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Significance of the Rates of Atmospheric Deposition Around Utah Lake

and Phosphorus-Fractionation of Local Soils

Joshua Glen Reidhead

A thesis submitted to the faculty of
Brigham Young University
in partial fulfillment of the requirements for the degree of

Master of Science

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ABSTRACT

Significance of the Rates of Atmospheric Deposition Around Utah Lake
and Phosphorus-Fractionation of Local Soils

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Master of Science

Eutrophic Utah Lake receives a large nutrient load from a variety of sources, including treated wastewater discharges, runoff and tributaries, recycling from bottom sediments and Atmospheric Deposition (AD). AD was the focus of this study and was comprised of two complementary parts. First was a study of nitrogen and phosphorus depositions from the atmosphere, and second was a study of phosphorous as contained in soils near Utah Lake via fractionation methods.

The soil samples were found to contain approximately 1,000 mg-P/kg soil for total phosphorus (TP). A separate phosphorus (P) fractionation gave slightly higher values, excluding the residual P, we are 95% confident that one gram of sample soil contains between 2.2 and 4.3 percent water soluble P, 0.6 to 1.1 percent loosely-bound P, 2.5 to 4.4 percent aluminum and iron-bound P, and 90.7 to 94.2 percent calcium-bound P.

AD results indicate that during the period from April 1 to Nov 17, 2018, Utah Lake received approximately 58 tons of soluble reactive P, 153 tons of TP, 118 tons of nitrogen (N) from nitrate, and 387 tons of N from ammonium via AD.

Nutrient quantities from AD are very large compared to the 17 ton/yr of P needed for a eutrophic loading to the lake. Because of the very large overall nutrient loading to Utah Lake, it is likely that some other limiting growth factors are controlling algal growth.

ACKNOWLEDGEMENTS

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1 INTRODUCTION

Eutrophic, basin-bottom Utah Lake sustains a rich and very productive ecosystem. It is also a popular recreation area while supplying irrigation water to the Utah and Salt Lake Canal, North and East Jordan Irrigation Companies, South Jordan Canal Company, Metropolitan Water District of Salt Lake and Sandy, and Kennecott Utah Copper, among others. Although irrigation has decreased with the ongoing urbanization of the area, Utah Lake water still irrigates thousands of acres of farmland in Utah and Salt Lake Counties.

Utah Lake experiences extremely high phosphorus (P) and nitrogen (N) loadings. However, the actual in-situ values of P and chlorophyll-a when used in the Carlson Index (Carlson, 1977) indicate the lake is only moderately eutrophic (Merritt and Miller, 2016). Ecologically speaking, a eutrophic body of water is one rich in nutrients and so supports a dense plant population (OED, 2018; Utah Lake, Lake Reports, date unknown). A eutrophic body of water can be very healthy, resilient and robust, naturally removing harmful substances and supporting rich natural habitats and an abundance and large variety of flora and fauna.

Utah Lake supports heavy algal growth and also experiences periodic algal blooms, sometimes with troublesome levels of cyanobacteria. This is particularly the case when the natural turbidity of the lake is less during calm periods of several days or more. Sometimes cyanobacteria produce toxins either while thriving or in decomposition after their short lives.In extreme cases these toxins can kill fish and other wildlife and can harm people as well. As a

result, regulators often seek ways to prevent toxic algal blooms. A method that works in some bodies of water is reducing nutrient inputs. This may be the case in many bodies of water, but for Utah Lake some experts conclude that even if there were no wastewater discharges to Utah Lake, there is far more than enough N and P from other uncontrollable sources for the lake to stay eutrophic (Merritt and Miller, 2016). The amount of Atmospheric Deposition (AD) nutrients to the lake is one of the key factors in these considerations.

Both N and sunlight are available in excess of phytoplankton growth requirements and do not limit growth in most reservoirs. Masaki Sagehashi, a Professor of Engineering at Hiroshima University (and many others) declared that the only way to control algal blooms today is through P removal (Sagehashi, 2001). For well over sixty years, P has been at the forefront of limnologic and hydrobiological research in limiting organic matter production and in causing eutrophication (Dévai et al., 1988; Rigler, 1956).

Critical levels for inorganic P have been established near 5 µg/l (0.005 mg/l) (Sawyer, McCarty and Parkin, 2003). In 1975, from the Eutrophication and Lake Restoration Branch at the EPA, David Larsen (Larsen and Mercier, 1975) submitted that in the summer months available P in excess of 10 µg/l or TP in excess of 20 µg/l are likely to produce "noxious blooms of algae."

I gathered and tested soil samples with P-fractionation methods to better understand the nutrients in soils around the lake. This portion of the study was to discover the composition of the soil likely to be a source for the P in Utah Lake. The soil P-fractionation provided results in water soluble P (WSP), loosely-bound P (LBP), aluminum & iron-bound P (AFBP), calcium-bound P (CBP) and residual P (RP). A separate soil TP test was also performed on the soil

samples. These are completely separate tests than those performed on AD samples for soluble reactive phosphorus (SRP), TP, N from nitrate, and N from ammonium.

Atmospheric N transport has long been studied, but P has been considered a minor constituent in atmospheric studies (Anderson and Downing, 2006). This is appearing to be a serious oversight for short range transport. Increasing evidence is building that airborne P has a large impact on our water (Stockdale et al., 2016) and several studies allude to the need to measure the AD of P (Ahn and James, 2001; Cole, Caraco and Likens, 1990; Jassby et al., 1994; Kopàček et al., 2011; Peters, 1986).

In 2018, Jacob Olsen undertook the initial study of the AD of P and N into Utah Lake (Olsen et al., 2018). This study is in part a continuation of that research, though with some changes and improvements. Olsen estimated that on the high end approximately 350 tons of total phosphorus (TP), and 460 tons of dissolved nitrogen (DN) entered the lake during the period of sampling in 2017 (Olsen et al., 2018).

The AD of P has not been given much attention. Recent research suggests that atmospheric P deposition can be a significant source for many ecosystems, especially when considering loads on shallow lakes (Olsen et al., 2018; Zhai, Yang and Hu, 2009). Some studies have shown that the greater the distance is from the shoreline the less deposition occurs, but these same studies demonstrate that P from the atmosphere can reach 50-fold to 70-fold more P than that deposited by streams (Cole, Caraco and Likens, 1990), particularly when there is a great deal of P in the geology/geography around the affected body of water. However, as the nutrients reach the lake, they spread well, despite the lakes' relatively large shoreline ("Utah Lake, Lake Reports", date unknown). Utah Lake is a cold polymictic lake, meaning (with the exception of the coldest weeks of the year) there is a great deal of mixing throughout the lake.

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Over 50 years ago scientists recognized that the climate around the lake was drier than it used to be (Varnes, Hunt and Thomas, 1953), and this makes wind erosion more likely (Bullock, 2005). Particularly from the south and the west, dust is often blown by strong winds towards the lake. Occasionally there is visible soil in the AD samples collected. A recent study initiated the sampling of nutrients from the current lakebed (Abu-Hmeidan, Williams, and Miller, 2018) but this study focuses on external sources.

2   METHODS

2.1   Soil Fractionation Analysis

2.1.1   Sampling

Measurements of soil were obtained using the procedures as outlined in the "Field Book for Describing and Sampling Soils" (Schoeneberger, Wysocki and Benham, 2012) together with the US Department of Agriculture's Soil Survey Manual (Soil Science Division, 2017). Chapter 5 of the latter discusses the SCORPAN Model for soil mapping. This method suggests paying close attention to soil, climate, organisms (any plants/animals affecting soil), relief (the slope of the land around a site), parent material, age and location. This was used as a guide in identifying proper sampling sites to reduce error or false conclusions. For example, no samples were taken from corrals/pastures because this would not be representative due to the high amount of "organism" activity affecting the soil.

Samples were taken from locations most likely to represent soils affecting the lake. For example, sample 29 was taken from a large sand dune (likely producing a great deal of airborne particles) and sample 27 was taken from higher on the hillside at 5400 ft, likely untouched by agriculture. Sample 32 was taken from farmed terraces that take up approx. 1200 acres on the west side of the lake. The locations sampled are shown in Figure 1, and listed in Tables 5 and 6 in the Appendix.
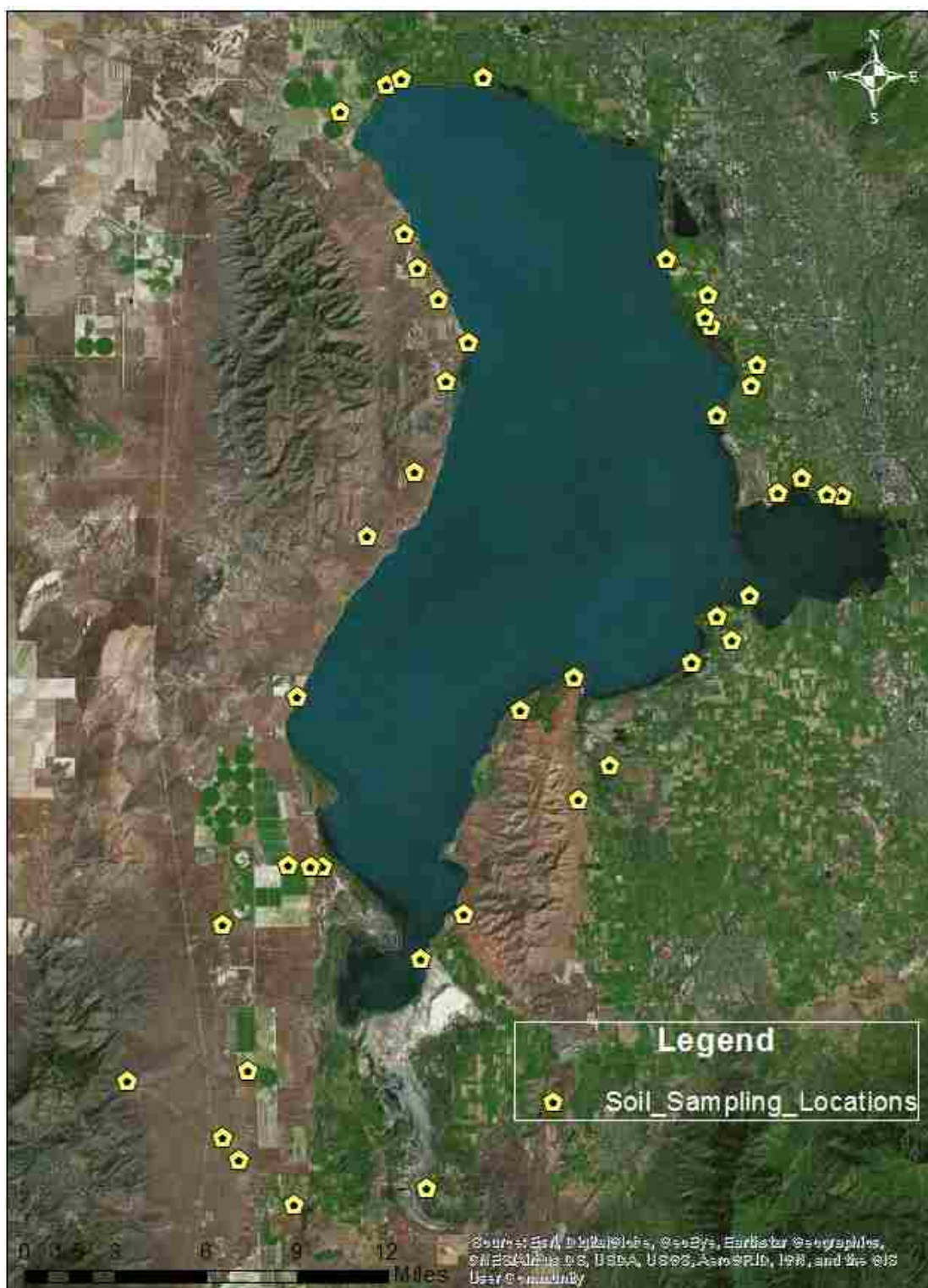
Figure 1: Locations of soil sampling for fractionation

A stainless steel "Oakfield Model HA 19" Tube Sampler (Figure 2) was used to take the samples either at the surface, or 6 to 12 inches down (see subscript in Table 5 in the Appendix). Samples were placed in 500 mL bottles (Figure 3), and soon after placed in a refrigerator.

Figure 2: Depiction of Oakfield Model HA 19 Tube Sampler used in soil sampling

Figure 3: Sample bottles with soil for phosphorus fractionation

2.1.2   Lab Procedures

The methods in the article by Moore and Coale "Phosphorus Fractionation in Flooded Soils and Sediments" (Moore and Coale, 2009), were slightly adapted for use by the Brigham Young University Environmental Analytical Laboratory (EAL), and the EAL methods were followed closely. Some modifications had to be made as the ICP-OES Plant Method (Inductively Coupled Plasma Optical Emission Spectroscopy Plant Method), which uses light waves to detect which elements are in the sample, requires a dissolved solids content to be less than 3%. The method to discover LBP requires the use of the soluble salt, KCl, which remained in the liquid during the centrifuging prior to the ICP-OES testing. The samples had to be diluted to 1/10 of the original then re-processed; this was enough for the ICP-OES to complete testing.

The method used involved adding 20 mL each of first water, then KCl, then NaOH, and finally HCl to one gram of a sample (using the same 1 gram portion of the sample throughout). Shaking the samples on the shaker for one hour, then two hours, then 16 hours, and 24 hours, respectively. I centrifuged the samples at 80 rotations per second for 10 minutes, then filtered the supernatants through 413 filter paper (pore size, 5 μm). 454 filter paper (pore size, 10 μm) is called for but was not available, see section 4. They were then measured the available P on the ICP-OES.

For the residual P and separate soil TP, I mixed 0.1 gram of dry sample with 10 mL nitric acid and ultrapure water to make 25 mL of solution. I then used a pressure microwave digester to completely break down the samples and tested them on the ICP-OES.

2.2   Atmospheric Deposition

2.2.1   Sampling

Measurements of AD were taken using the same methods as the sampling done in 2017 (Olsen et al., 2018) from the "Review of deposition monitoring methods" (Erisman et al., 2017). The sampling was continued from that of Olsen the first week of April, 2018. It was done weekly when possible, until the coldest months of the year (Tables 8 thru 11). Due to decreasing amounts of deposition, sample gathering was reduced to every other week.

There are 5 sampling sites around Utah Lake (Figure 4):
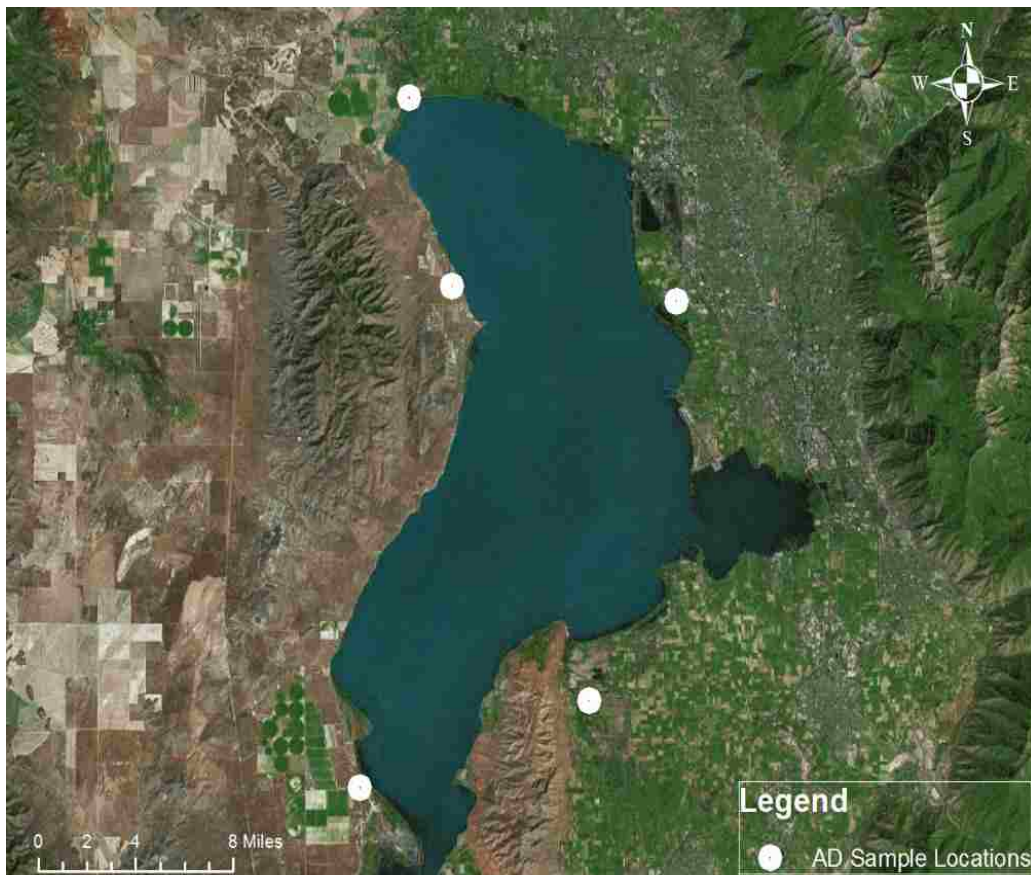
Figure 4: The five AD sampling locations around Utah Lake, ArcGIS

- Orem Waste Water Treatment Plant (O) (40.27595, -111.7372) is 40 ft south of a shed. There is a parking lot just north and east of the shed. There is an old, unused asphalt road 20 ft west of the sampler, and the sampler rests on the northern end of a vacant field with little plant growth. The entire site is located within a light industrial area in Orem.

- Lakeshore/Lincoln Point (LS) (40.11291, -111.78893) is on the southern edge of a property with light farm traffic. On August 18, 2018 it was relocated to more than 100 ft further away from that light traffic. To the south is a large open field with light brush, and there is a wetland just to the east with several large migratory birds from early spring to fall.

- Mosida (M) (40.07712, -111.92574) is surrounded by a large, scattered brush field. In 2017 and until August 18, 2018, it was located approximately 140 ft from the nearest road. At that time, it was moved to a more distant location some 500 ft from that road, and over 1100 ft from center pivot sprinkler irrigated fields.

- Saratoga Springs (SS) (40.28234, -111.8706) is located south of the city at the edge of a property (abandoned since late summer of 2018), approximately 500 ft from the highway. A small dirt road leading to the property is rarely used. There are small structures just over 50 ft away to the south, east and north. A large unused field borders the site on the south and west.

- Utah Lake Pump Station (PS) (40.35931, -111.8963) is perhaps the least representative site for Utah Lake for "global" AD due to the thick phragmites just under 10 yards away on two sides. Small particles from the plants occasionally

enter the samples, though the plants likely mitigate construction dust from local

housing developments. It is the closest site to the actual lake.

There are also 2 sampling sites near Farmington Bay for comparison (Figure 5):
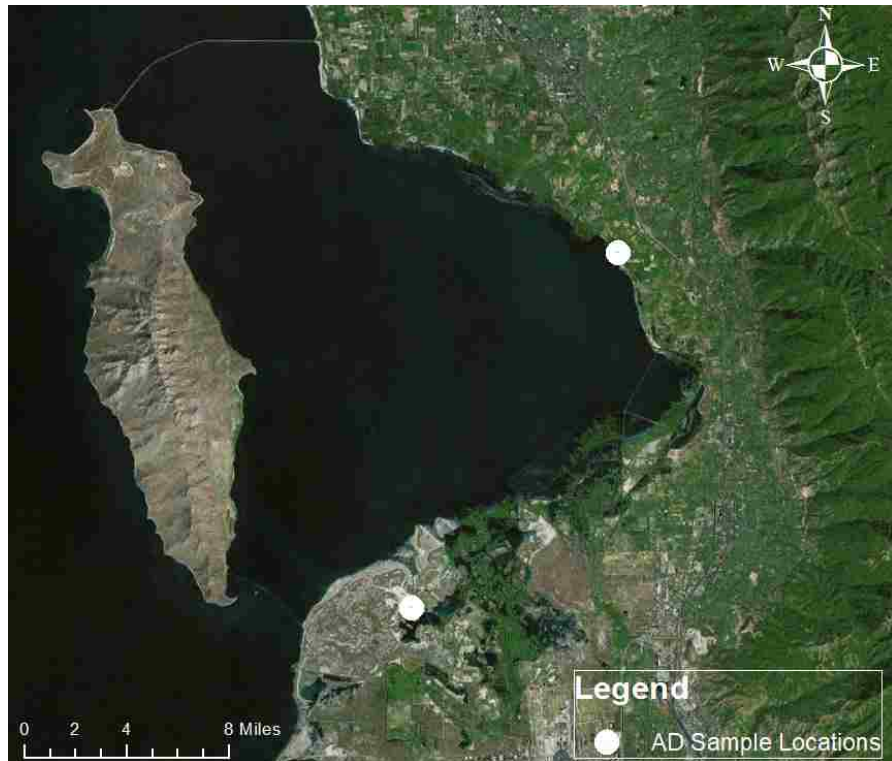
Figure 5: The two AD sampling locations around Farmington Bay

- Central Davis Water Reclamation Facility (CD) (40.9991, -111.95135) is located

  on a large berm of soil lakeside of the water treatment facility in Farmington. It is

  bordered by well-watered fields to the east and wetlands to the west. It stands next

  to a dirt road that occasionally receives light traffic.

- Browns Island (BI) (40.8466, -112.06777) is located just southeast of Antelope Island on the southeast corner of the Great Salt Lake. It is on a slight berm above the wetlands just outside of the West Crystal Unit of Farmington Bay. Though the sampler at CD did not collect from May to July and that at BI wasn't collecting until September, the rest were fairly consistent.

The samplers consist of two 2-gallon buckets placed on a steel table at sites described in figures 4 and 5. To clean the sample buckets I scrubbed them with Phosphorus-free detergent and rinsed them with deionized (DI) water. I then soaked the buckets in an acid bath for at least 24 hours before setting them upside down on clean paper towels to dry. After drying, the wet AD bucket is placed as is on the table to collect rain water from the storms affecting Utah Lake (Figure 6). The dry AD bucket is filled with three liters of water (four during the hottest months of the year to reduce sample loss due to evaporation) to retain soil and dust particles deposited. The sample buckets remain, collecting dust and soil from the atmosphere (Figure 7) for the sampling period (Tables 8 thru 11). After they are gathered from the field, a 500 mL representative sample is taken from the dry deposition bucket, and the wet sample is combined with DI water to add up to a complete 500 mL sample. The 500 mL samples are then taken to the lab to be tested.

For the first six weeks into the official sampling for 2018, a well distributed sample was taken from the bucket, then any insects were filtered out during the lab testing process. Afterwards, the insects were carefully removed before being taken to the lab. To do so, I used an acid-washed, and DI water rinsed, plastic screen (while wearing acid-washed, and DI water rinsed, nitrile gloves) to scoop the insects from any sample that contained insects.

Figure 6: Photo of wet AD over Utah Lake, photo credit Tanner Risk, Summer 2018.

Figure 7: Sampler at Mosida, facing north, smoke over lake in background, example of table with buckets.

2.2.2 Lab Procedures

Methods used in the testing of AD samples are found in the 2005 Western States Method Manual (Gavlak, 2005) and were carried out by the Brigham Young University Environmental Analytical Laboratory (EAL).

When the samples arrive at the lab, if they appear clean, they are immediately tested for NO_3 and NH_4 straight from the bottle, otherwise they are filtered through a 0.45 micron filter first. For SRP, 20 to 25 milliliters are filtered through a 0.45 micron filter with a syringe, then mixed with one milliliter of "Reagent B" (see solution details at end of section). The sample is then analyzed with the spectrophotometer at 880 nanometers, with DI water and "Reagent B" for a blank. The resultant absorbance times 1.5 gives the milligrams per liters of SRP in the water sample.

For TP, 20 ml of sample are combined with 3 ml of nitric acid and pressure microwaved to denature proteins and break down the solids of the sample, then the samples are tested on the ICP-OES.

Making "Reagent B": Dissolve 0.02908 grams of antimony potassium tartrate in 10 ml of distilled water. Dissolve 1.2 grams of ammonium molybdate in 25 ml of distilled water. Make 100 ml of 5 N $H2SO4$ by adding 14.1 ml of concentrated $H2SO4$ to water and bringing to a volume of 100 ml. Add these three solutions together and bring to a volume of 200 ml with distilled water. Dissolve 1.056 grams of ascorbic acid into solution. Solution is light sensitive so must be made on day of use.

2.3 Statistics/Calculations

2.3.1 External Influences

As this was an observational study (as opposed to a lab experiment) it was impossible to remove the many external influences affecting the data. For example, if there was very little precipitation this year, there would be fewer wet days where the wind would not be able to lift the dust off of the ground, thus there would likely be more dry AD into the lake. If this occurred though, there would likely be less nutrients entering the lake from runoff, but there is no good way to measure these.

2.3.2 Soil Fractionation Analysis

Of the 49 soil samples gathered (Figure 3), only 42 were used, because of various sample issues (Figure 8). I removed those soil samples that would likely contribute the least to our knowledge of what is entering the AD samplers and retained the soil samples that would best contribute to the aims of the study. The first soil sample removed was chosen because, after the sampling was completed, it was discovered that this soil was not natural and an insignificant percentage of the region and thus not representative (or likely valuable for this study). The other 6 soil samples that were removed were chosen because, after analysis of their location and their appearance they appeared likely to never produce any AD downwind (for example, a bog with thick phragmites) (Figure 9). Blanks and four duplicates were used throughout the testing for validation.
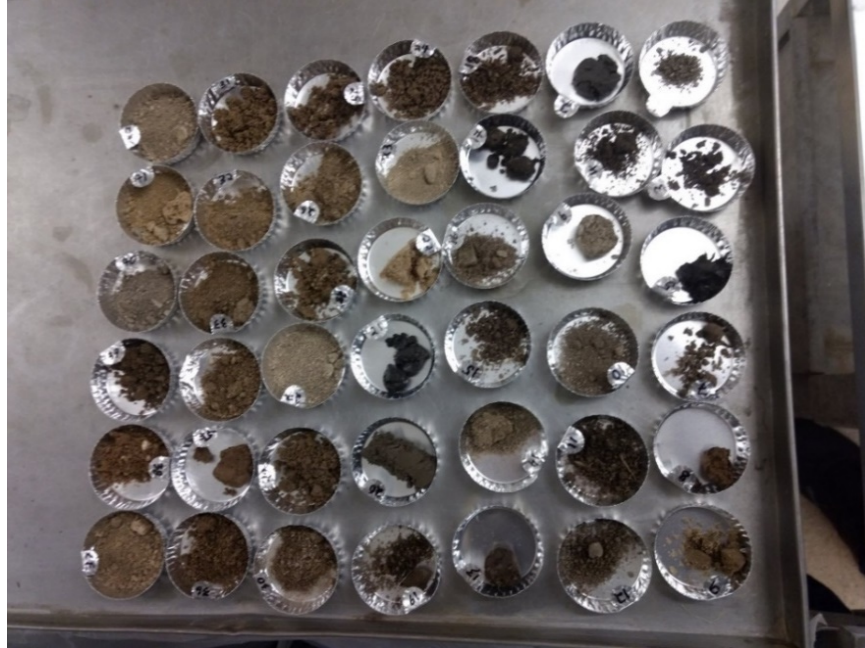
Figure 8: Soil samples weighed and prepared to be dried out to find moisture content

Figure 9: Samples from east of the lake removed before testing, for best results

2.3.3 Atmospheric Deposition

I ran a Kruskal-Wallis Test to assess the variability of the means for the AD data. I used this test because it does not require normality and it is resistant to outliers (which are present in the data due mostly to large storm events/local forest fires (Figures 10 and 11)).

Figure 10: Photo of smoke over Utah Lake, during spike in September 2018

Though a portion of the deposition is global (from sources a great distance from the samplers themselves), the sites are expected to each be different and represent local transport because of local wind patterns (Figure 12), climate, and soil sources.

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Figure 11: Photo of smoke over Utah Lake, blocking the sun, during spike in September, 2018

Figure 12: Example of haze from dust blowing across lake, likely from southwest, taken from Lincoln Point, photo credit google

I discovered algae in several AD samples which means that in less than a week airborne phytoplankton can be deposited in the samples and begin growth. This means the results for both

P and N levels will be somewhat lower than the actual nutrients deposited in these samples as the nutrients were used by the phytoplankton.

Since ammonium gets converted to nitrate by bacteria, I ran a test comparing ratios of N from ammonium (Am-N) to N from nitrate (N-N) and the respective times it took driving from the sample sites to the lab. Some samples spend only a few minutes in transit to the lab and others, over 8 hours. A bivariate fit of the Ratios of NO_3 to NH_4 in any sample versus the time in returning to the lab is shown in Figure 32 in section 3.2. The greater the magnitude in slope on this chart, the greater the effect of time-in-transit has on rates of Am-N and N-N.

2.3.4   Interpolating Atmospheric Deposition Data across the Lake

In the 2017 study by Jacob Olsen, the simple kriging method was used via Aquaveo's GMS to interpolate data across the lake (Olsen et al., 2018). This method appears to offer good approximations. It is necessary to assume some loading to the center of the lake to perform this analysis, and Olsen assumed values at several locations near the center of the lake. ArcGIS offers several tools for this purpose, but all require several more data points to calculate effective interpolations. With the relatively small amount of data being gathered to understand the total AD to this large area, it seemed appropriate to perform a more general interpolation.

The method decided upon was the development of a simple mathematical model (Figure 13). For our purposes this model appears sufficient at estimating what is actually happening with the AD across Utah Lake. Its main assumptions are similarity between sample sites, a linear decrease in nutrients towards a single point of zero deposition at the center of the lake, and an average deposition used for the area of the lake lying outside of the polygon built between the sites where actual AD data is being gathered.

There are different views on the actual rate of change of deposition over a body of water. From one article on terrestrial insect availability (Norlin, 1967) some researchers hold strongly to an exponentially decreasing model while others use the same article to reason that the model should be more linear.

$$Base = Area_1 + Area_2 \qquad\qquad Area_1 = \frac{Side_1 * Side_2}{2} \qquad\qquad Hyp = \sqrt{side_1^2 + side_2^2}$$

$$Area_2 = \frac{base * height}{2} = \frac{side_3 * side_1}{2} \qquad\qquad Volume = \frac{1}{3} * Base * height$$

Height = Distance from base plane to point near center of lake
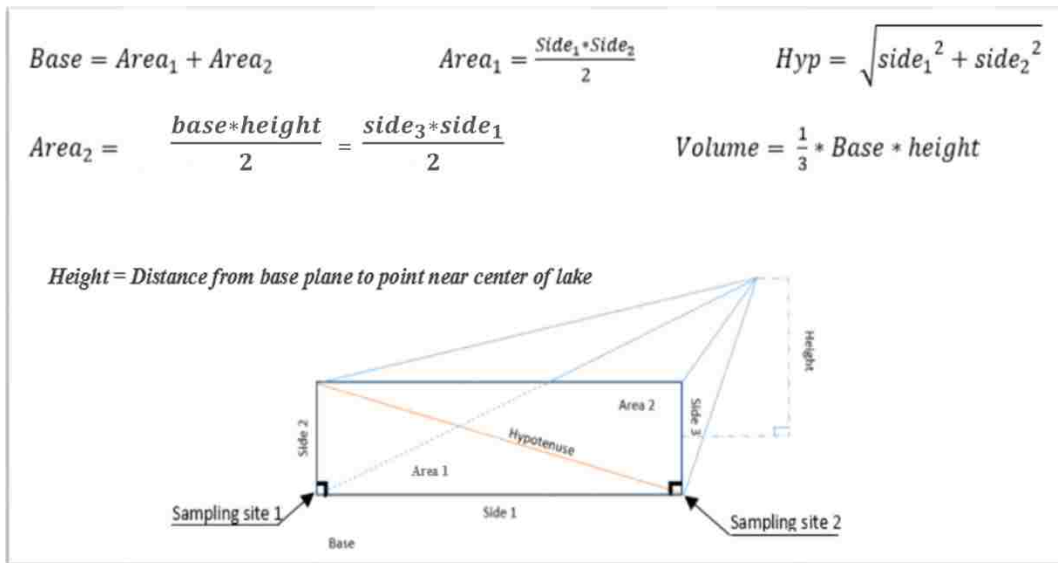
Figure 13: Basic mathematical equations to interpolate data across Utah Lake

Thomas Mehner and his team agree with an exponential model stating that they care most about insects, insect parts and debris; items that may not carry as well in the wind (Mehner et al., 2005). Others (Cusimano, 2016; Wurtsbaugh, 2007) conclude that deposition over a lake is much more constant, with the same amount of certain types of deposition occurring at the center as on the shoreline. Norlin does mention that especially during the summer months, certain altitudes can transport items globally and that as they enter the atmosphere above a lake (especially in the evenings) they decrease in altitude (Norlin, 1967). There are several factors at play and definitely

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no perfect model, but this model, linear with a single point of zero in the center, is likely an effective estimate at what is actually getting into the lake.

This model computes the volume of a sideways obtuse pyramid created between each sampling site with its tip at the center of the lake, and is repeated between each site. It projects the deposition decreasing linearly with increased distance towards the center, and is based strictly on the data gathered each week without any minimums or maximums. (Figure 13 and Table 2).

Figure 14 is a depiction of the lines used in the mathematical interpolation of the AD data across the lake. As these are only measured numbers, any extra land included can be considered equal to any equal area of lake that is excluded. Thus, for purposes of this study, we can estimate that almost 90 million square meters (approximately 25%) of the lake are not included in the interpolation data. This will be taken into account by multiplying the final values by that estimate, a factor of approximately 1.225.

As a test for this model, a very simple geometrical model was tested in parallel. A simple model assuming even deposition across the lake would include a polygon with the area of the lake multiplied by the average of the amounts deposited at each site. Since we are conservatively assuming zero at the center of the lake, this "even deposition model" is computed. Then a pentagonal pyramid with its point at the center of the lake is subtracted from this total (Table 3). Though the simpler model has shortcomings in assuming the lake has all equal sides and a normalized data set, it should approximate the more complex model. The results from the more complex model used are more conservative (Tables 2 and 3), and they should approach the actual AD numbers more closely.
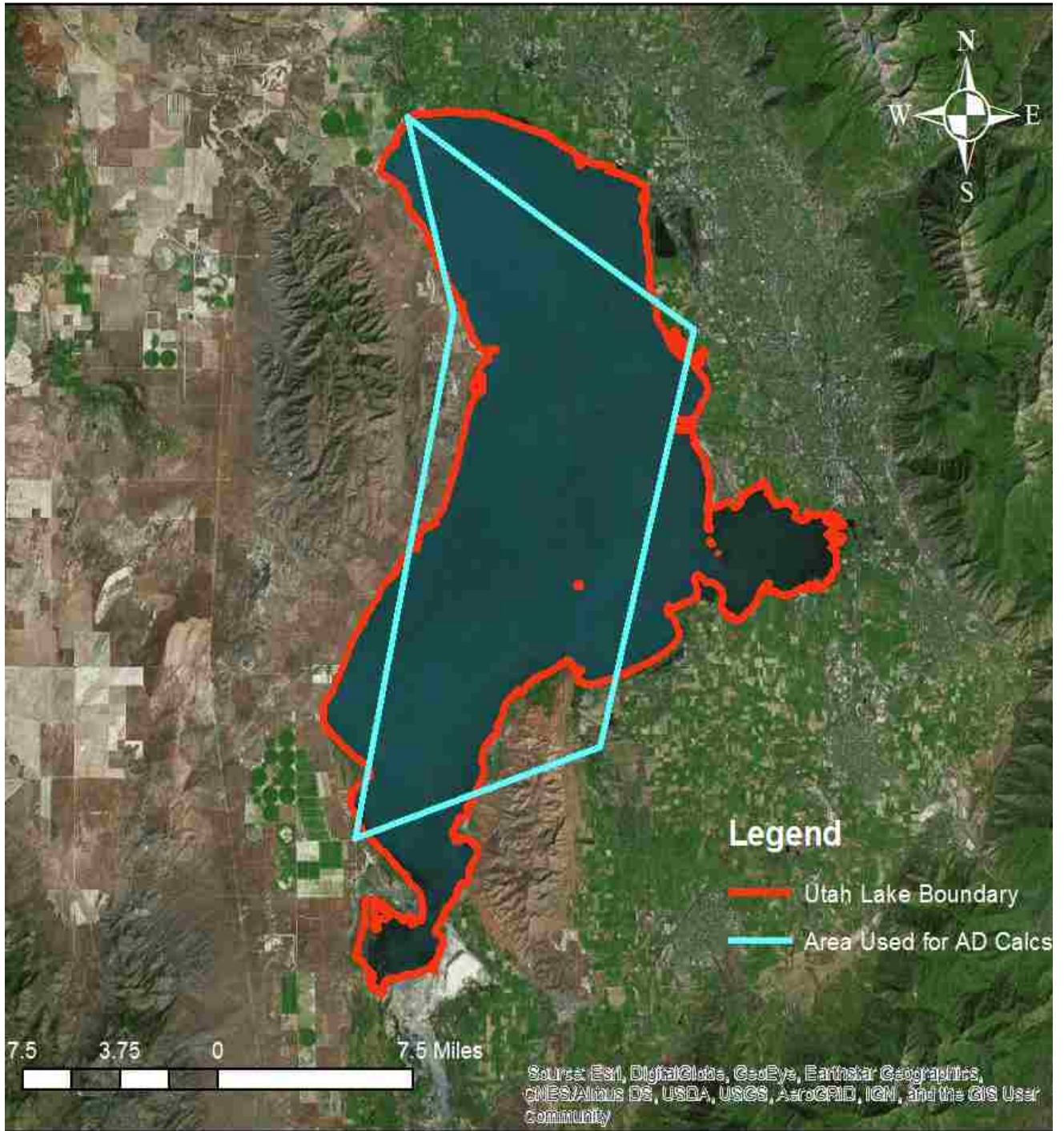
Figure 14: Graphic of boundaries for interpolation calculations for AD

3   RESULTS

3.1   Soil Fractionation Analysis

The complete P-fractionation results are in Table 6 in the Appendix, and the following statistics on the soil data are simplified in Table 1.

8 samples were randomly selected for calculating the residual P and the separate soil TP (Figure 35 in the Appendix). They give means of 294 ppm and 902 mg-P/kg soil, respectively.

Considering the soil from around the entire lake, discounting residual P and separate soil TP, we are 95% confident that any 1 gram of soil tested contains from 848 to 1307 mg-P/kg (Figure 35 in the Appendix). For residual P alone we are 95% confident that any 1 gram of soil contains between 166 and 423 mg-P/kg soil (Figure 35 in the Appendix). Thus, the TP from the fractionation would lie between 1014 and 1730 mg-P/kg soil, whereas we are 95% confident that the separate soil TP is between 684 and 1119 mg-P/kg soil (Figure 35 in the Appendix)

Of the soils tested from the west side of the lake, discounting the residual P and separate soil TP, we are 95% confident that any one gram sample of soil will contain between 740 and 1080 mg P/kg soil with an average of 910 mg/kg. Again discounting the residual P and separate soil TP, we are 95% confident that the P in this same one gram of soil will contain between 2.2 and 4.3 percent WSP (approx. 20 to 39 mg-P/kg soil), 0.6 to 1.1 percent LBP (approx. 5.4 to 10

mg-P/kg soil), 2.5 to 4.4 percent AFBP (approx. 22.6 to 40 mg-P/kg soil), and 90.7 to 94.2

percent CBP (approx. 824 to 854 mg-P/kg soil) (Figure 36 and 37 in the Appendix).

Table 1: Simplified output of data from Figures 35 thru 37 in Appendix A

95% Confidence Values from the entire study	Expected Values	Range		Units
P-fractionation -residual P	1077.5	848	1307	mg/kg
residual P	294.5	166	423	mg/kg
TP from fractionation (sum from from above)	1372	1014	1730	mg/kg
separate TP	901.5	684	1119	mg/kg
95% Confidence Values from only West of the Lake				
P-fractionation -residual P	910	740	1080	mg/kg
(Percentages from P-fractionation -residual P)				
water soluble P	3.3	2.2	4.3	%
loosely-bound P	0.9	0.6	1.1	%
aluminum & iron-bound P	3.5	2.5	4.4	%
calcium-bound P	92.5	90.7	94.2	%
(Values based on Percentages in mg/kg)				
water soluble P	29.6	20.02	39.13	mg/kg
loosely-bound P	7.7	5.46	10.01	mg/kg
aluminum & iron-bound P	31.4	22.75	40.04	mg/kg
calcium-bound P	841.3	825.37	857.22	mg/kg

A two-sided t-test on the 8 samples between the TP-fractionation and the separate soil TP

is shown in Figure 15. The results of this test offer evidence that these paired values are not

statistically equal to each other when theoretically they should be.

This difference may be due to imperfect shaking that may not have released all of the P it

was designed to release, incorrect filters with 5 µm openings instead of the 10 µm that the test

calls for, and incomplete sealing for the pressure chambers during the microwave portion of the

fractionation (after the pressure microwave portion, the samples still has small granules which means the P may not have been fully released to be measured). See section 4.1 for details.

Matched Pairs
Difference: Separate TP-SUM P

Separate TP	901.574	t-Ratio	-3.92567
SUM P	1169.25	DF	7
Mean Difference	-267.68	Prob > |t|	0.0057*
Std Error	68.1859	Prob > t	0.9971
Upper 95%	-106.44	Prob < t	0.0029*
Lower 95%	-428.91		
N	8		
Correlation	0.81036		

Wilcoxon Signed Rank

	Separate TP-SUM P
Test Statistic S	-18.000
Prob>|S|	0.0078*
Prob>S	0.9961
Prob<S	0.0039*
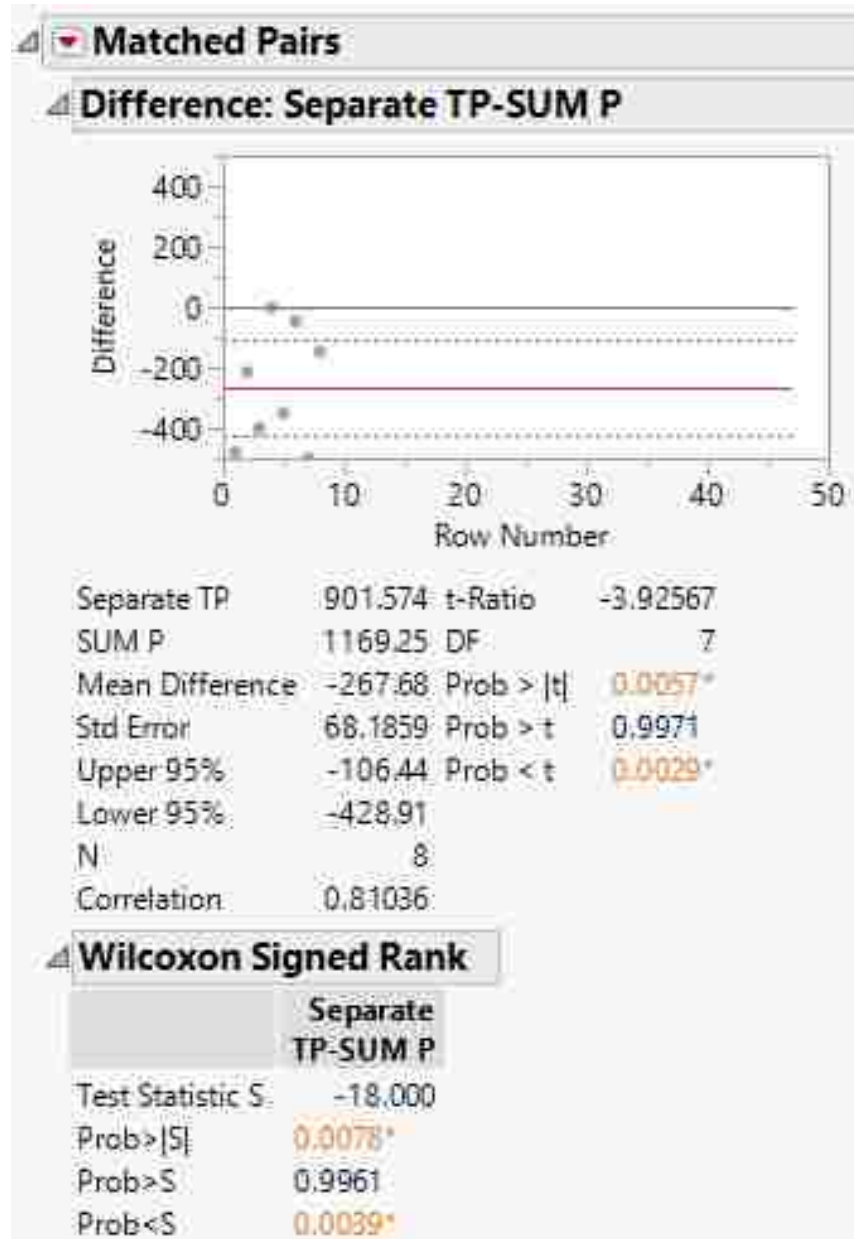
Figure 15: Two-sided t-test for sum of P-fractionation portions (WSP) and separate soil TP, via JMP, statistical software

3.2 Atmospheric Deposition

Table 2 displays the estimated AD from April to November of 2018.

Table 2: Total AD results for entire lake for 7.5-month sampling period

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

Table 3 displays the results from the simplified method as discussed in section 3.3.4 performed as a check to the model actually used (Table 2). The locations were normalized, and the weekly AD results were averaged thus simplifying the calculations needed to estimate the total AD. The two methods give results that are very close. They are completely separate geometric methods yet only vary from 0.94% to 1.01%.

Table 3: Total AD estimate for entire lake based on simplified geometric methods

Soluble Reactive Phosphorus	58.9	Tons
Total Phosphorus	162.0	Tons
Nitrate-Nitrogen	123.6	Tons
Ammonium-Nitrogen	382.5	Tons

Table 4 depicts the totals and weekly averages of AD by site. The totals for BI and CD are significantly lower because there were fewer weeks where measurements were taken at those

sites (10 and 23 respectively). LS had 30, PS 32, M 32, SS 32, and O 32. And Figure 20 shows comparisons of nutrients deposited by site, for 2017 and 2018.

Table 4: AD Totals and weekly averages over sampling time period

	Soluble Reactive Phosphorus				mg/m^2		
Site abbrv.	BI	CD	LS	M	SS	PS	O
7.5 Month Totals	10.1	44.0	249.9	336.8	412.9	94.6	71.0
Weekly Average	1.26	2.20	7.81	10.52	2.22	2.96	12.90
	Nitrate-Nitrogen			mg-N/m^2			
Site abbrv.	BI	CD	LS	M	SS	PS	O
7.5 Month Totals	107.9	287.6	410.5	468.9	418.2	562.0	556.9
Weekly Average	13.49	9.92	14.16	16.17	14.42	19.38	19.20

Table 4: AD Totals and weekly averages over sampling time period, continued

	Total Phosphorus			mg/m^2			
Site abbrv.	BI	CD	LS	M	SS	PS	O
7.5 Month Totals	41.3	96.0	586.9	763.2	1362.0	284.1	168.5
Weekly Average	5.16	3.31	20.24	26.32	46.97	9.80	5.81
	Ammonium-Nitrogen			mg-N/m^2			
Site abbrv.	BI	CD	LS	M	SS	PS	O
7.5 Month Totals	248.4	701.8	1788.2	2093.8	1290.5	696.8	1695.8
Weekly Average	31.05	24.20	61.66	72.20	44.50	24.03	58.48

The AD outliers are included with the rest of the data because they came during large storm and high-wind events, and sometimes during large local forest fires as well (Figures 10 and 11). They are significantly different than the other weeks during the year, but they are the results we need to understand the AD numbers affecting Utah Lake. They bring critical information needed for this study, and for policy making moving forward. The daily depositions by site and nutrient in mg/m2 are shown in figures 17 thru 24.
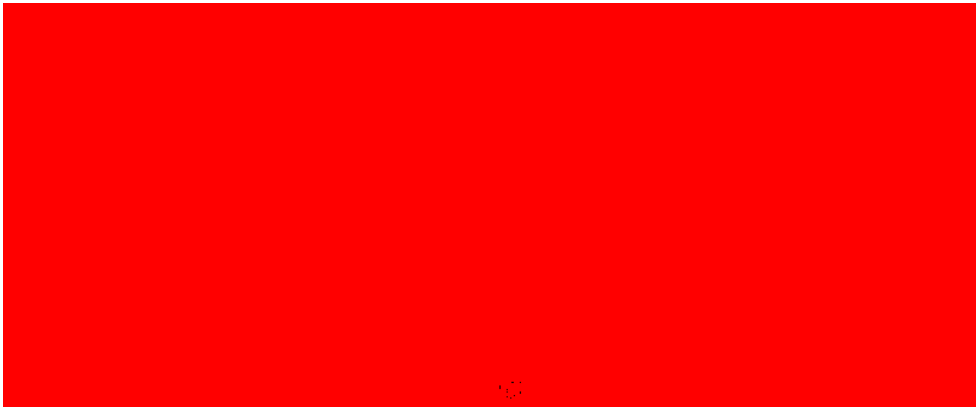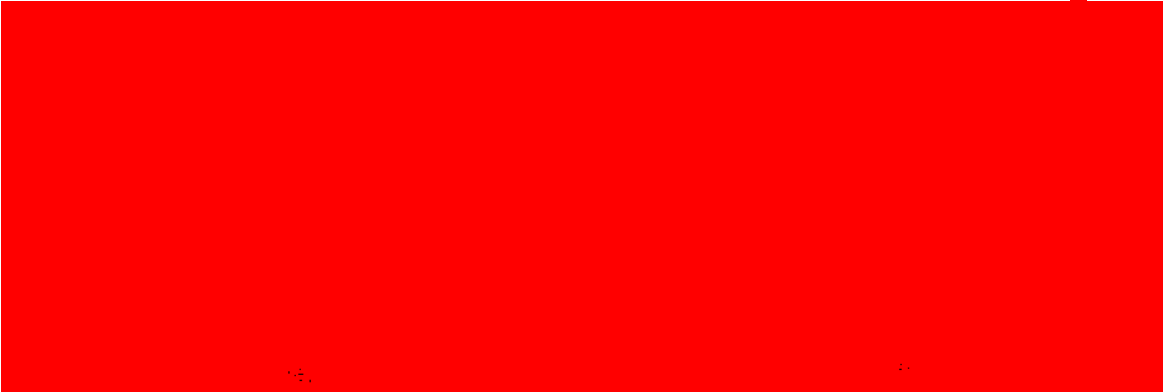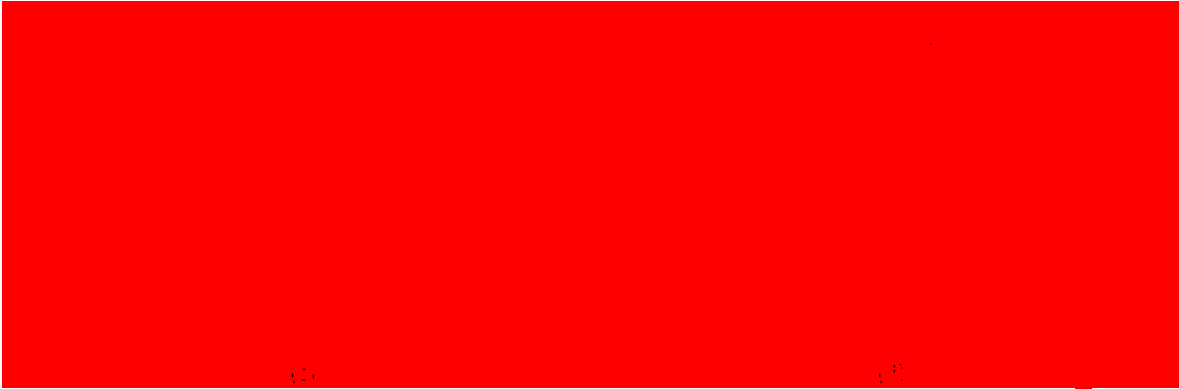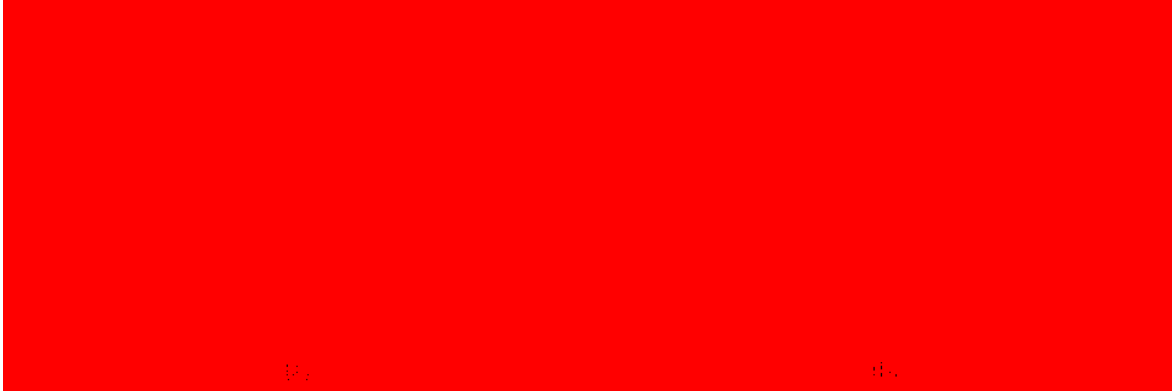
Figure 16: Weekly AD numbers for 2017 & 2018, with and without Saratoga Springs 2017
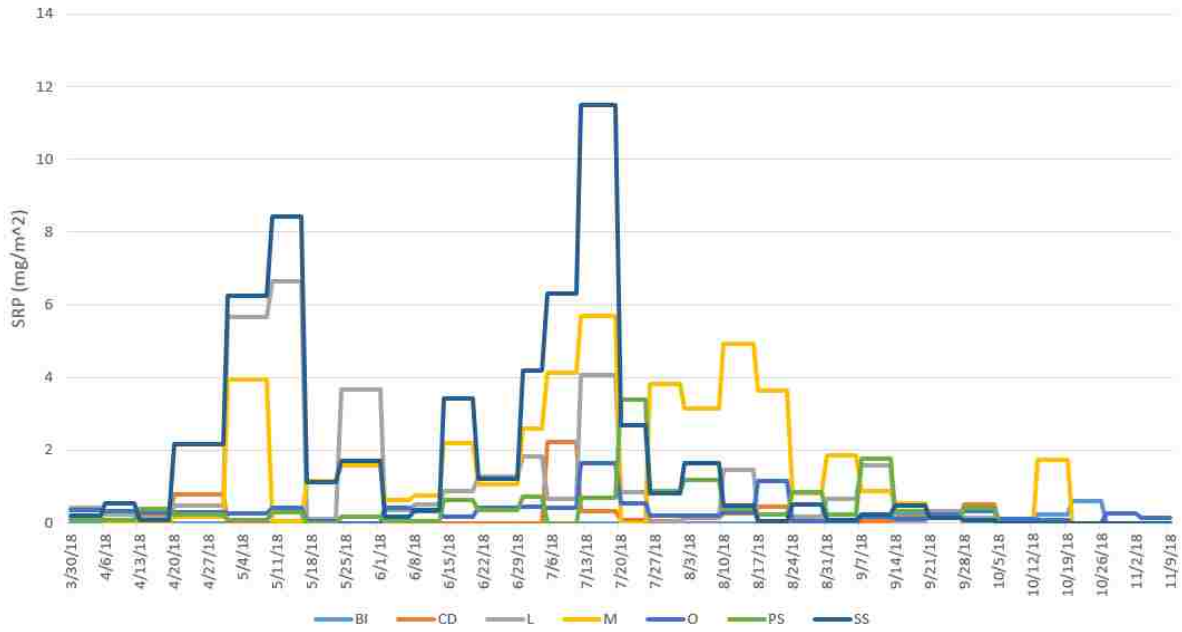
Figure 17: Daily SRP deposited in mg/m^2 by site, during sampling period
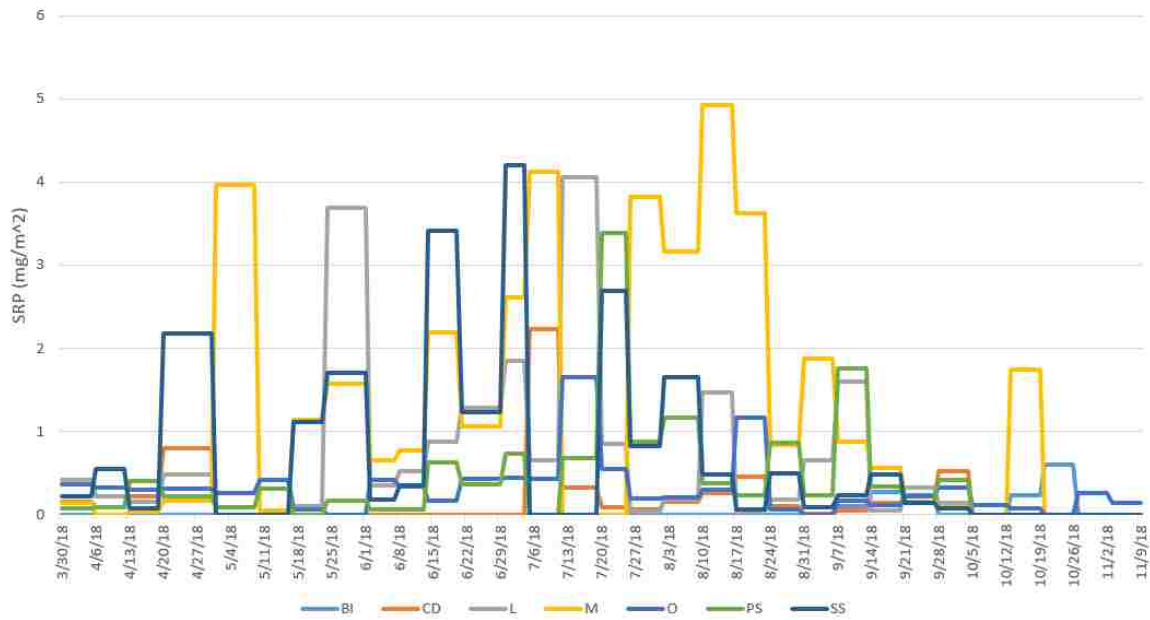
Figure 18: Daily SRP deposited in mg/m^2 by site, during sampling period, with values above 5 mg/m^2 removed
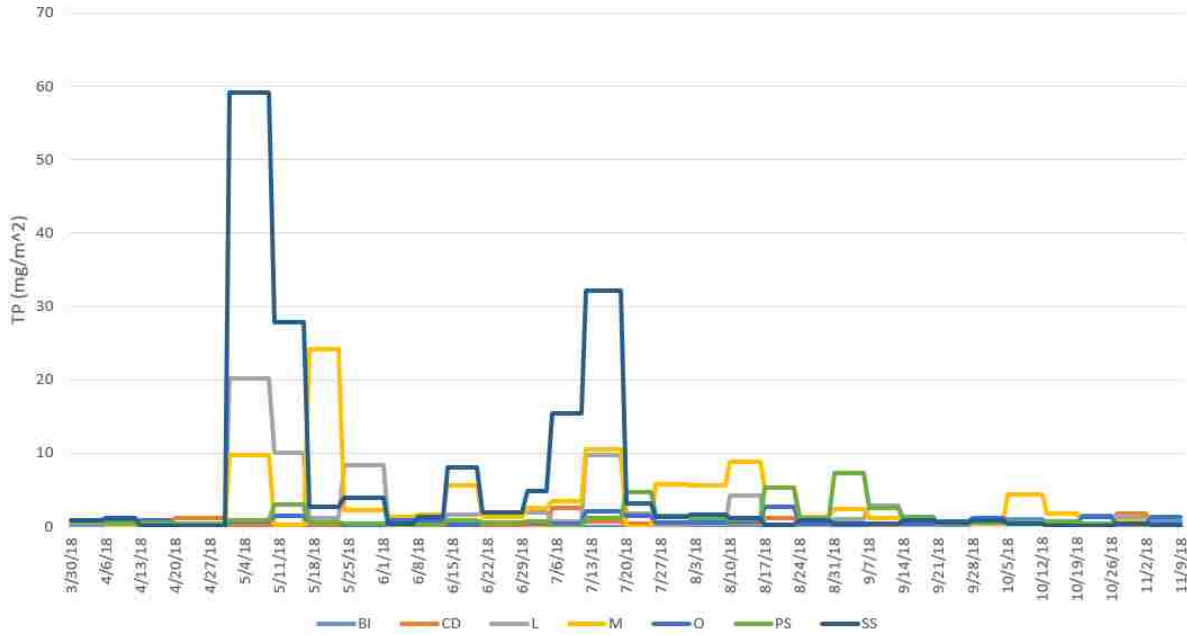
Figure 19: Daily TP deposited in mg/m^2 by site, during sampling period
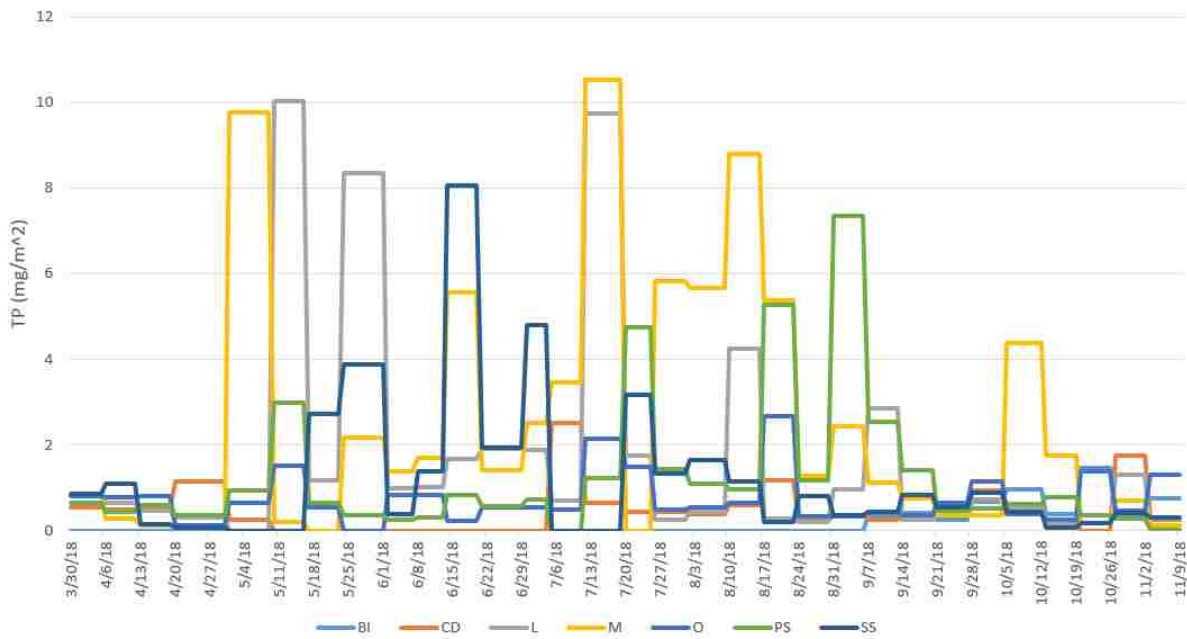
Figure 20: Daily TP deposited in mg/m^2 by site, during sampling period, with values above 11 mg/m^2 removed
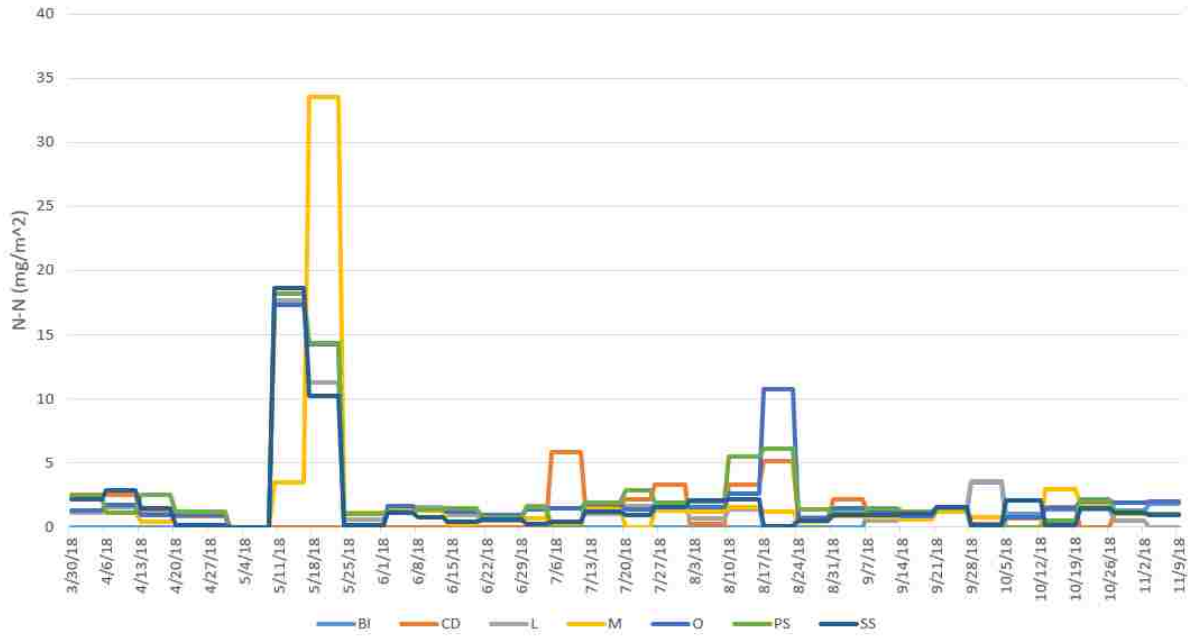
Figure 21: Daily N-N deposited in mg/m^2 by site during sampling period
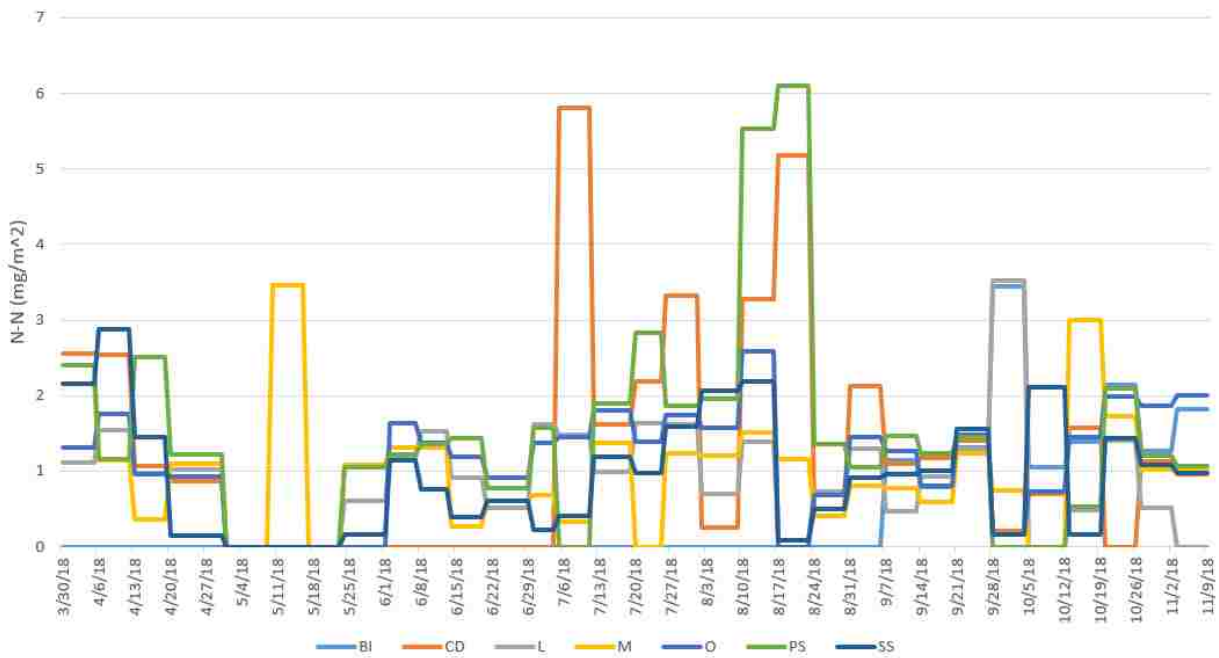
Figure 22: Daily N-N deposited in mg/m^2 by site, during sampling period, with values above 7 mg/m^2 removed
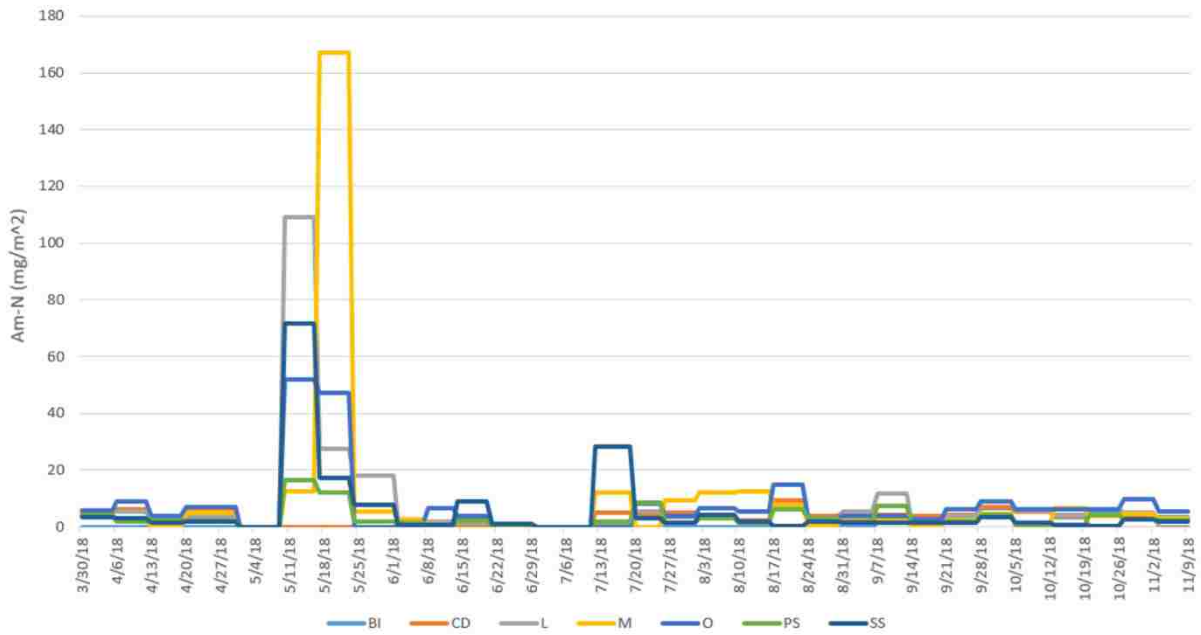
Figure 23: Daily Am-N deposited in mg/m^2 by site, during sampling period
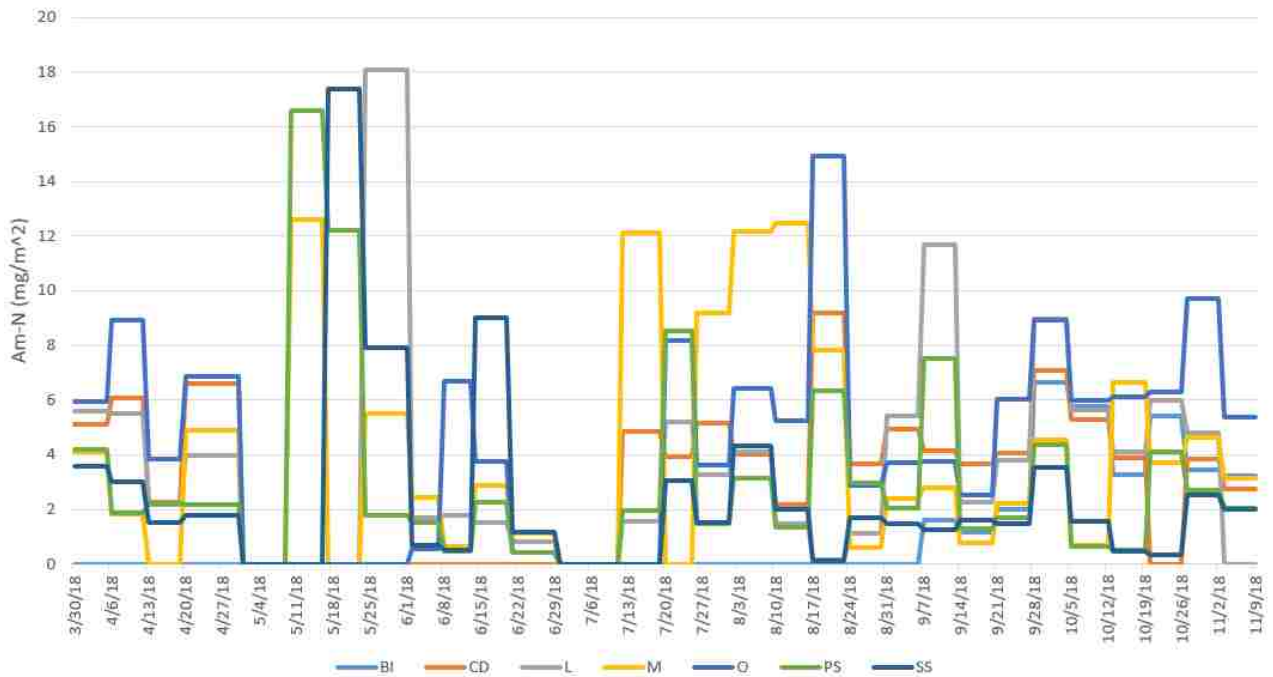
Figure 24: Daily Am-N deposited in mg/m^2 by site, during sampling period, with values above 20 mg/m^2 removed

Figures 25 thru 27 are visuals from JMP statistical software taken from July to the end of the year in order to compare the most data with the most sites and to test the median AD. The chi-square approximations for the Kruskal-Wallis Test are insignificant for SRP AD with a p-value of 0.398 (Figure 25), for TP with a p-value of 0.178 (Figure 26), and for N-N with a p-value of 0.143 (Figure 27). If the p-values were below 0.05 then we could assume the sample sites are significantly different and that the AD is largely from local sources. Since they are not, we cannot draw any conclusions.

Oneway Analysis of SRP By Sites

Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Expected Score	Score Mean	(Mean-Mean0)/Std0
CD	19	840.000	1073.50	44.2105	-1.824
L	17	982.000	960.500	57.7647	0.172
M	19	1288.00	1073.50	67.7895	1.675
O	19	1076.50	1073.50	56.6579	0.020
P	19	1064.50	1073.50	56.0263	-0.067
S	19	1077.00	1073.50	56.6842	0.023

1-Way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
5.1466	5	0.3982

Figure 25: Wilcoxon/Kruskal-Wallis Results SRP July – November

Oneway Analysis of TP By Sites

Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Expected Score	Score Mean	(Mean-Mean0)/Std0
CD	19	855.000	1092.50	45.0000	-1.802
L	19	953.000	1092.50	50.1579	-1.057
M	19	1327.00	1092.50	69.8421	1.779
O	19	1044.00	1092.50	54.9474	-0.365
P	19	1247.00	1092.50	65.6316	1.171
S	19	1129.00	1092.50	59.4211	0.274

1-Way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
7.6321	5	0.1777

Figure 26: Wilcoxon/Kruskal-Wallis Results TP July – November

A chi-square approximation for the Kruskal-Wallis Test for Am-N on the other hand, has a p-value of 0.0049. We are able to reject the null and state that the medians are not equal for

Am-N (Figure 28). Thus the AD for Am-N is not distributed evenly. It is likely that the sources for N from ammonium are local.

Oneway Analysis of N-N By Sites

Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Expected Score	Score Mean	(Mean-Mean0)/Std0
CD	19	1174.00	1073.50	61.7895	0.775
L	17	816.000	960.500	48.0000	-1.168
M	19	866.000	1073.50	45.5789	-1.605
O	19	1317.00	1073.50	69.3158	1.884
P	19	1199.00	1073.50	63.1053	0.969
S	19	956.000	1073.50	50.3158	-0.907

1-Way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
8.2531	5	0.1428

Figure 27: Wilcoxon/Kruskal-Wallis Results N-N July – November

Oneway Analysis of Am-N By Sites

Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Expected Score	Score Mean	(Mean-Mean0)/Std0
CD	19	1214.00	1073.50	63.8947	1.086
L	17	1039.50	960.500	61.1471	0.637
M	19	1142.50	1073.50	60.1316	0.531
O	19	1393.50	1073.50	73.3421	2.478
P	19	862.000	1073.50	45.3684	-1.636
S	19	676.500	1073.50	35.6053	-3.075

1-Way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
16.7904	5	0.0049*

Figure 28: Wilcoxon/Kruskal-Wallis Results Am-N July – November

If we rerun the Kruskal-Wallis Test with SS removed, the p-value increases to 0.1073 (Figure 29). SS has a significantly different median than the other sites. Local sources likely

affect AD of nutrients at all sites, but this test confirms that there are local Am-N sources contributing to the SS site, and likely that area of Utah Lake.

Oneway Analysis of Am-N By Sites

Wilcoxon / Kruskal-Wallis Tests (Rank Sums)

Level	Count	Score Sum	Expected Score	Score Mean	(Mean-Mean0)/Std0
CD	19	926.000	893.000	48.7368	0.310
L	17	809.000	799.000	47.5882	0.094
M	19	896.500	893.000	47.1842	0.029
O	19	1096.50	893.000	57.7105	1.935
P	19	643.000	893.000	33.8421	-2.378

1-Way Test, ChiSquare Approximation

ChiSquare	DF	Prob>ChiSq
7.6018	4	0.1073
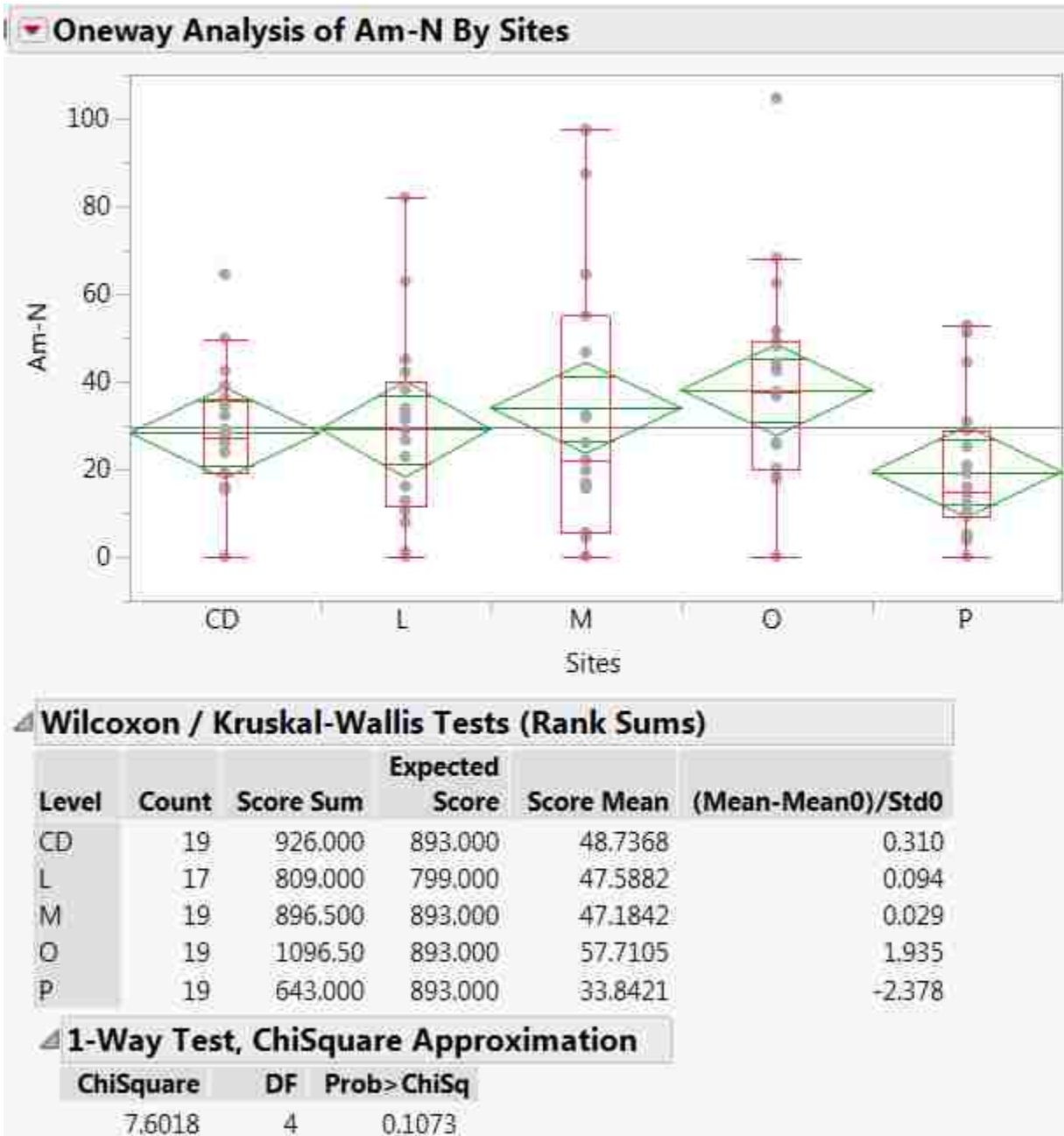
Figure 29: Wilcoxon/Kruskal-Wallis Results Am-N July – November w/Saratoga removed

Figure 30 is a visual of the results of the test for the correlation between the ratios of NO3 to NH4 versus the time the samples wait with the lid on before reaching the lab. If there were correlation, there would be a relative positive trend, but as you can see there is none. When the outliers are removed any positive correlation that does appear is minimal. Based on this result, transport time doesn't affect the quality of the samples.
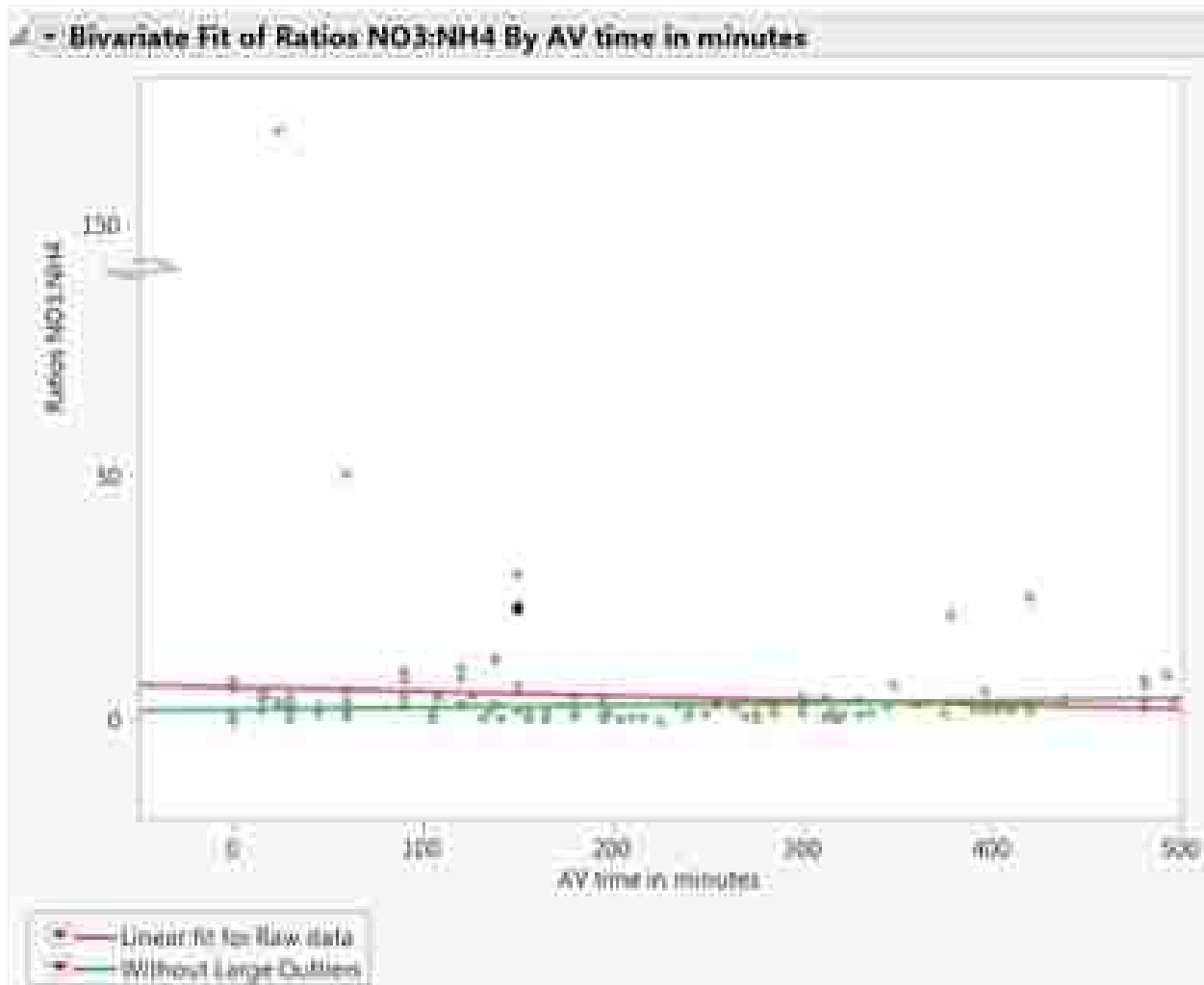
Figure 30: Bivariate Fit of $NO_3:NH_4$ by average times in transit

4 DISCUSSION

4.1 Soil Fractionation Analysis

Several precautions were taken to make sampling as representative as possible, but limited access to private lands made it impossible to sample the soil immediately affecting Utah Lake randomly. Thus, while valuable information, conclusions drawn from these data cannot be perfectly projected onto all soil around Utah Lake. With the variety of soils obtained and the locations covered, these methods are sufficient for the purposes of this study in approximating the soils that will affect the lake by AD. A complete repetition of the P-fractionation will likely provide slightly higher and more accurate levels of types of P coming into the lake with improved shaking, correct filters, and complete sealing of microwave pressure chambers.

Over 40 hours of shaking was required of the 46 soil samples tested. For the first 20 hours (the portion for testing the amounts of WSP, LBP, and AFBP in the samples) the sample tubes were placed upright rather than on their sides. This likely resulted in lower P numbers for these tests than actually present in the samples as the samples may not have mixed thoroughly, and possibly higher numbers than actual for CBP.

When samples were filtered before the actual analysis in the ICP for each test, they were filtered through "413" filter paper instead of "454" filter paper. The difference between these two is mainly size. "413" filter paper retains particles that are larger than 5 micrometers, but "454" paper only retains particles that are larger than 10 micrometers. This may have contributed

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to the gap between the totals measured directly from the soil sample and the totals combined from the several fractionation tests and the residual P because the paper that was used removed particles down to a half the size of what should have been included in the final results.

Likely the most significant error occurred with the use of the microwave pressure chamber for the residual P and the TP. The lids to the pressure chambers require extensive manual pressure with a widening mechanism to increase their rim size in order to best seal the chamber. This test is done to completely pulverize the soil into a liquid to be tested on the ICP. This did not occur as there were granules of soil still in the samples when the test was completed. The results from the ICP were very likely low, as the granules of soil were not able to be included in the testing. This may explain the largest discrepancy (Figure 15) as the separate soil TP is slightly lower than the average of the sums of the other fractionation values.

4.2   Atmospheric Deposition

The state of Utah responded to Olsen's study done in 2017 (Olsen et al., 2018) via Dr. Janice Brahney concluding, among other things, that nutrients already in the lake ecosystem are not viable sources of nutrients to the lake, and that true sources of external AD are regional. We argue, and there is research to support, that local nutrients outside of the lake, which will potentially change the lake when they enter, are necessary to consider (Brahney et al., 2015; Ellis, Craft and Stanford, 2015). We have confirmed with recent local soil sampling that there are high levels of P in the local soils (Tables 6 and 7 in the Appendix). Even if these are not true sources of long-range AD, local AD is a source of nutrients into Utah Lake, and for this paper is referred to as AD.

Even if we discounted the effects of large storms and local forest fires, the increasing concentrations of nutrients in the summer months are expected (Figures 17 thru 24). The lowering water elevations expose lake sediments to the wind and the soil outside of the lake are more vulnerable to wind erosion during the dryer summer months as well.

While it is very unlikely that birds would fly into the small buckets to have "bird baths," they can be seen in the shallows of Utah Lake and contribute nutrients to the system, most notably through their waste (Koelliker et al., 2004). Although an AD sample was taken November 2nd from LS that contained bird feces, and this sample was run to discover the contents. No SRP was found in this sample, but there was 0.15 ppm TP. When removed, this sample increased the average AD measured (since it was below average) so it was not removed and remains with the reported numbers.

While it is still unclear how to best incorporate insects into the calculations for actual deposition rates, the insects were removed from samples prior to being tested starting on June 9th, 2018. It appears that this may be the main difference between the data gathered in 2017 compared to the data gathered in 2018. Saratoga Springs had a great deal more SRP, Nitrogen from Ammonium, and TP than the other locations in 2017, and Saratoga Springs had many more insects than the others during 2018. Since the location of the site was not changed, it is likely that the amount of insects to get into the samples in 2017 was very similar to the numbers recorded in 2018. This inference is possible because it attributes the excess nutrients at Saratoga Springs to the insects. Although there are many factors at play, other than timeframe this is the main difference between the two years of sampling.

There are various opinions on how to deal with insects that are prone to get into samples. Scientists have found that insects may play a large part in a lake's nutrient budget (Mehner et al.,

2005). Thus, when studying the actual deposition into a large body of water bordered by healthy active wetlands, insects may be a large source of nutrients. Again, for simplicity, and an extra layer of conservatism, the insects were removed for a greater part of the sampling in 2018.

Not enough tests were completed for large enough numbers of the insects that were removed to determine effective averages of nutrients contained in the terrestrial or aquatic insects deposited in samples (Table 5). Thus no conclusions will be draw here.

Table 5: P and N proportions in insects removed from samples

Table 5 represents the two samples of insects that were large enough to return results, though the types of insects or exact ratio to water were not recorded.

When there were mistakes made in sampling or in the actual testing of the samples, the sample was discarded, or measured for the lesser amounts of nutrients left (for the times that parts of the samples were spilled/lost).

The caps used to seal the bucket that isn't currently collecting a sample were replaced with new, more durable caps on July 15th. The old caps were tested for nutrients with an amount much greater than any suspected to enter the samples, and were found to have insignificant amounts of all but Nitrogen from NO_3. This was still a very minimal amount, but for data taken before July 14, it is possible that some NO_3-N measurements were slightly high due to the old caps.

5   CONCLUSIONS

5.1   Soil Fractionation Analysis

The P-fractionation for the local soils around Utah Lake was performed to better understand the soils entering the AD samples and to determine the source of the AD. The results from the lab may be slightly lower than actual values, as discussed above, but they do offer some insight into the volume of P from the soils local to Utah Lake and the forms it takes as well.

The amount of TP measured from various soils local to Utah Lake give numbers not far from 1 mg/g, or 1 mg of P per g of soil (expected TP values from Table 1). This means that for every gram of local soil/dust that is deposited into Utah Lake, 1 mg of TP is deposited. Using Larsen-Mercier's estimated 20 µg/l for an algal bloom (Larsen and Mercier, 1975), considering the addition of non-submerged soils only, it would take close to 56 g of soil per square meter of lake surface area for a bloom across the entire lake (3rd row from the bottom in Figure 31).

Figure 31 uses the Larsen-Mercier's estimation for nutrients needed to cause a harmful algal bloom (Larsen and Mercier, 1975) to approximate soil needed for a harmful algal bloom to occur across the lake, if AD of local soil were the only nutrient affecting Utah Lake. For water levels on three different dates with respective approximate surface areas, the table shows calculations for an estimated soil requirement per meter of lake water and for the same amount of soil as it would be deposited in a sample bucket in the last two rows.

	May 7th	June 5th	FULL	
Elevation	4486.8	4488.1	4489	feet
Approx SA	2.9E+08	3.5E+08	3.9E+08	meters^2
Vol. Acft	664416	777605	902400	acre feet
Vol. Gal	2.2E+11	2.5E+11	2.9E+11	gal
TP needed	0.02	0.02	0.02	mg/l
for Algal	7.6E-05	7.6E-05	7.6E-05	g/gal
Bloom	1.6E+07	1.9E+07	2.2E+07	g
Per meter^2	0.0575	0.0551	0.0571	g TP/m^2
Sediment	57.50	55.12	57.08	g sed./m^2
needed	2.4	2.3	2.4	g sed./bucket
0 at center	3.6	3.5	3.6	g bucket w/Cons. Center

Figure 31: Rough calculations to estimate soil only contribution to HAB

Though apatite (CBP) percentages are likely lower than the test results show (see paragraph two in section 4.1), apatite makes up a large percent of the P in the soils local to Utah Lake. This correlates with research (Walker and Syers, 1976) as apatite is the primary stage P takes after weathering (Figure 32).
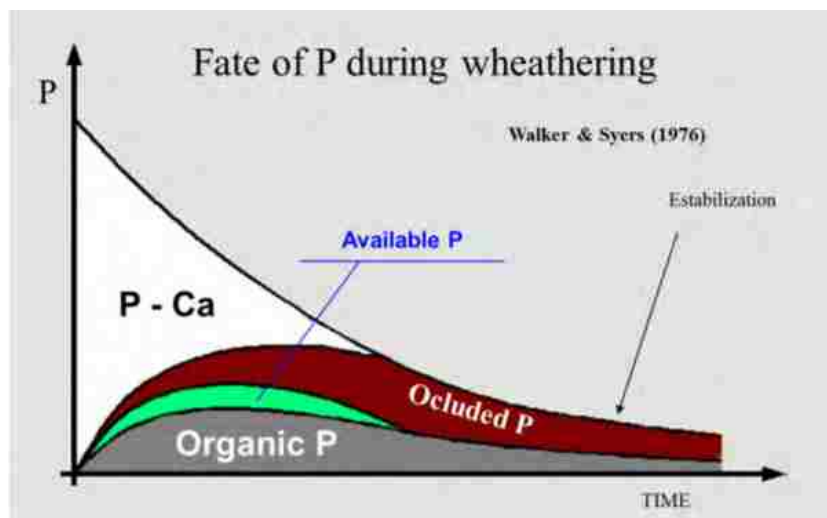
Figure 32: Depicts transition of P from apatite to the occluded stage (Gatiboni, 2012; Walker and Syers, 1976)

Figure 32 accurately implies that CBP is not immediately available for use by organisms. Occluded P refers to P that is even less available than apatite, physically encapsulated by other non-P minerals (Fenton, 1999). But as depicted in Figure 32, available P does stem from CBP.

Water-soluble P, loosely-bound P, and aluminum & iron-bound P make up at least 6 to 10% of the P of the estimated 1 mg-P/g soil surrounding the lake. Thus for every 1 g of soil blowing to the lake, 0.06 to 0.10 mg is potentially available for use by phytoplankton.

Warren Casbeer collected just under 100 samples upstream of Utah Lake from Deer Creek Reservoir during a large drawdown (Casbeer, Williams and Borup, 2018). A P-fractionation on these samples gave very similar numbers to those listed above. Hani Abu-Hmeidan analyzed over 100 sediment samples from within Utah Lake and found TP results of the same magnitude (Abu-Hmeidan, Williams and Miller, 2018).

Figure 33 shows the several phosphoria outcroppings in northern Utah. Much of this was deposited over 250 million years ago (Rupke, 2015), and that many years of erosion can distribute large amounts of P. The same sources that contributed P to Deer Creek Reservoir sediments and current Utah Lake sediments, have likely contributed to the P in the soils around Utah Lake.

5.2   Atmospheric Deposition

From the second phase of the AD study (2018), the numbers are generally the same magnitude as those in the first (2017). Though differences in the data would be expected as the actual rates of AD occurring between years are different, also the interpolation methods were different and the adjustments to the samplers, as discussed earlier, may have affected sampling numbers slightly.

Figure 33: Depiction of Phosphoria outcroppings in Northeastern Utah (Rupke, 2015)

As in the 2017 study, this 2018 study was performed to estimate AD of nutrients to Utah Lake. With five sample sites around Utah Lake, and two located closer to the Great Salt Lake, the results among sites are largely similar. The report done with data from 2017 found a lower bound and an upper bound for AD based on levels of contamination. The outcome was two extremes of data (Olsen et al., 2018). The 2018 study produced only one set of data with only obvious contaminants removed, but the numbers lie within the range found in 2017.

With the exception of AD measurements for Am-N at SS, in all 4 categories of AD measured in this study (SRP, TP, Am-N, and N-N) there is good evidence that the median nutrient values among sites are similar (Figures 25-29).

N-N and Am-N are not significantly affected by the time spent in transit from sample site to the lab (Figure 30)

There is a significant inflow loading rate of nutrients into Utah Lake from AD (Tables 2, 3, and 4). Results are in the same range as values found in 2017. AD needs to be considered in water quality evaluations as well as policy making.

6   FURTHER RESEARCH

6.1   Soil Fractionation Analysis

For improved results, the fractionation analysis should be rerun with the samples always placed horizontally on the shaker. The proper filter paper should be used, and greater care should be taken to perfect the seal of the pressure chamber lids (see section 4).

We have an idea now of the phosphorus makeup in the soil surrounding Utah Lake. The shallow lake is saturated with sediment that is almost constantly moving around (Figure 34)

Figure 34: Utah Lake from Space, creamy sediment mixing, photo credit NASA

The next step to better understand the soils affecting Utah Lake may be to further study the sediments already in the lakebed. Abu-Hmeidan has already initiated a sediment analysis (Abu-Hmeidan, Williams and Miller 2018), and a more in depth study will improve our understanding of the chemistry of Utah Lake.

Atmospheric Deposition

6.2 As more sites are added there will be better representation of the actual amounts of deposition entering the lake. Samplers could be made taller to raise the buckets further from the ground. Placing a sampler at sites on the lake and close to the middle of the lake will help determine the actual attenuation of AD across the lake. One way to validate the data short term is analyzing duplicates close to each other at the sample locations.

As enough soil is gathered in the AD samplers, a combination of AD and fractionation would further the knowledge significantly. P-fractionation can be performed on the soil captured in the samples and compared with those numbers calculated from the local soils to those of Utah Lake.

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APPENDIX A
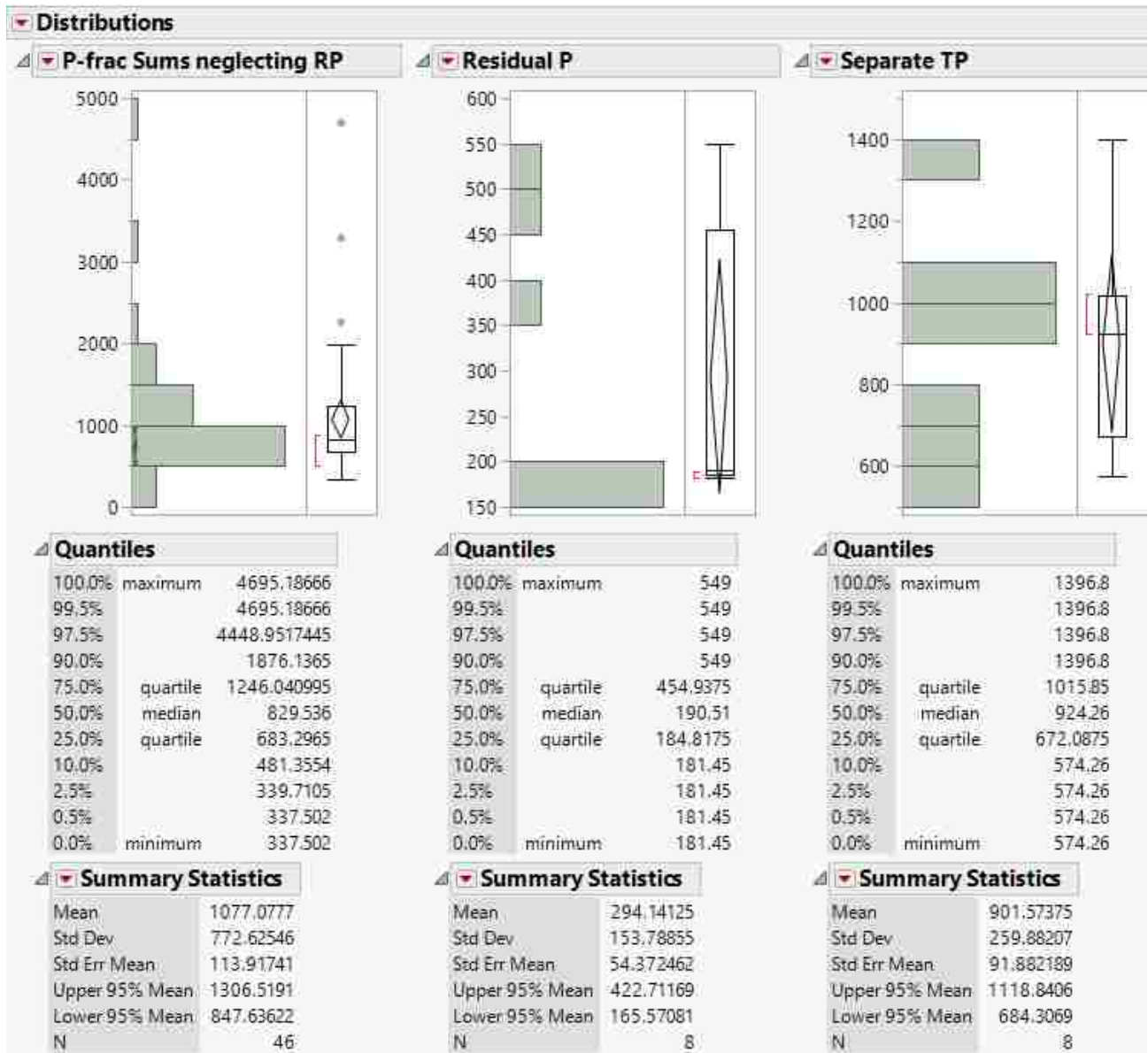
Figure 35: Statistics on residual P and separate soil TP, in ppm

Distributions

WSP%

Quantiles		
100.0%	maximum	9.17%
99.5%		9.17%
97.5%		9.17%
90.0%		8.49%
75.0%	quartile	3.67%
50.0%	median	2.65%
25.0%	quartile	1.49%
10.0%		1.08%
2.5%		0.87%
0.5%		0.87%
0.0%	minimum	0.87%

Summary Statistics	
Mean	0.0326715
Std Dev	0.0241735
Std Err Mean	0.0051538
Upper 95% Mean	0.0433894
Lower 95% Mean	0.0219535
N	22

Confidence Intervals				
Parameter	Estimate	Lower CI	Upper CI	1-Alpha
Mean	0.032671	0.021954	0.043389	0.950
Std Dev	0.024173	0.018598	0.034545	0.950

LBP%

Quantiles		
100.0%	maximum	2.201%
99.5%		2.201%
97.5%		2.201%
90.0%		2.007%
75.0%	quartile	1.094%
50.0%	median	0.675%
25.0%	quartile	0.438%
10.0%		0.214%
2.5%		0.183%
0.5%		0.183%
0.0%	minimum	0.183%

Summary Statistics	
Mean	0.0082889
Std Dev	0.0057707
Std Err Mean	0.0012303
Upper 95% Mean	0.0108475
Lower 95% Mean	0.0057303
N	22

Confidence Intervals				
Parameter	Estimate	Lower CI	Upper CI	1-Alpha
Mean	0.008289	0.00573	0.010847	0.950
Std Dev	0.005771	0.00444	0.008247	0.950

Figure 36: Statistics on individual fractionation percentages west of lake for WSP and LBP from soil work (samples 23-46)

Al&Fe%

Quantiles

100.0%	maximum	8.66%
99.5%		8.66%
97.5%		8.66%
90.0%		6.76%
75.0%	quartile	4.74%
50.0%	median	3.30%
25.0%	quartile	1.69%
10.0%		1.01%
2.5%		0.85%
0.5%		0.85%
0.0%	minimum	0.85%

Summary Statistics

Mean	0.0348739
Std Dev	0.0213218
Std Err Mean	0.0045458
Upper 95% Mean	0.0443274
Lower 95% Mean	0.0254203
N	22

Confidence Intervals

Parameter	Estimate	Lower CI	Upper CI	1-Alpha
Mean	0.034874	0.02542	0.044327	0.950
Std Dev	0.021322	0.016404	0.03047	0.950

CaP%

Quantiles

100.0%	maximum	96.952%
99.5%		96.952%
97.5%		96.952%
90.0%		96.573%
75.0%	quartile	95.744%
50.0%	median	93.947%
25.0%	quartile	88.885%
10.0%		86.835%
2.5%		82.734%
0.5%		82.734%
0.0%	minimum	82.734%

Summary Statistics

Mean	0.9241657
Std Dev	0.0394909
Std Err Mean	0.0084195
Upper 95% Mean	0.941675
Lower 95% Mean	0.9066565
N	22

Confidence Intervals

Parameter	Estimate	Lower CI	Upper CI	1-Alpha
Mean	0.924166	0.906656	0.941675	0.950
Std Dev	0.039491	0.030382	0.056435	0.950

Figure 37: Statistics on individual fractionation percentages west of lake for AFBP and CBP from soil work (samples 23-46)

Table 6: Soil sampling and P-fractionation, with coordinates of sample location

From	Coordinates of Sample Site		moist cntnt	WSP (ppm)	LBP (ppm)	AFBP (ppm)	CBP (ppm)	Residual P (ppm)	Total fract (ppm)	Separate soil TP (ppm)
1	40.21067	-111.67811	44.2	3636	152.15	102.24	804.8		4695.1	
3	40.21711	-111.69775	43.5	2158	64.95	85.78	979.4		3288.1	
6	40.25092	-111.72164	34.4	606.8	41.54	39.84	1137.2		1825.3	
7	40.25839	-111.71894	41.7	401	30.52	49.96	1018.8		1500.2	
9	40.27586	-111.74347	408.6	377.2	45.03	100.02	220.4		742.65	
10	40.28406	-111.74200	20.0	648.8	14.27	42.98	36.68		742.75	
11	40.29700	-111.76203	22.9	114.38	7.54	30.36	673.6		825.87	
13	40.16712	-111.73829	28.4	183.42	24.24	46.68	592.6		846.94	
15	40.15019	-111.74971	28.0	636.6	24.35	30.68	477.4		1169.0	
17[1]	40.11255	-111.78903	24.4	321	31.54	43.52	1228.6		1624.6	
17[2]	40.11255	-111.78903	34.4	315.8	8.68	30.04	578.8	549	1482.3	1002.5
18[1]	40.14483	-111.80577	14.3	982.2	28.82	97.88	1149.4		2258.2	
18[2]	40.14483	-111.80577	23.5	92.82	2.57	21.22	1081.2		1197.8	
19[1]	40.13283	-111.83175	11.9	140.6	5.86	32.68	860.8		1039.9	
19[2]	40.13283	-111.83175	19.6	213.4	5.41	23.82	790.2		1032.8	
20	40.04199	-111.87877	8.5	97.64	26.38	33.46	672	192.63	1022.1	1020.3
21	40.05831	-111.85825	22.8	153.78	105.6	68.34	1063		1390.7	
22[1]	40.10039	-111.80417	51.6	40.42	86.02	103.9	386		616.34	
22[2]	40.10039	-111.80417	13.6	23.8	25.08	92.36	643.8	187.48	972.52	925.5
23[1]	39.95856	-111.87625	81.7	9.23	0	39.46	350.6	474.75	874.03	659.07
23[2]	39.95856	-111.87625	59.4	82.82	5.78	18.122	243.4		350.12	
24	39.95261	-111.93914	5.4	32.9	20.66	11.25	528.2		593.00	
25	39.96881	-111.96581	5.0	69.56	8.86	34.78	857		970.2	
26	39.97698	-111.97325	13.0	61.9	9.78	18.83	585.8	181.45	857.75	711.14
27	39.99748	-112.01899	18.7	29.32	8.52	21.1	481		539.94	
28	40.00164	-111.96135	8.1	53.44	12.98	35.42	487.8		589.64	
29	40.05477	-111.97325	2.9	7.41	2.32	3.38	324.4		337.50	
30	40.07666	-111.94190	26.6	42.38	32.32	104.34	1296.4		1475.4	
31	40.07570	-111.92555	22.8	63.94	18.66	56.18	1855.8		1994.5	
32	40.07594	-111.93164	27.3	40.22	15.4	121.48	1225.2	395.5	1797.8	1396.8
33	40.13750	-111.93804	17.8	17.34	4.24	16.11	845.2		882.89	
34	40.19647	-111.90442	8.5	9.268	1.94	47.16	1003.6		1061.9	
35	40.21929	-111.88201	7.4	20.46	5.12	42.46	684.6		752.64	
36	40.25262	-111.86699	11.4	22.66	4.38	14.10	654.2		695.33	
37	40.26671	-111.85669	21.3	36.9	4.26	17.58	1343.8		1402.5	
38	40.28208	-111.87031	15.6	10.78	6.44	40.2	1027.4	188.39	1273.2	923.02

Table 6: Soil sampling and P-fractionation, with coordinates of sample location, continued

From	Coordinates of Sample Site		moist cntnt	WBP (ppm)	LBP (ppm)	AFBP (ppm)	CBP (ppm)	Residual P (ppm)	Total fract (ppm)	Separate soil TP (ppm)
39	40.29385	-111.88043	10.8	20.66	3.42	7.96	741.4		773.44	
40	40.30594	-111.88651	13.8	13.16	2.38	11.56	863.2	183.93	1074.2	574.26
41	40.35054	-111.91734	20.1	35.68	4.82	26.78	653.4		720.68	
42	40.36012	-111.89549	11.5	8.69	3.06	20.14	637.4		669.29	
43	40.36249	-111.88814	6.0	13.46	2.92	5.84	663.4		685.62	
44	40.36265	-111.84934	9.2	16.64	1.44	15.89	720.4		754.37	
Dup1	40.21067	-111.67811	44.2	4.39	0.22	38.72	473.2		516.52	
Dup20	40.04199	-111.87877	8.5	1.24	1.02	37.52	334.2		373.98	
Dup33	40.13750	-111.93804	17.8	12.01	9.06	50.12	758.4		829.59	
Dup36	40.25262	-111.86699	11.4	11.53	6	30.66	730.4		778.58	
Blank				5.06	0.5	0.41	0.72		6.68	

*Note, superscript 1 signifies this sample was taken from the surface and 2 means the sample was taken from between 6 and 12 inches below the surface.

Table 7: Soil sampling details, for fractionation, snip from ArcMap

FID	Shape *	Id	Site_Name	Side_of_La	Wetness	Domestic_A	Flora_gree	Unnatural	Relief
0	Point	0	Site3	E	Moist	N	Heavy	Local	Flat
1	Point	0	Site1	E	Moist	N	Y	Local	Flat
2	Point	0	Site2	E	Moist	Y	Y	Local	Flat
3	Point	0	Site5	E	Dry	N	Y	Local	Flat
4	Point	0	Site6	E	Moist	Past	Y	Local	West
5	Point	0	Site7	E	Dry	Past	Y	Unnatural	North
6	Point	0	Site8	E	Dry	N	Y	Local	Flat
7	Point	0	Site9	E	Wet	N	Y	Local	Flat
8	Point	0	Site10	E	Dry	Past	Y	Unnatural	Flat
9	Point	0	Site11	E	Dry	N	Light	Local	Flat
10	Point	0	Site12	SE	didn't use	didn't use	didn't use	didn't use	didn't use
11	Point	0	Site4	E	didn't use	didn't use	didn't use	didn't use	didn't use
12	Point	0	Site14	SE	didn't use	didn't use	didn't use	didn't use	didn't use
13	Point	0	Site15	SE	Dry	Past	Y	Local	Flat
14	Point	0	Site16	SE	didn't use	didn't use	didn't use	didn't use	didn't use
15	Point	0	Site17	S	Dry	Recent	Light	Unsure	Flat
16	Point	0	Site13	SE	Dry	N	Light	Local	Flat
17	Point	0	Site18	S	Dry	N	Y	Unsure	North
18	Point	0	Site19	S	Dry	Past	Y	Unnatural	North
19	Point	0	Site20	S	Dry	Y	Light	Unnatural	Flat
20	Point	0	Site21	S	Dry	Recent	N	Local	Flat
21	Point	0	Site22	S	Dry	N	Light	Local	East
22	Point	0	Site23	S	Moist	Past	Light	Local	Flat
23	Point	0	Site24	S	Moist	Past	Light	Unnatural	Flat
24	Point	0	Site25	SW	Dry	N	Light	Natural	Flat
25	Point	0	Site26	SW	Dry	N	Light	Natural	East
26	Point	0	Site27	SW	Dry	N	N	Natural	Flat
27	Point	0	Site28	SW	Dry	Past	Y	Natural	Flat
28	Point	0	Site29	SW	Dry	N	N	Unnatural	Flat
29	Point	0	Site30	W	Dry	Past	Light	Natural	Flat
30	Point	0	Site31	W	Dry	Past	Light	Natural	Flat
31	Point	0	Site32	W	Dry	Past	Yes	Unnatural	Flat
32	Point	0	Site33	W	Dry	Past	Light	Natural	East
33	Point	0	Site34	W	Dry	N	Light	Natural	SouthEast
34	Point	0	Site35	W	Dry	N	Light	Natural	SouthEast
35	Point	0	Site36	W	Dry	N	Light	Natural	East
36	Point	0	Site37	W	Dry	Past	Y	Natural	Flat
37	Point	0	Site38	W	Dry	Past	Y	Natural	Flat
38	Point	0	Site39	W	Dry	N	N	Unnatural	Flat
39	Point	0	Site40	W	Dry	N	N	Unnatural	Flat
40	Point	0	Site41	NW	Dry	Past	N	Unnatural	Flat
41	Point	0	Site42	NW	Dry	N	N	Unnatural	Flat
42	Point	0	Site43	N	Dry	P	N	Unnatural	Flat
43	Point	0	Site44	N	Dry	N	N	Unnatural	Flat

Table 8: Weekly AD results by site for SRP, results in ppm

Sample c	Time passed (days)	Soluble Reactive Phosphorus						
		BI	CD	L	M	O	PS	SS
4/6/18	7	N/A	1.08	2.94	0.97	2.55	0.56	1.51
4/13/18	7	N/A	0.58	1.54	BDL	2.32	0.62	3.88
4/20/18	7	N/A	1.50	1.06	0.24	2.08	2.81	0.51
5/1/18	11	N/A	8.81	5.28	1.82	3.36	2.43	23.96
5/10/18	9	N/A	N/A	50.97	35.66	2.38	0.80	56.10
5/17/18	7	N/A	N/A	46.59	0.35	2.93	2.16	59.06
5/24/18	7	N/A	N/A	0.71	8.01	0.39	BDL	7.79
6/2/18	9	N/A	N/A	33.16	14.19	BDL	1.45	15.32
6/8/18	6	N/A	N/A	2.12	3.89	2.48	0.37	1.08
6/14/18	6	N/A	N/A	3.14	4.60	2.02	0.36	2.07
6/21/18	7	N/A	N/A	6.13	15.32	1.18	4.42	23.91
6/30/18	9	N/A	N/A	11.55	9.55	3.89	3.22	11.08
7/5/18	5	N/A	N/A	9.22	13.04	2.20	3.65	21.00
7/12/18	7	N/A	15.60	4.62	28.89	2.98	BDL	44.26
7/20/18	8	N/A	2.59	32.47	45.56	13.23	5.47	91.84
7/26/18	6	N/A	0.53	5.09	BDL	3.27	20.32	16.14
8/2/18	7	N/A	0.39	0.21	26.78	1.35	6.15	5.77
8/10/18	8	N/A	1.19	1.40	25.27	1.65	9.38	13.17
8/17/18	7	N/A	1.84	10.30	34.44	2.10	2.61	3.39
8/24/18	7	N/A	3.19	0.25	25.40	8.17	1.64	0.45
8/31/18	7	N/A	0.66	1.24	5.82	0.45	6.02	3.51
9/7/18	7	N/A	0.10	4.57	13.10	0.01	1.61	0.62
9/14/18	7	0.69	0.30	11.18	6.11	1.15	12.34	1.61
9/21/18	7	1.94	0.98	0.35	3.88	0.82	2.33	3.38
9/28/18	7	1.61	0.98	2.24	1.09	1.56	0.99	0.97
10/5/18	7	BDL	3.65	1.03	0.58	2.31	2.92	0.54
10/13/18	8	BDL	BDL	BDL	BDL	0.93	BDL	BDL
10/20/18	7	1.63	BDL	0.57	12.23	0.57	BDL	BDL
10/27/18	7	4.21	BDL	BDL	BDL	BDL	BDL	BDL
11/3/18	7	BDL	BDL	BDL	BDL	1.80	BDL	BDL
11/10/18	7	BDL	BDL	N/A	BDL	0.95	BDL	BDL
11/17/18	7	BDL	BDL	N/A	BDL	BDL	BDL	BDL
	232	Utah Lake Weekly average				8.06	Daily	1.15

Table 9: Weekly AD results by site for TP, results in ppm

Sample c	Time passed (days)	Total Phosphorus						
		BI	CD	L	M	O	PS	SS
4/6/18	7	N/A	3.80	5.88	5.83	5.60	4.50	6.03
4/13/18	7	N/A	3.45	4.62	2.00	5.40	3.11	7.76
4/20/18	7	N/A	3.49	3.17	0.94	5.72	4.21	1.01
5/1/18	11	N/A	12.64	3.30	1.16	1.47	4.05	0.78
5/10/18	9	N/A	2.36	182.15	87.91	5.94	8.42	531.85
5/17/18	7	N/A	N/A	70.26	1.41	10.57	20.92	195.03
5/24/18	7	N/A	N/A	8.13	168.78	3.89	4.47	19.03
6/2/18	9	N/A	N/A	75.13	19.64	BDL	3.27	34.89
6/8/18	6	N/A	N/A	6.01	8.34	5.07	1.47	2.28
6/14/18	6	N/A	N/A	6.05	10.25	4.93	1.78	8.30
6/21/18	7	N/A	N/A	11.67	39.01	1.53	5.89	56.44
6/30/18	9	N/A	N/A	17.21	12.61	4.83	5.21	17.33
7/5/18	5	N/A	N/A	9.36	12.54	2.67	3.65	24.06
7/12/18	7	N/A	17.68	4.84	24.19	3.40	BDL	107.70
7/20/18	8	N/A	5.19	78.01	84.36	17.23	9.73	257.69
7/26/18	6	N/A	2.63	10.57	BDL	8.91	28.56	19.08
8/2/18	7	N/A	3.04	1.78	40.72	3.42	10.02	9.37
8/10/18	8	N/A	3.18	3.51	45.41	4.29	8.86	13.17
8/17/18	7	N/A	4.14	29.78	61.68	4.63	6.81	7.95
8/24/18	7	N/A	8.25	1.93	37.59	18.67	36.91	1.47
8/31/18	7	N/A	1.67	1.41	8.94	2.38	8.19	5.56
9/7/18	7	N/A	2.54	6.76	17.05	2.33	51.48	2.54
9/14/18	7	2.52	1.76	19.91	7.82	3.06	17.81	3.09
9/21/18	7	2.82	2.51	1.83	5.27	2.48	9.82	5.84
9/28/18	7	1.69	3.57	2.68	2.59	4.50	3.20	3.73
10/5/18	7	4.82	6.58	5.14	2.55	8.09	3.65	6.28
10/13/18	8	7.78	4.70	4.38	35.11	3.02	5.04	3.58
10/20/18	7	2.71	1.73	1.13	12.23	1.70	5.52	0.55
10/27/18	7	10.22	BDL	1.24	1.16	9.69	2.44	1.19
11/3/18	7	2.21	12.21	9.05	4.92	3.27	1.95	2.92
11/10/18	7	5.22	1.86	N/A	0.89	9.10	0.19	2.21
11/17/18	7	1.27	0.07	N/A	0.26	0.76	2.97	3.32
	232	Utah Lake Weekly average			20.15		Daily	2.87

Table 10: Weekly AD results by site for N-N, results in ppm

Sample c	Time passed (days)	Nitrate-Nitrogen BI	CD	L	M	O	PS	SS
4/6/18	7	N/A	17.89	7.84	15.05	9.16	16.87	15.06
4/13/18	7	N/A	17.83	10.79	8.02	12.35	8.07	20.16
4/20/18	7	N/A	7.48	6.86	2.59	6.76	17.56	10.14
5/1/18	11	N/A	9.58	11.22	12.05	10.28	13.38	1.56
5/10/18	9	N/A	N/A	N/A	N/A	N/A	N/A	N/A
5/17/18	7	N/A	N/A	123.73	24.28	121.50	127.67	130.43
5/24/18	7	N/A	N/A	79.20	234.78	99.57	100.23	71.80
6/2/18	9	N/A	N/A	5.44	9.74	BDL	9.44	1.41
6/8/18	6	N/A	N/A	7.07	7.93	9.78	7.35	6.85
6/14/18	6	N/A	N/A	9.18	7.90	8.29	8.19	4.54
6/21/18	7	N/A	N/A	6.36	1.89	8.37	10.02	2.77
6/30/18	9	N/A	N/A	4.71	5.54	8.25	7.05	5.54
7/5/18	5	N/A	N/A	8.09	3.43	6.86	7.89	1.13
7/12/18	7	N/A	40.71	10.39	2.38	10.22	BDL	2.84
7/20/18	8	N/A	12.96	7.92	11.03	14.46	15.20	9.49
7/26/18	6	N/A	13.17	9.78	BDL	8.32	17.03	5.87
8/2/18	7	N/A	23.25	11.32	8.70	12.19	13.01	11.14
8/10/18	8	N/A	1.99	5.62	9.62	12.54	15.63	16.47
8/17/18	7	N/A	22.98	9.73	10.59	18.09	38.71	15.28
8/24/18	7	N/A	36.29	0.64	8.13	75.08	42.66	0.63
8/31/18	7	N/A	3.47	5.12	2.87	4.75	9.48	3.50
9/7/18	7	N/A	14.88	9.13	5.70	10.15	7.35	6.46
9/14/18	7	7.97	7.72	3.25	5.48	8.83	10.24	6.70
9/21/18	7	5.49	8.21	6.49	4.18	5.68	8.61	7.08
9/28/18	7	9.24	9.84	9.07	8.66	10.36	10.21	10.94
10/5/18	7	24.08	1.46	24.67	5.20	1.16	BDL	1.15
10/13/18	8	8.38	5.64	BDL	BDL	5.84	BDL	16.94
10/20/18	7	9.76	10.97	3.39	20.96	10.18	3.68	1.10
10/27/18	7	15.03	BDL	9.88	12.13	13.93	14.65	10.10
11/3/18	7	8.83	7.94	3.62	7.11	13.07	8.46	7.60
11/10/18	7	12.76	6.76	N/A	7.10	14.00	7.45	6.79
11/17/18	7	6.36	6.60	N/A	5.83	6.92	5.94	6.77
	232	Utah Lake Weekly average			16.18		Daily	2.31

Table 11: Weekly AD results by site for Am-N, results in ppm

Sample c	Time passed (days)	Ammonium-Nitrogen BI	CD	L	M	O	PS	SS
4/6/18	7	N/A	35.78	39.22	28.65	41.75	29.23	25.10
4/13/18	7	N/A	42.56	38.54	12.70	62.53	13.04	20.94
4/20/18	7	N/A	15.95	15.31	0.00	27.03	15.45	10.64
5/1/18	11	N/A	72.78	43.56	53.96	75.32	23.92	19.60
5/10/18	9	N/A	N/A	N/A	N/A	N/A	N/A	N/A
5/17/18	7	N/A	N/A	763.74	88.16	364.49	116.13	501.42
5/24/18	7	N/A	N/A	192.70	1169.18	330.21	85.35	121.55
6/2/18	9	N/A	N/A	162.95	49.50	BDL	15.97	71.19
6/8/18	6	N/A	N/A	10.25	14.60	3.42	9.19	4.21
6/14/18	6	N/A	N/A	10.75	3.77	40.08	2.85	3.11
6/21/18	7	N/A	N/A	10.73	20.27	26.28	15.91	63.11
6/30/18	9	N/A	N/A	7.19	10.25	4.01	3.68	10.37
7/5/18	5	N/A	N/A	N/A	N/A	N/A	N/A	N/A
7/12/18	7	N/A	N/A	N/A	N/A	N/A	N/A	N/A
7/20/18	8	N/A	38.89	12.67	97.17	BDL	15.81	225.43
7/26/18	6	N/A	23.71	31.30	BDL	49.01	51.08	18.20
8/2/18	7	N/A	36.08	22.78	64.35	25.49	10.47	10.67
8/10/18	8	N/A	32.17	32.66	97.47	51.48	25.01	34.43
8/17/18	7	N/A	15.17	10.33	87.29	36.61	9.44	14.08
8/24/18	7	N/A	64.34	1.04	54.86	104.54	44.30	0.84
8/31/18	7	N/A	25.77	7.78	4.23	20.06	20.76	11.76
9/7/18	7	N/A	34.49	38.00	16.73	25.99	14.25	10.29
9/14/18	7	11.36	28.96	81.92	19.57	26.22	52.75	8.80
9/21/18	7	8.23	25.81	15.99	5.42	17.58	9.11	11.24
9/28/18	7	13.96	28.34	26.48	15.45	42.27	11.86	10.39
10/5/18	7	46.55	49.69	62.69	31.73	62.37	30.69	24.72
10/13/18	8	46.10	42.32	44.94	5.54	47.95	5.04	12.42
10/20/18	7	22.77	27.14	28.85	46.58	43.00	3.68	3.30
10/27/18	7	37.87	BDL	42.00	25.99	44.22	28.69	2.38
11/3/18	7	24.27	26.86	33.79	32.27	68.06	18.87	17.54
11/10/18	7	22.62	19.15	N/A	21.89	37.55	14.29	14.14
11/17/18	7	14.64	15.84	N/A	16.21	18.25	BDL	8.61
	232	Utah Lake Weekly average			53.62		Daily	7.66