.5 $mg/m^2$ while the unscreened sampler at Orem for the same day was only 1.6 $mg/m^2$. This extremely high screened sample was far more than three standard deviations above the mean. With no evidence of insect, plant or muddy water, there is no explanation for this outlier. On the other rare occasions where screen samples were higher than unscreened samples, the differences were much lower.

Generally, however, AD values from the screened samplers were lower than from the unscreened NADP samplers. Statistical comparisons were performed similar to the high vs low tables. Box and whiskers plots for screened and unscreened TP and DIN samples are shown in Figure 21 and 22 respectively.

## TP-Screened



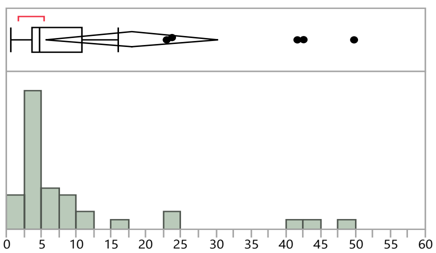

**Quantiles**

| | | |
|---|---|---|
| 100.0% | maximum | 59.91 |
| 99.5% | | 59.91 |
| 97.5% | | 59.02 |
| 90.0% | | 22.89 |
| 75.0% | quartile | 3.82 |
| 50.0% | median | 2.30 |
| 25.0% | quartile | 1.39 |
| 10.0% | | 0.98 |
| 2.5% | | 0.71 |
| 0.5% | | 0.70 |
| 0.0% | minimum | 0.70 |

**Summary Statistics**

| | |
|---|---|
| Mean | 6.50 |
| Std Dev | 12.31 |
| N | 41.00 |
| Skewness | 3.16 |
| Kurtosis | 10.07 |
| Minimum | 0.70 |
| Maximum | 59.91 |
| Median | 2.30 |

## TP-Not Screened




**Quantiles**

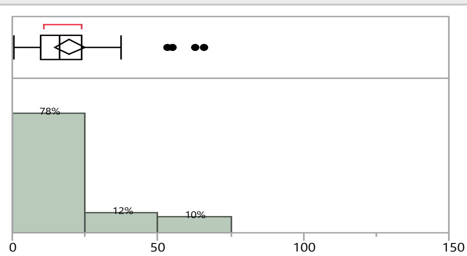
| | | |
|---|---|---|
| 100.0% | maximum | 232.5 |
| 99.5% | | 232.5 |
| 97.5% | | 225.1 |
| 90.0% | | 48.35 |
| 75.0% | quartile | 10.87 |
| 50.0% | median | 4.70 |
| 25.0% | quartile | 3.66 |
| 10.0% | | 1.96 |
| 2.5% | | 0.68 |
| 0.5% | | 0.65 |
| 0.0% | minimum | 0.65 |

**Summary Statistics**

| | |
|---|---|
| Mean | 17.95 |
| Std Dev | 38.95 |
| N | 41.00 |
| Skewness | 4.57 |
| Kurtosis | 23.87 |
| Minimum | 0.65 |
| Maximum | 232.5 |
| Median | 4.70 |

Figure 21. Distributions and summary statistics for the screened and unscreened TP samples collected side-by-side. The x-axis does not include the full range of the data to better show detail in the lower range. Data units are $mg/m^2$/week.

## DIN-Screened



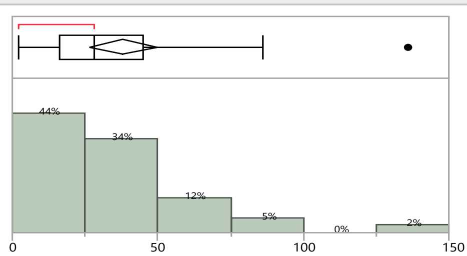

**Quantiles**

| | | |
|---|---|---|
| 100.0% | maximum | 65.88 |
| 99.5% | | 65.88 |
| 97.5% | | 65.73 |
| 90.0% | | 50.11 |
| 75.0% | quartile | 24.00 |
| 50.0% | median | 16.47 |
| 25.0% | quartile | 9.722 |
| 10.0% | | 3.975 |
| 2.5% | | 0.768 |
| 0.5% | | 0.652 |
| 0.0% | minimum | 0.652 |

**Summary Statistics**

| | |
|---|---|
| Mean | 19.76 |
| Std Dev | 15.90 |
| N | 41.00 |
| Skewness | 1.506 |
| Kurtosis | 2.024 |
| Minimum | 0.652 |
| Maximum | 65.88 |
| Median | 16.47 |
| Range | 65.23 |
| Interquartile Range | 14.28 |

## DIN-Not Screened




**Quantiles**

| | | |
|---|---|---|
| 100.0% | maximum | 193.5 |
| 99.5% | | 193.5 |
| 97.5% | | 190.6 |
| 90.0% | | 74.92 |
| 75.0% | quartile | 44.93 |
| 50.0% | median | 28.05 |
| 25.0% | quartile | 16.01 |
| 10.0% | | 5.511 |
| 2.5% | | 2.230 |
| 0.5% | | 2.221 |
| 0.0% | minimum | 2.221 |

**Summary Statistics**

| | |
|---|---|
| Mean | 38.03 |
| Std Dev | 36.52 |
| N | 41.00 |
| Skewness | 2.486 |
| Kurtosis | 8.136 |
| Minimum | 2.221 |
| Maximum | 193.5 |
| Median | 28.05 |
| Range | 191.3 |
| Interquartile Range | 28.93 |

Figure 22. Distributions and summary statistics for the screened and unscreened DIN samples collected side-by-side. The x-axis does not include the full range of the data to better show detail in the lower range. Data units are $mg/m^2$/week.

The histogram x-axis does not include the full range of the data to better present the data distribution in the lower range. For both the TP data (Figure 21) and the DIN data (Figure 22), the graphical plots show large differences in the distributions. For the two panels in each figure, the x-axis is the same scale allowing a direct visual comparison of the box-and-whisker plot.

We compared the differences in the mean concentrations of TP and DIN using a paired t-test. Since the distributions were so skewed, we applied a natural log transformation on the data before performing the test. The p-values were 0.0018 and 0.016 for the paired P and DIN data (Data not shown), respectively, were well below the 0.05 significance level indicating that there is a statistically significant difference between the screened and unscreened samples. The unscreened samples in mg/m$^2$ had on average 3 times the amount of TP as the screened samples.

Another comparison of screened vs unscreened is depicted in the box and whiskers plot in Figure 23.

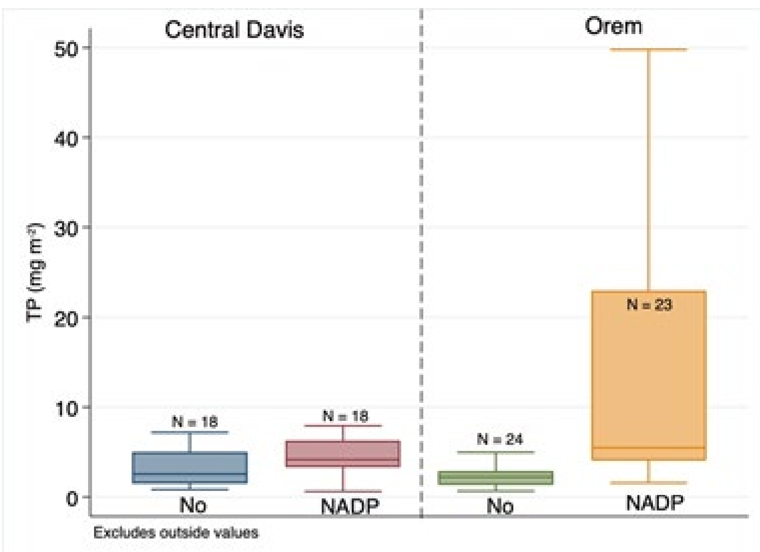



Figure 23. Comparison of TP between Central Davis and Orem sites and non-NADP (screened) vs. NADP (non-screened) dry-side sample buckets. Note, the "No" label applies to the "non NADP" samplers, which were the screened samples. The non-screened samples were from the NADP samplers – as per NADP protocol. These sites were selected because they were located a great distance from the sampler(s) that had collected insects. The elevated bar for the Orem site was due to one sample which we believe to be an outlier.

While it is easy to assume that the screens on the samplers provided a barrier to insects or vegetation, it should also be pointed out that the two sites where this test was conducted had a history of no insect or plant contamination. The samplers were already installed on the top of levees that were about 3 m above the surrounding landscape and had no vegetation extending above the height of the table surface. Therefore, this was the purest possible test for evaluating the effect of screens on particulate dust and aerosols entering the buckets.

Nevertheless, as discussed above, there remains scientific evidence and support for allowing the measurement of insect and plant contamination as there is no doubt, particularly for terrestrial insects and plant material, that these materials are a normal source for nutrient loading to lake surfaces and particularly the Utah Lake Surface.

## Lake Interior Measurements

In addition to the questions of sampler location and potential contamination from insects, etc., the final objective and perhaps the culmination of this work is to determine the pattern of the AD gradient across the lake and the total AD on the lake surface. Deposition rates of local dust decreases dramatically with distance, and particularly in calmer winds, though this fall-off is attributed to that fact that the majority of the initial setting dust is composed of larger particles that settle rapidly (Cole et al. 1990, Dolislager et al. 2012, VanCuren et al. 2012a, 2012b,). However, dust from sources more distant may be carried by stronger winds and be transported great distances (Jassby et al. 1994, Morale-Baquero, et al. 2013, Yu et al. 2015, Zhao et al. 2017, Veranth et al. 2003). Our sampling strategy is designed to measure this type of transport as well as dust mobilized from locally disturbed landscapes or aerosols from urban sources. Clearly however, a critical question we have all raised since the beginning of our program was how to assess AD on the interior of the Utah Lake. With samplers located near the shoreline we can capture dusts from all important sources and estimate what is being transported across the lake surface based on various mathematical hypotheses.

We were not comfortable with our initial Kriging techniques, nor the data analysis performed by Brahney (2019) because we had witnessed both transport of dust across the lake and frequent inversions-sometimes for many continuous weeks during winter and early morning inversions resulting from the accumulation of aerosols above the lake from the cool, down-canyon evening/early morning breezes from local Wasatch Front Canyons year-round.  While we initially used very conservative estimates using linear or exponential declines to zero or near-zero deposition rates in the center of the lake (see 2017 and 2018 data above), to at least provide conservative estimates, we needed to address this question because estimated ranges of deposition exceeded more than two orders of magnitude.

We placed a measurement station on the interior of the lake (Figure 1) at Bird Island (Figure 14) to characterize the spatial distribution and falloff of AD across the interior of Utah lake. The Bird Island sampler was situated approximately 5 m above the ground/lake level. The rim of the sample buckets are approximately 0.3 meters higher than the table.

Over the 5 months (July to November) of 2020 that the Bird Island sampler was deployed it had higher or similar AD rates as the shoreline samplers, with the exception for TP for the month of October. The windrose in Figure 14 shows that frequent winds could carry dust from the northwest shoreline area or the southeast (across urban and rural zones of Utah Valley). These were represented by our sampling stations at the pump station and at the lakeshore site. However, after dozens of days sampling on the lake for other projects, we conclude that, although the wind rose is based on >10 years of data, the weather station at the Provo Airport does not represent air movement in the center and west side of the lake. Nor does it represent the prevailing and prefrontal winds from the southwest as seen in the windrose at our Mosida site or that at Delta (Figures 8 and 9).

We evaluated the correlation between AD nutrient concentrations at the four shoreline sites and those measured at the Bird Island site. We used both reduced and full statistical regression models, though there were only 16 co-collected observations. We found that while the data among the sites were similar, the models were only minimally successful in predicting Bird Island concentrations with $r^2$ values on the order of 0.6.

In most samples, the Bird Island values were higher than most of the shoreline samples (Tables 22 and 23). We expect that this is because of variable winds occurring across Utah Lake (i.e., downslope SE and east winds from the canyons during evening and early morning; SW winds during afternoon; and a combination during the passage of frontal boundaries – the combination of which could serve to concentrate dust and aerosols over the lake.

Table 22. Monthly TP deposition data comparing results from the lake interior sampling location (Bird Island) to data from lake shore sample locations. Except for October, Bird Island, the lake interior site, had higher AD rates than the average of the 4 shoreline sites. All data represent deposition rates in $mg/m^2$/month.

| Month | Bird Island | Lakeshore | Mosida | Pump Station | Orem | Avg of 4 shore sites |
|---|---|---|---|---|---|---|
| July | 5.35 | 6.62 | 7.40 | 2.56 | 3.73 | 5.08 |
| August | 9.37 | 2.55 | 3.13 | 4.36 | 2.31 | 3.09 |
| September | 36.25 | 3.75 | 6.17 | 19.91 | 16.45 | 11.57 |
| October | 1.73 | 4.70 | 3.36 | 2.49 | 8.42 | 4.74 |
| November | 33.34 | 6.01 | 2.89 | 3.34 | 9.51 | 5.44 |

All data represent deposition rates in $mg/m^2$/month.

Table 23. Monthly DIN deposition data comparing results from the lake interior sampling location (Bird Island) to data from lake shore sample locations. Except for August, Bird Island, the lake interior site, had higher AD rates than the average of the 4 shoreline sites. All data represent deposition rates in $mg/m^2$/month.

| Month | Bird Island | Lakeshore | Mosida | Pump Station | Orem | Avg of 4 shore sites |
|---|---|---|---|---|---|---|
| July | 31.93 | 24.91 | 21.25 | 17.28 | 19.84 | 20.82 |
| August | 28.87 | 35.50 | 38.31 | 30.02 | 37.94 | 35.44 |
| September | 52.29 | 35.47 | 25.28 | 20.21 | 26.40 | 26.84 |
| October | 16.39 | 16.84 | 15.37 | 9.58 | 11.14 | 13.23 |
| November | 27.17 | 14.51 | 13.24 | 2.62 | 15.36 | 11.43 |

All data represent deposition rates in $mg/m^2$/month.

These results run contrary to our previous assumption that AD deposition rates decrease rapidly away from the shore. This assumption was based on guidance we received from Brahney (2019). In retrospect, we believe that the measurements used to support this assumption, which were made at two points, one near an unpaved road and the second on a boat located in the lake just off the shore from the road, measured the initial fall-off of the larger particles mobilized by the road traffic which is consistent with other published patterns (Veranth et al 2003, Chow et al. 1999). We believe our shoreline samples are representing accurate AD rates but are measurements of finer particles that can be transported over longer distances. In other words, we placed our shoreline samplers away from trafficked unpaved and paved roads, and we believe the measurements at these locations are not affected by these larger particles (except perhaps for earlier samples collected near the gravel pit, see discussion above). We are now measuring smaller suspended dust particles that can be transported several kilometers without significant decrease in deposition rates, depending on wind speeds, that are more similar to that described by Jassby et al. (1994). Our data showed that the deposition rates measured by the shoreline samplers continue over the lake, with little difference in the Bird Island data supporting this hypothesis.

Tables 24 and 25, which have TP and DIN monthly deposition rates, respectively, indicated that AD rates measured at the Bird Island sampler are generally higher than those measured at shoreline samplers. Two exceptions being 1) The Bird Island site measured a 64% lower TP AD rate than the average of the shoreline samplers in October of 2020; and 2) The Bird Island sampler measured a 19% lower AD rate for DIN than the average of shoreline samples in August of 2020. Based on this information, we did not need to assume that rates significantly decreased away from the shoreline in 2017 (Olsen et al. 2018) and 2018 Reidhead 2019, Brahney 2019). Data collected at Bird Island show that these assumptions were incorrect, that mid-lake deposition rates are generally similar to or greater those measured by shoreline samplers. Still, more accurate estimates could be made with additional shoreline and lake interior stations, with the highest priority being on the west side of the lake.

The windrose in Figure 14 shows that Bird Island would be most influenced by shoreline rates from the northwest shore of Utah Lake and the area north of the Mosida sampling site. Neither of these areas have a shoreline sampler. The northwest shore area does not have much agriculture but is experiencing urban expansion in the cities of Lehi and Eagle Mountain. We are exploring the possibility of placing a sampler in this area for future collections.

Mid-Lake and Shoreline Sampler Correlations

To characterize the relationship between the data measured mid-lake at the Bird Island location with the shoreline samplers, we performed a general linear F-test. The general linear F-test attempts to predict the Bird Island results using data from the shoreline samplers. We examined both a full model which uses all 4 shoreline sample sites to predict the Bird Island results and reduced models created by removing each sample sites sequentially (Ramsey 2012). We used JMP Pro® to create and evaluate the models using the extra sum of squares test. We used log-transformed data because of the skewed distribution.

As expected, the full model most accurately predicted TP deposition rates at Bird Island using data from all four shoreline sites. Analysis indicated that the model was influenced by outlier observations. Normally these outliers would be removed from the model development however, considering that there are only 16 samples available we did not remove any data points from the model. The TP models indicated that there is some evidence for Lakeshore (p-value 0.0308) and for Orem (p-value = 0.0323) AD rates being related to Bird Island TP. The Pump Station TP rates have a lower p-value (0.0124) indicating better predictive power even though those two sites are the furthest apart physically. The Mosida site did not indicate any strong statistical evidence for a linear relationship to Bird Island TP (p=0.0880).

There are no strong relationships between the Bird Island site and multiple shoreline sites. This seems logical in that the wind-rose information from figures 14, 8, and 9 show dramatically different wind patterns, depending on the location of the weather station used and the time of day that such patterns develop. Indeed, it appears that all dominant winds, whether the prevailing SW winds or the evening local downcanyon breezes, converge on Utah Lake. This would logically tend to concentrate suspended particles over the lake and likely on daily basis.

## Monthly Average Analysis, 2017 to 2020

We compared average monthly AD rates from 2017 to 2020 to understand monthly variation and variations between pre-screened and post-screened samples. For each site, we computed a monthly average from the measured weekly AD shown in Figure 24 for TP and DIN, respectively. We also determined a monthly average for each of the site values. These results are presented in Tables 24 and 25 for the DIN and TP data, respectively.

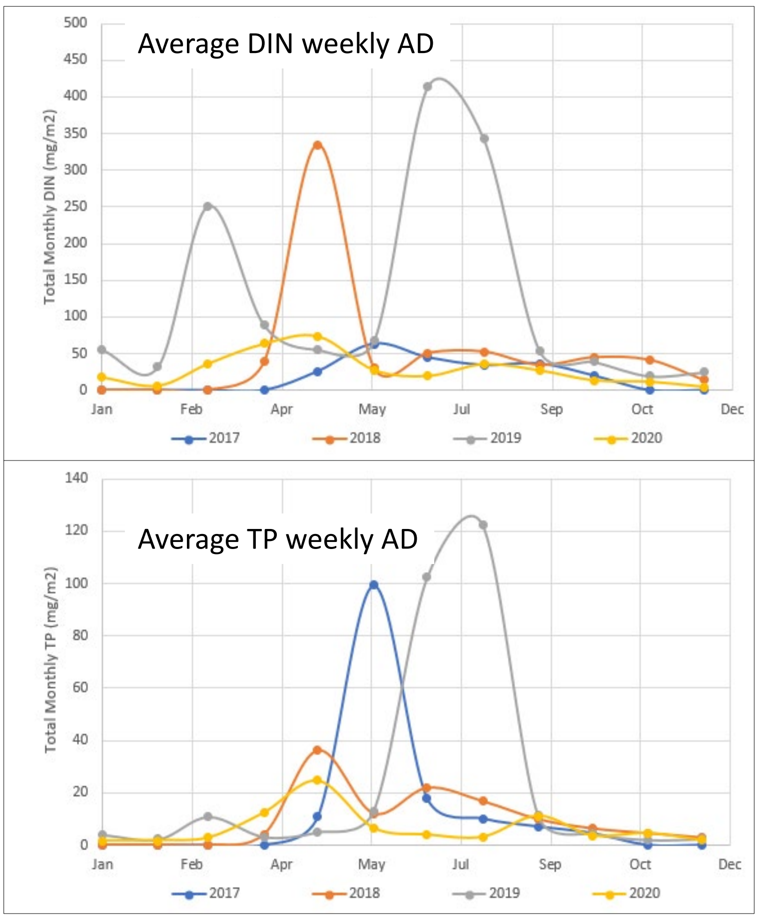



Figure 24. Monthly average of weekly AD for DIN and TP in the top and bottom panels, respectively. Values are in $mg/m^2$/week.

The dry months of spring and summer are the dominant periods for atmospheric deposition in and around Utah Lake. As summer progresses the landscape gets dryer and wind events become more common. Also, the chance from monsoon rain, including local convective high-velocity gust events, increases in July and August.

Table 24. Monthly average of weekly DIN AD measurements ($mg/m^2/week^1$)

| Month | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|
| Jan | N/A | N/A | 54.88 | 17.34 |
| Feb | N/A | N/A | 32.13 | 5.72 |
| Mar | N/A | N/A | 251.57 | 36.20 |
| Apr | N/A | 38.84 | 88.89 | 63.50 |
| May | 25.96 | 334.52 | 55.17 | 73.58 |
| Jun | 63.16 | 29.56 | 67.20 | 27.24 |
| Jul | 44.26 | 50.71 | 414.19 | 19.23 |
| Aug | 34.10 | 52.27 | 342.39 | 35.44 |
| Sep | 36.12 | 33.94 | 53.46 | 26.84 |
| Oct | 19.77 | 44.42 | 39.03 | 13.23 |
| Nov | N/A | 40.94 | 19.25 | 11.43 |
| Dec | N/A | 13.58 | 24.51 | 4.28 |

Table 25. Monthly average of weekly TP AD measurements ($mg/m^2/week^1$)

| Month | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|
| Jan | N/A | N/A | 4.08 | 1.66 |
| Feb | N/A | N/A | 2.36 | 1.80 |
| Mar | N/A | N/A | 10.97 | 2.86 |
| Apr | N/A | 4.25 | 3.29 | 12.57 |
| May | 10.91 | 36.43 | 5.15 | 24.82 |
| Jun | 99.32 | 12.20 | 13.13 | 6.56 |
| Jul | 17.82 | 22.02 | 102.40 | 3.97 |
| Aug | 10.15 | 16.85 | 122.43 | 3.09 |
| Sep | 7.09 | 9.91 | 11.31 | 11.25 |
| Oct | 4.58 | 6.38 | 4.54 | 3.65 |
| Nov | N/A | 4.55 | 2.16 | 4.57 |
| Dec | N/A | 2.90 | 2.44 | 1.84 |

Both the figures and tables show that adding screens to the sample buckets in 2020 had a significant impact on the summer data. Figure 13 shows spikes of TP in 2017 and 2019, that occurred in May and July respectively, while the 2020 data never showed a spike with a similar magnitude. The only spike occurred in May before the screens were installed. We believe that adding screens to the collection buckets caused the major change, as the 2020 non-summer months have data similar to the other years.

Inclusion or exclusion of outliers remains debatable and particularly for terrestrial insects. There is clear evidence that terrestrial insects land or fall on lake surfaces and can play an important part in food web relationships (Mehner et al. 2005, Norlin (1964, 1967), Ruzycki et al. 2001, Wurtsbaugh et al. 1975) and this can occur in large lakes. Moreover, because the two samplers with the largest occurrence of insect "contamination" were at the immediate shoreline (Saratoga Springs and Mosida), it is likely that a similar density of insects fell on the lake surface extending from and between these sample sites. Moreover, this abundance of insects primarily occurs for a relatively short period of time, about six weeks in late spring/early summer. One way to resolve this is to perform the loading calculation for weekly samples, (as was suggested for Dr. Wood Miller by Dr. Gay), a process which was performed for the 2019 and 2020 data (see below). Therefore, the only remaining unknowns would be how far this "fallout" extends and therefore, what proportion of the lake should be included in the analysis and whether this "fallout" declines in an exponential or linear pattern, (a question addressed here with respect to dust and aerosols). Further, we believe that "outliers" occurring as a result of summer thunderstorms are not real outliers in the sense that outliers typically result from contamination of a sampling device or analytical error, or perhaps a rare climatic event. However, in this case, the many dozens of times that these types of muddy samples have been collected demonstrates that these summer storms are not only common, but that they result in exceptional contributions of TP, SRP and DIN to the lake surface. In conclusion, therefore, including outliers dominated by insect deposition may result in a slight overestimation of actual values if only inorganic particles are sought; however, removing all outliers that include insects or dust or muddy rainstorms results in a clear underestimation of actual deposition values. One way to resolve this debate, as mentioned above, is simply to use the average of the other sites in the calculations and apply the Kriging techniques for multiple time frames, a practice that we will continue for 2022 data.

## Estimates of Nutrient Loading to the Utah Lake

In this section we provide a brief discussion of previous load estimates and how they were computed to better describe the improvements and place them in context.

In 2017 Olsen, et al. (2018) assumed that AD rates decreased significantly away from the shore, with AD rates at the center of the lake matching background long-range transport estimates. To estimate the total load to the lake, they added 5 hypothetical locations inside the lake and assumed background AD rates of 0.019 mg $m^{-2}$ $day^{-1}$ at these locations (Olsen et al. 2019). They then used ordinary kriging to compute the spatial distribution across the lake at each sample time, then integrated those spatial maps through time to estimate the total load. Reidhead (2020), rather than using kriging or other standard geo-spatial statistical methods, used an interpolation method that assumed linear fall-off of AD rates away from the shore, with deposition rates assumed to be zero at the center of the lake. This was based on the general understanding of local dust sources composed of large particles and there is lots of evidence that deposition rates decrease dramatically with distance, though this fall-off is attributed to that fact that the majority of the initial dust loads are larger particles that settle rapidly (Zhao et al. 2017, Veranth, et al. 2003, Chow, et al. 1999). These same studies show that the smaller dust fractions are much lighter, have slow settling velocities, and can be transported over large distances. This type of transport is what we are attempting to quantify with shoreline stations located away from local point dust sources and, of course, a station placed in the interior of the lake to evaluate longer-distance transport.

We placed a measurement station on the interior of the lake at Bird Island to characterize the spatial distribution and falloff of AD on Utah lake to determine if AD rates measured on the lake shore significantly decreased in the lake interior. The Bird Island sampler was placed at least 5 meters above the lake surface (Figure 15). The tops of the sample buckets are approximately 0.3 meters higher than the table. We believe there was minimal contamination (which would be dilution) of the samples with lake water.

To estimate total deposition on Utah Lake, we loaded the sampling results for each site to each location around the lake. We then created a random raster within the extent of the Utah Lake layer. We used the Kriging tool within ArcGIS Pro, following the kriging steps described earlier, to load interpolated values onto the Utah Lake raster. We then extracted just the cells within the Utah Lake layer using the "Extract by Mask" tool. Finally, we summed every cell within the Utah Lake raster to compute the total nutrient loading for the whole lake in milligrams for that week. This process was repeated for each week in 2019 and 2020 for both TP and DIN.

Estimates of nutrient loading for the 2019 and 2020 data also included simple kriging with a standard variogram to interpolate among the 4 sample points for 2019 and the 5 sample points for 2020 between the sample points using ArcGIS. This interpolation method is the same as performed by Olsen et al., (2018). However, by using the data from Bird Island to represent deposition on the interior, the fall off rate is very different. Notably, this method used on the 2019 and 2020 data means that the estimated deposition rates generally increased as it progressed towards the center of the lake, while in 2017 and 2018, Olsen (2018) and Reidhead (2019) used rapid fall off rates to long-range NADP-measured regional background concentrations with distance towards the center of the lake.

For sites that had missing values for a given week, we used the average of the remaining sites for that week. We also used the average to replace the high outliers, which continues to be debatable on whether these outliers due to wind events or if they are merely statistical outliers.

We used ordinary kriging (OK) as implemented in Arc GIS Pro® with a standard variogram. We followed the methods of Olsen (2019), but as discussed above, we have a better understanding of deposition distribution rates across the lake. We know that AD rates are relatively consistent over the lake, so for 2019 data we applied OK using the 4 lakeshore sample points without the pseudo points used previously to force rates at the center of the lake to lower values. For 2020 we used data from the 5 sample locations, including Bird Island, in the center of the lake. We also estimated Bird Island data for months without measurements with details described below.

For 2019 data, we used OK to interpolate the spatial distribution of AD for each sample using data from the four lakeshore sample sites. We used a different approach for the 2020 data. For the 5 months of 2020 (July to November) during which we had data from Bird Island, we used OK and data from all 5 sites to estimate spatial distributions. For the other 7 months of 2020 (January to May and the month of December) we estimated Bird Island AD rates using the regression equations generated from the statistical analysis described above. In situations where the model estimation resulted in a negative value or a value that did not fit with other data, we used the mean of the 4 sites, rather than the model predicted value. This was rare. We did not attempt to include Bird Island data for 2019, we just assumed a continuous spatial distribution as computed by the OK approach.

For both 2019 and 2020, we did impute missing values at any given site. If a site was missing a measurement for a given week, we estimated the missing value as the average of the other sites for that week. If a site measurement appeared to be an outlier, we excluded that value and only used the remaining sites in computing the average.

Once we had a complete data set for 2019 (4 sites) and 2020 (5 sites) we loaded the data into ArcGIS Pro®. Using ArcGIS, we used the Kriging tool to generate a raster layer that represented the AD rates for that week. We computed a raster for each week in 2019 and 2020. We then applied a mask to only select the cells within the Utah Lake boundary. These rasters represented AD rates in mg/m$^2$/week. We then multiplied the raster by the lake area to obtain the total weekly deposition, then summed these data to estimate the total annual deposition. We completed these steps for both TP and DIN. For convenience, we converted the results from milligrams/year to tons/year.

As discussed above, even though the linear regression performed on the Bird Island sampler compared with the other samplers did not return strong evidence that the Bird Island AD could be predicted by the other samplers, we used the results from the regression analysis for 2020 because we felt it better represented full lake AD. We did not estimate Bird Island data for 2019.

Finally, Table 26 shows estimated total annual TP loads of 262 and 133 tons for 2019 and 2020, respectively with total annual DIN loads of 1,052 and 482 tons for 2019 and 2020, respectively. As mentioned above, we believe the 2019 data are greater than the 2020 data because of the screens used during 2020. As described above, the 60% loss of space, due to the screen filaments themselves, not only excluded insects but likely a considerable amount of legitimate dust and aerosol particles that settled on the screens and even perhaps remobilized with ensuing winds.

Table 26. Total annual AD nutrient loads to Utah Lake for 2019 and 2020.

| **Nutrient** | **2019** | **2020** |
|---|---|---|
| TP[1] | 262 | 133 |
| DIN[1] | 1,052 | 482 |

[1] All data are in tons/year.

Our 2019 and 2020 data represent the most thorough assessment of important variables resulting in the most accurate estimates of AD to date. We initiated a bulk sampler program – emulating the majority of AD protocols from throughout the world; we empirically assessed the importance of all of the criticisms brought by the Science Panel and Dr. Gay, made modifications to the sampling equipment where suggested and purchased NADP-approved wet and dry samplers in order to address these important variables. Careful comparisons of the 2019 and 2020 data with earlier years and between these two years reveal the relative importance of the various adjustments.

Most notable, 2020 values are about half of those for 2019 for both TP and DIN. Our data showed a statistically significant effect of installing screens in the dry-side buckets. Not only did these effectively prevent insects and plant debris from entering the sample (which we discussed above as still being debatable), but we believe the 500-micron mesh also captured large amounts legitimate dusts and aerosols – reducing the quantity of deposited material that was captured and measured.

## Conclusions

We have performed four years of wet/dry and bulk AD sampling for Utah Lake, including more than 500 samples for each project. The bulk deposition program started with 8 samplers near Utah Lake and one near the Wasatch Front foothills on the BYU campus. These samples represented lake-side deposition as well as agricultural and urban AD. Because of the sampler design and frequency of sample collection, there is a general consensus among the principal scientists, including Dr. Gay, that these samples represent a conservative estimate of total AD to the Utah Lake.

Our wet/dry sampling program evolved from utilizing 5 samplers around the lake to four samplers around the lake and one in the south/central portion of the lake. We carefully evaluated the variables that were criticized in our earlier design, including table height, and screened vs unscreened dry-side buckets. We also minimized potential contamination of splash from the lid by installing a thick matting material called Miner's Moss®. There were no significant differences between low vs high table height and samples did not appear to be influenced by potential splash from the lid apparatus. However, the 500-micron screens significantly reduced (by about 50%) the mass of total P and SRP entering the sample. We attributed this to the large amount of the bucket opening (60%) occupied by the screen filaments themselves. This "filtering effect" is the primary reason why the 2020 AD estimates for the whole lake are about one half of that for 2019. Moreover, this screened reduction occurred for both DIN and TP, suggesting that a similar impact on results is occurring for both analytes.

The great majority of insect "contamination" was the terrestrial insects that were captured during about a 6-week period in spring and early summer and primarily at one site – rather than emerging midges. Literature review indicated that while terrestrial insects make significant contributions to the food web, the total contribution of P and N to the nutrient budget is minimal (<2.1%; Mehner 2004). With this information and discussion, we conclude that removal of insect contamination is irrelevant to the total nutrient budget while use of 500 micron screens significantly reduced the true AD to the Utah Lake surface. Overall, the total accumulated deposition over twelve months and across all the other sampling sites dwarfs the impact of the addition of a relatively few insects for a few samples at one station. For example, with screens placed on the Bird Island sampler, we still measured overall slightly greater amounts of AD at this site than the shoreline sites. There was NO attenuation or fall-off of AD mass with distance from the shoreline sites. Nevertheless, in view of the perhaps persistent criticism about insect or plant contamination, we have replaced our screens with 1 mm-mesh for the 2022 sampling season. We believe that this will capture the great majority of insects and plant parts while allowing about 65% of the bucket surface area open for particle passage for inclusion to the sample.

Also, we maintain that the very high AD numbers measured at Saratoga Springs in 1917, were likely due to the active gravel pit. However, an evaluation of the sampler location revealed that, due to the proximity of the pit to the lake's edge, relative to the sampler location, indicates that more dust travelled over the lake (at least 1000 m) than what was measured in our sampler. Therefore, although anthropogenic in nature, the continual excavation and in such proximity to the lake, makes this gravel pit a source of considerable dust that should not be ignored.

Table 27. A summary of all the estimated AD values from the various authors and programs. Olsen et al. and Reidhead data were modified (increased by 25%) from earlier versions of this report in order to provide an annual rate of deposition rather than the 7.5 months and 8 months of actual sample collection.

| Author | Years sampled | Sample type | Total P Load (tons) | SRP/O-P Load (tons) | Inorganic N (tons) |
|---|---|---|---|---|---|
| W. Miller 2021 | 2017-2020 | Bulk | 77 | 24.9 | 316 |
| W. Miller 2021 | 2017-2020 | Bulk, Precipitation-weighted | 115 | | 422 |
| Olsen et al. (2018) | 2017 | 12 Mo. Wet/dry, samples with visible particles removed | 10 | NA | 57 |
| Olsen et al. (2018) | 2017 | 12 Mo. Wet/dry All data | 430 | | 570 |
| Reidhead (2019) | 2018 | 12 Mo. Wet/dry floating debris removed but no outliers removed | 193 | 71 | 636 |
| Barrus et al. (2021) | 2019 | 12 Mo. Wet/dry no screens, floating debris removed | 262 | NA | 1052 |
| Barrus et al. (2021) | 2020 | 12 Mo. Wet/dry, screens in place, Bird Is. installed | 133 | NA | 482 |
| Brahney (2019) | Lit review | Multiple types, Global, regional, Modelling | 3.5-13.4 | 2.7-7.9 ("Bioavailable") | 153-288 |
| USGS | 2020 | Bulk samplers surrounding Great Salt Lake | NA | NA | 355 |

Nevertheless, I have included all of the estimates provided by the various researchers, including removal of "outliers" and with and without use of 500-micron screen.

We have included an additional illustration of the different results, based on the different methods of developing AD estimates on Utah Lake (Figures 26 and 27)  Overall, based on this data and considerable evaluation of the various methods and sources and variables involved in each program, I estimate that total AD of nutrients on Utah Lake lies in the range of 150 to 200 metric tons per year for total P and in the range of 600 to 900 metric tons for DIN.

We included the data from the Olsen et al. (2018) "all samples with visible particles removed" to demonstrate that if every sample with a single visible particle were removed from the data set, only invisible, aerosol to dissolved particles, even for the dry side, will be a part of the sample. This is the likely reason why this value is similar to NADP wet samples collected at high-elevation undisturbed, pristine sites such as in the national parks in eastern Utah as developed by Brahney (2019). However, this is just not reasonable in the context of continually drying playas, exposed to frequent winds that coat the entire Wasatch front with dusty/muddy AD samples on a regular basis. Moreover, sample years subsequent to 2017 did not include the extremely high values sourced from the gravel pit as identified in Figure 17. Please note that the type of Kriging again, appropriately limited this source to the triangle pointing to the center axis on the lake (Figure 4). Yet, the results indicated that this gravel pit is an important source of dust to the lake. I maintain that to ignore this source, is to ignore reality.

For comparison, Figure 23 is a USGS image generated from data collected around Great Salt Lake. As with the NADP, USGS does not typically measured P in their AD program. As shown in the inserted photos, USGS used bulk samplers fitted with screens to collect these AD samples at the shoreline of Great Salt Lake. First, note that there is local variability in sample results – conditions imperceptible if using regional data or even using just one or two samples to represent the local conditions around Great Salt Lake or Utah Lake. Second, note the apparent presence of screens tied to the top of the USGS samplers – potentially as fine a mesh as our samplers. Thirdly, taking an approximate mean of various USGS samples of 1000 mg/m$^2$, and applying this value to the surface area of Utah Lake, would equate to about 355 metric tons of DIN on Utah Lake, a value notably similar to our screened DIN values for Utah Lake (Table 26).

Throughout our different approaches (bulk vs wet/dry) and NADP vs our original design, our sampling results have ranged from 114 tons per year (bulk, precipitation-weighted) to 430 tons per year (excluding the "clean sample data" from Olsen 2018) for TP and from 482 to 1052 tons per year to DIN. For DIN, it is notable that our measurements are clearly in the range of USGS values as well as those developed by the CMAQ model and the TDep working group from NADP (see Table 11 from Brahney 2019 or Table 28 below).

Thus, multiple types of measurements and modelling have resulted in similar DIN values for Utah Lake. Moreover, is appears than some sort of filtering results in similar measurements between the USGS and our data. Because our filtering removed 40 to 50% of TP and DIN. It seems logical that our measurements of TP would be similarly comparable if such other local sources of AD were available. Notwithstanding, our local data, including a sampler in the interior of the lake, provides the best estimates to date for TP and DIN deposition on Utah Lake. A final notable note: Brahney (2019) included a table of N data based on the CMAQ model and the TDEP working group from NADP and other affiliated networks to provide an estimate total N to Utah Lake. A remarkably similar value to our measurements and final estimate of DIN to Utah Lake. Perhaps there is hope afterall.

Table 28. A copy of Table 11 from Brahney (2019) labelled "Estimated range of wet, dry, and total N deposition to Utah Lake from the CMAQ model and TDep working group from NADP and other affiliated monitoring networks."

| | Utah Lake | | Total N |
|---|---|---|---|
| | Wet | Aerosol | |
| | mg N $m^{-2}$ $yr^{-1}$ | | |
| $NO_3^-$ | 90-125 | 100-400 | |
| $NH_4^+$ | 100-150 | 50-150 | |
| Total N | 200-300 | 200-400 | 400-700 |

Also, as the debate may apparently continue, I add a quote from Cole et al. (1990) "as a test of the collectors, we deployed three of them set up in the usual way, i.e. containing 1 liter of dilute NaCl solution, and three identical collectors, which contained no liquid, in a large clearing about 0.5 m from the lake. The "wet" collectors caught 16.21$\pm$ 10.91 umol P $m^{-2}$ $d^{-l}$ during a 3-d deployment, while the "dry" collectors caught only 1.7$\pm$0.6 umol $m^{-2}$ $d^{-1}$ in the same period. The dry collectors did accumulate some moisture during deployment, so the actual difference in collection efficiency between a wet and dry surface is probably even greater."

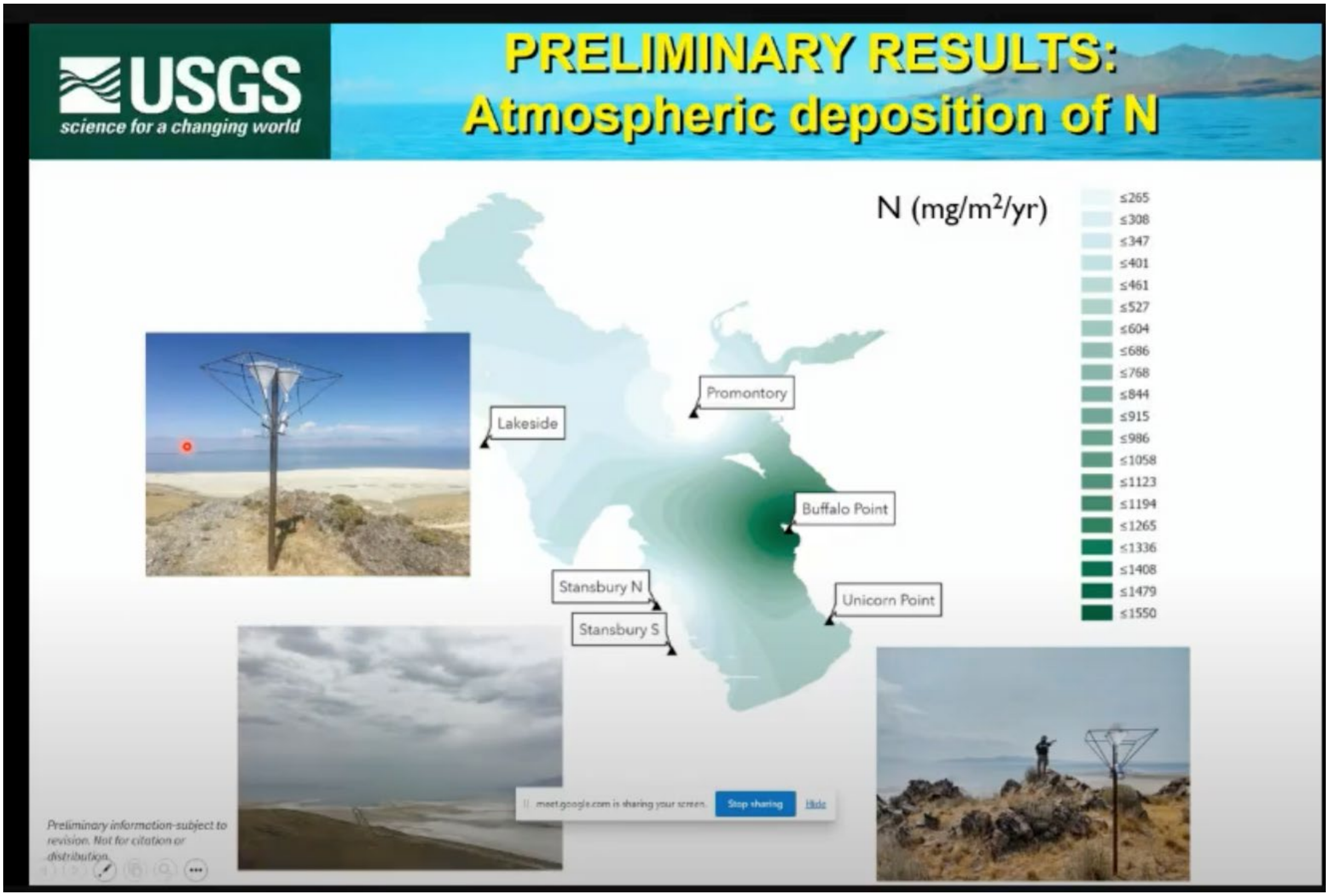



Figure 25. Graphic prepared by the USGS Atmospheric Deposition Program summarizing data collected at shoreline sites around Great Salt Lake

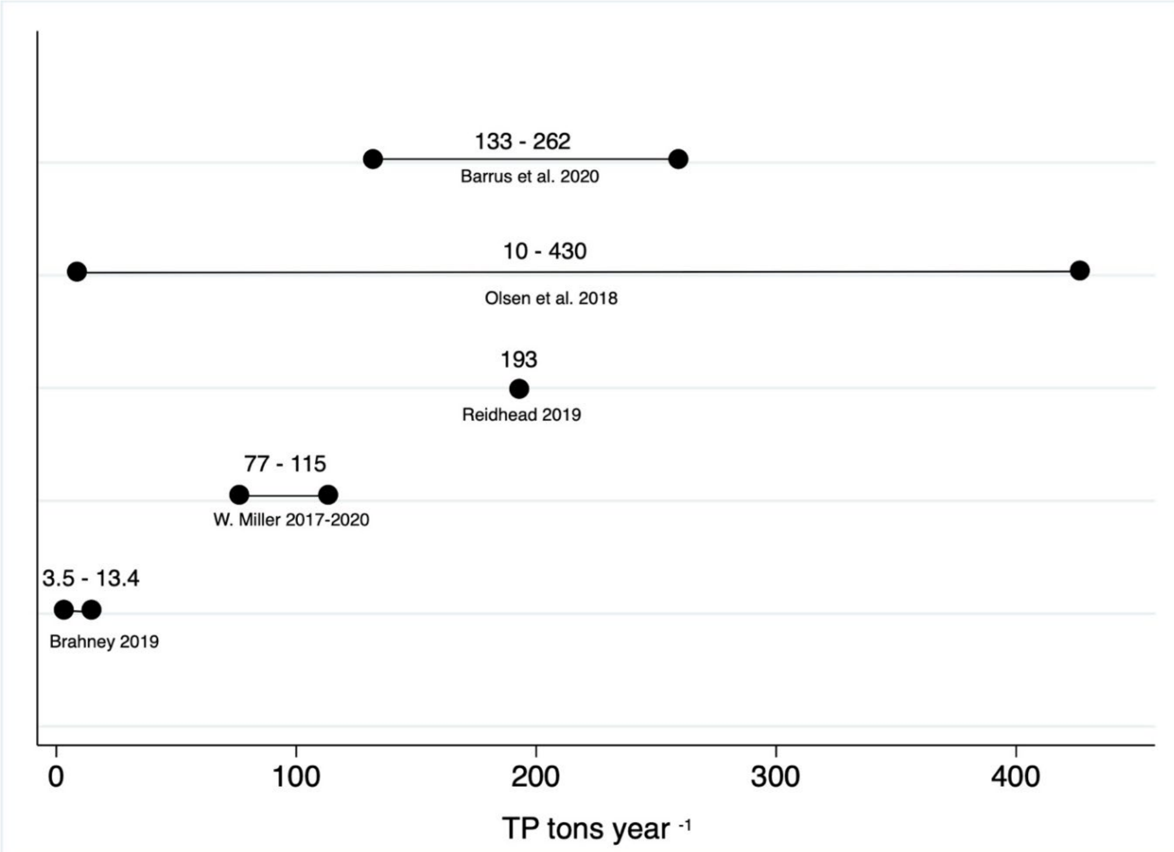



Figure 26. Estimated ranges of atmospheric deposition of total P on Utah Lake developed from local measurements of wet/dry samples, [Barrus et al. 2021 with screens (low) and without screens (high)]; Olsen , outliers removed (any particles – data removed - (low) and including all sample data - (high); Reidhead 2019, floating debris removed before analysis, Total deposition reported for Olsen and Reidhead were modified by extrapolating from the 7.5 and 8 months of actual measurements to include annual deposition rates); Miller (2017 – 2020 includes Bulk sample data (based on averages (low) and precipitated weighted averages (high); Brahney (2019) calculations based on literature values from regional, global, urban and dust on snow values).

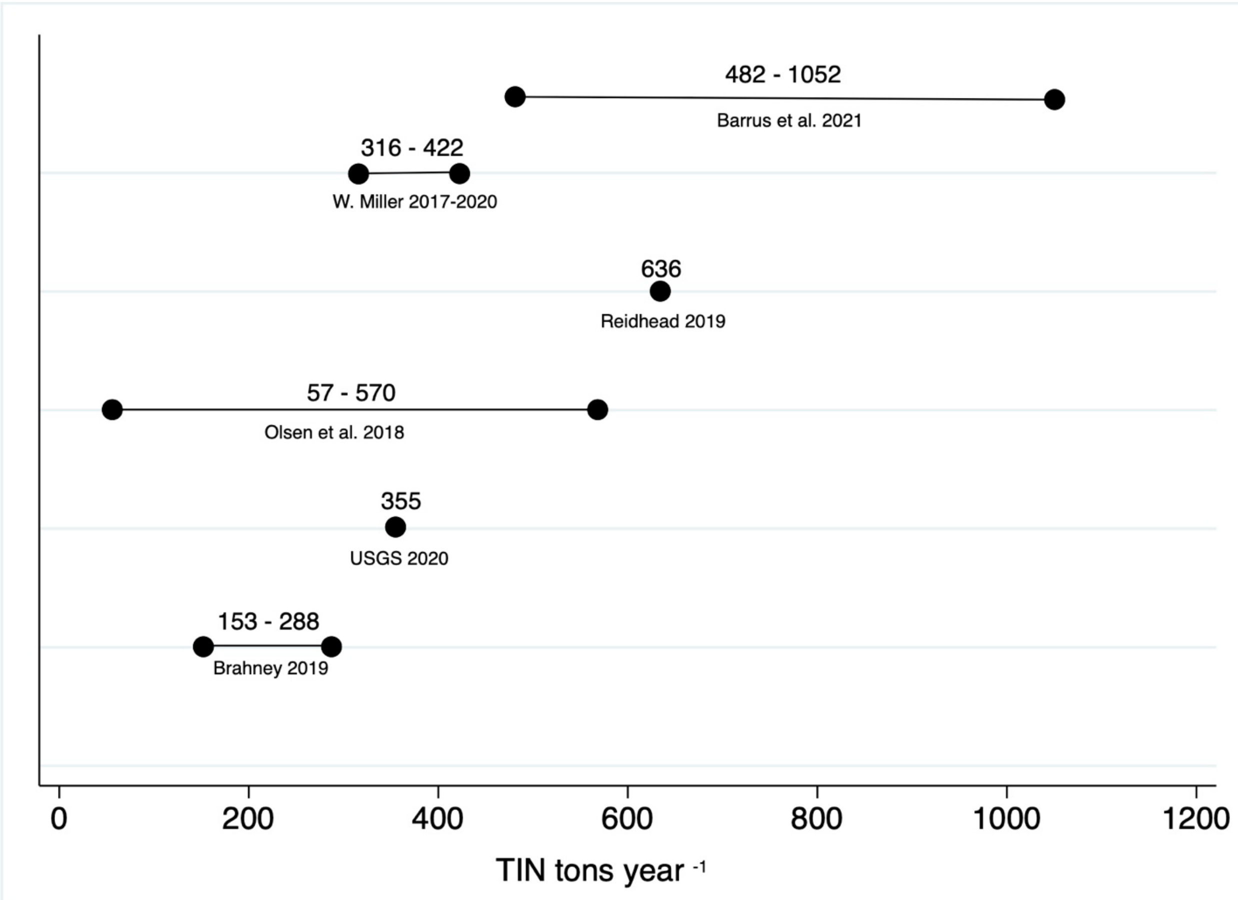



Figure 27. Estimates of atmospheric TIN deposition on Utah Lake developed from local measurements of wet/dry samples, [Barrus et al. 2021 with screens (low) and without screens (high)]; Olsen , outliers removed (any particles – data removed - (low) and including all sample data - (high); Reidhead 2019, floating debris removed before analysis; Miller (2017 – 2020 includes Bulk sample data (based on averages (low) and precipitated weighted averages (high); Brahney (2019) calculations based on literature values from regional, global, urban and dust on snow values). As with Figure 26. The Olsen (2018) and Reidhead (2019) data were updated to estimate total annual deposition of TIN.

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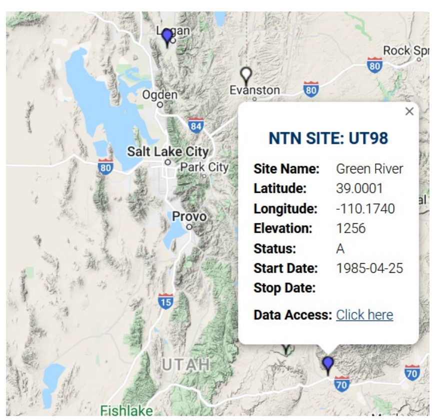
David Gay Notes, 3/12/2022

1. From the note for table 2c. I wanted to compare the NADP measurement for total N concentration (i.e. Nitrate + Ammonia  which is all we measure). I converted our values to get average N concentration rather than nitrate concentration. I get an average concentration of N in mg/L of 0.59 mg N/L which is significantly lower than your value of 2.77. Your measure is bulk deposition and ours in wet deposition. This would suggest that the average amount of dry deposition to your collection is on the order of 2.1 mg/L of dry deposition to the bulk collectors. That is 75% dry deposition and 25% wet deposition. Assuming i did not make a math error, and our site at Green River is somewhat similar (Logan did not make the 2020 map), then this could be a significant comparison that you would want to add in to the text here. A lot of this dry deposition would end up in the lake through direct deposition to the water surface, but would not necessarily end up in the tributaries. i.e. tributary loadings would not be highly concentrated with dry deposition, but it would show up in the lake water.

Average NADP Values at nearest site

| | mg/L | conv | mg N/L |
|---|---|---|---|
| NO3 | 0.9 | 0.22 | 0.198 |
| NH4 | 0.5 | 0.776 | 0.388 |
| Totals | | | 0.586 |



2. From Table 3, and the average TP sample, the outliers table. I noted several samples in there that were of long duration (ie. Dry conditions prevail) and have high TP or TN. Example TN on July 17, Feb 15, Aug 22, and TP on July 17 and July 25 Aug 22, all have very high concentrations. This is a very good indication that the samples on at least these days had significant DRY deposition. You could add to this analysis with some indication of very windy conditions, observations of dust storms in the paper, or meteorological record. All of this goes to support your thesis that dry deposition is a very big player in your TP TN issues in the lake. You may also want to add total precipitation per sample and days since the last rain/sample so that some of these high values that are likely dry deposition stand out in your table and your arguments.

3. I guess I would consider it a conservative estimate of wet deposition but closer to the real world estimate of total deposition. If these numbers are used as wet deposition of total P and total N, then yes these estimates are greater than wet deposition for sure. See the comparison to NADP values above. How good of an estimate of dry + wet is tough to gage. How well does a metal funnel represent a natural surface or the lake surface? A lot of people would argue that it isn't a very good estimate of dry deposition at all, and that the values of true dry deposition to the lake surface could be much greater than these values. So i do not think it is correct to say it is a conservative estimate of dry deposition of P or N, and the same for total deposition of either; it could be higher.

4. From the precipitation weighted discussion. As I remember, we talked about two separate concepts.
   a. Precipitation weighted average concentrations
   b. Accounting for precipitation that fell into the lake but was not sampled (outside of sampling period, invalid analysis, etc.

   There are certainly many ways to do either of these.

   For a. above, when you talk about an average concentration for the year, you absolutely want to use the precipitation weighted average for the weekly concentrations. Without question, use PWMean Concentration. Here is an extreme example:

Precipitation Weighted Average Example

| Week | Concentration | Precipitation amount | Numeric Average of Concentration | Weighting (P*Conc) |
|---|---|---|---|---|
| | mg/L | L | | |

| | | | | |
|---|---|---|---|---|
| 1 | 10 | 0.05 | 10 | 0.5 |
| 2 | 10 | 0.06 | 10 | 0.6 |
| 3 | 10 | 0.04 | 10 | 0.4 |
| 4 | 10 | 0.05 | 10 | 0.5 |
| 5 | 150 | 0.002 | 150 | 0.3 |
| Totals | | 0.202 | 38<br>mg/L | 2.28<br>mg/L |

This shows that a high value can skew the average concentration tremendously because of the high concentration in week 5. But the week 5 value was only in a very very small amount of rain. So NADP calculates this average to use in our maps (for this site, we would use 2.28) and not the straight numerical average. You can also do this by season. Because if we had a week where we knew it rained, but did not have a valid measurement of the chemistry, we would substitute in 2.28 for the missing measurement, and multiply though by the precipitation to get the deposition for the week with missing data and a better estimate for the entire year.

In several of these measurement projects, you did measure during most months but not all. This is an approach you could use to estimate the deposition for the months you don't have samples for.

Dr. Miller has seemed to do something similar here, but I am not 100% sure how it was done, based upon this information.

5. I am not sure I agree with this sentence (local vs broad regional sources).
   For example, all of our sites in Utah would be representative of the aerosols generated in the playa in the SW, but we wouldn't want a local source (like a gravel pit near the site. This would increase the values we would measure at a site located one mile downwind of the pit, versus 1 mile upwind of the pit. We would want sites that would give a very similar number regardless of where we put it in a county (say).
   And to the minimal deposition sentence. I would say that the NADP site would want exactly the deposition from the broad regional sources.
   However, for your project, the important sources are all of them a) the long range transport and regional sources that NADP would collect, and b) the local sources (a rock quarry at the edge of the lake) that NADP would not want in its sample because this source only has an impact on the lake. But for your project, this kind of source could be the most important source of all. The urban signal for example. We would not

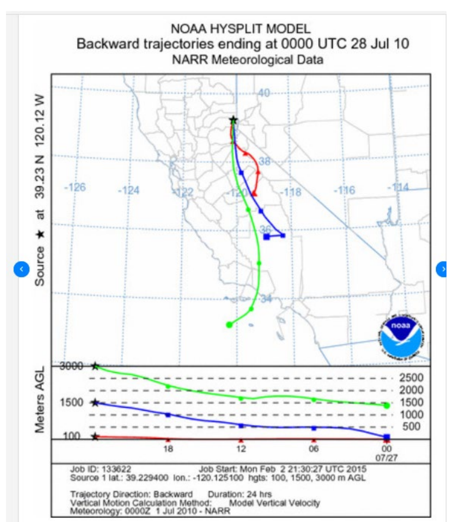
put an NADP site in the middle of salt Lake City and add these values to our maps because it is a local source that is not experienced by most of Utah.
However, the city certainly is going to affect the deposition to all lakes around it, and are important for your project.

6. I made some quick estimates of deposition from our maps to yours to see if I could recalculate your use of 0.112 mg DIN m−2 week−1 that you used based on 20214 NADP maps. I may have made a mathematical error, but I calculated DIN from NADP values based on the concentration as measured by us, and on our deposition maps for 2020 (see https://nadp.slh.wisc.edu/maps-data/ntn-gradient-maps/). With these calculation (see below) I am getting significantly more wet deposition that 0.112 mg DIN/m2 week. Again, i made the calculation two ways and am getting 3.29 and 4.8 on the high end (mg/m2 week, assuming annual value divided by 52. Certainly you will want to check my math, but my value is much different. About 15 times more.

| | |
|---|---|
| Deposition | |
| | inches ppt per |
| 11.5 | year |
| 292.1 | mm ppt per year |
| 292.1 | L per year per sq meter |
| | assumed DIN concentration |
| 0.586 | mg/L |
| 171.1706 | mg/m2 year calculated |
| 3.291742 | mg/m2 week average |
| | |
| From our Maps | |
| | kg/hectare per year, low |
| 0.5 | estimate |
| 2.5 | "" high estimate |
| | |
| 0.00005 | kg/m2 year low |
| 0.00025 | " low |
| | |
| 50 | mg/m2 year low |
| 250 | high |
| | |
| per | |
| 0.961538 | mg/m2 week low |
| 4.807692 | high |

7. Per the Brahney dry deposition measurement methods, her old design (marble) and new design (multiple glass plates) are valid methods, and at least in my opinion should be considered here. I have suggested that with a your wet deposition collectors (NCON), bulk collectors, and Brahney dry deposition collection, and with analysis on all samples for total P and N, the resulting estimates (plus model estimates for the lake) would be a very good database to make full decisions on. I have mentioned this in the past, and repeat it here.

8. From the Brahney discussion, it occurred to me that most of the wet deposition samples are single rain events (or total rain in the past 24 hours). This presents an opportunity. You can do back trajectory models (quite easily in fact) for each hour of the day during which rain occurred and include a few hours before each rain event. With this you can show exactly (well actually an approximation) of what direction the wind was blowing from at the surface (say 400 meters AGL) in the mid atmosphere 1200 meters AGL) and at some level very high. This will give you very very strong evidence of whether the air at the time of wet deposition is flowing from the playa or not flowing from the playa. You can easily do this analysis for each and every rain event. HYSPLIT will even estimate wet and dry deposition for you if you have source emissions data. I just grabbed a quick example of a multi level back-trajectory. The map shows the 2 d location, and the graph on the bottom shows the elevation of each trajectory over time. I would suggest starting with the high concentration/deposition days found in your measurements.




9. For the criticism of the Brahney et al. discussion, it occurred to me again that they easy way to get beyond the argument of which NADP sites to compare to is to establish an NADP NTN site at Utah Lake (again I am not suggesting this to put funds into my own

program). With an NTN site at the lake, you will get weekly precipitation only concentration and deposition for nitrate, ammonium and orthophosphate for the location. You get two things in return: a) independent verification of your measurements to say that you have independent confirmation of these, and b) you get beyond the argument of what NADP sites are appropriate or not appropriate to compare to your measurement network (elevation, location in Utah, etc.

10. Table 22. First of all, i would have never guessed this result. These are huge differences. I would expect criticism will come on these observations, such as “Can you prove that there is no contamination going on in the lake that is not representative of the lake surface?” “Condensation into the bucket because the sampler is colder than the water, for example?” “Mist/droplets from waves being added to the sample?”
    a. Do the wet only samples also show this difference? Is the difference in the dry side?
    b. Bird poop in the dry side? Are the birds using it as a resting place (although then you get into the argument of bird feces as a source)?

    You might want to pull out very short term samples (2 or 3 day samples) that have not likely had a long time to collect contamination; i.e. to provide evidence that it is the atmosphere and not some other problem occurring. If you find the same with wet deposition side of the sampler and short term samples, this will give you more evidence that the observations are correct, and that the urban core and shifted wind on the east side of the lake are a major contributor.

11. From the conclusions “there is a general consensus among the principal scientists, including Dr. Gay, that these samples represent a conservative estimate of total AD to the Utah Lake. “. Perhaps i am not clear on what you are saying here, but here is my opinion. Bulk samples are approximations of total deposition. In general, they are the best we can reasonably due to measure total deposition, because making a dry deposition measurement is very very difficult and how to do it correctly is far from being settled. Wet deposition we know how to do, and therefore bulk measurements will be higher than wet measurements because of the addition of some of the dry deposition. And this brings us to the determination of how well bulk samples represent the dry deposition component. I think most would conclude that they do these measurements very poorly. It is an open metal device and in this case we hope it

simulates dry deposition to an active water surface. How well does it do this? We do not know.

So I am not 100% sure of what you mean when you say a conservative measurement of total AD to Utah Lake. I think these measurements are a reasonable approximation of total deposition to Utah Lake. Real dry deposition could be higher or lower than what the bulk samples measure. This is the basic reason of why NADP does not make dry deposition measurements with our buckets; we didn't know how well they represented reality.