



Theses and Dissertations

2021-04-08

Improvements of Atmospheric Deposition Sampling Procedures and Further Analysis of its Impact on Utah Lake

Seth Michael Barrus
Brigham Young University

Follow this and additional works at: <https://scholarsarchive.byu.edu/etd>



Part of the [Engineering Commons](#)

BYU ScholarsArchive Citation

Barrus, Seth Michael, "Improvements of Atmospheric Deposition Sampling Procedures and Further Analysis of its Impact on Utah Lake" (2021). *Theses and Dissertations*. 8940.

<https://scholarsarchive.byu.edu/etd/8940>

This Thesis is brought to you for free and open access by BYU ScholarsArchive. It has been accepted for inclusion in Theses and Dissertations by an authorized administrator of BYU ScholarsArchive. For more information, please contact scholarsarchive@byu.edu, ellen_amatangelo@byu.edu.

Improvements of Atmospheric Deposition Sampling and
Further Analysis of its Impact on Utah Lake

Seth Michael Barrus

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

Master of Science

A. Woodruff Miller, Chair
Gustavious P. Williams
M. Brett Borup

Department of Civil and Environmental Engineering
Brigham Young University

Copyright © 2021 Seth Michael Barrus

All Rights Reserved

ABSTRACT

Improvements of Atmospheric Deposition Sampling Procedures and Further Analysis of its Impact on Utah Lake

Seth Michael Barrus
Department of Civil and Environmental Engineering, BYU
Master of Science

This study focused on Atmospheric Deposition (AD) loading on Utah Lake. Utah Lake is susceptible to Harmful Algal Blooms (HABs) because of its large surface area to volume ratio, proximity to Great Basin dust sources, and various wind patterns from close mountain ranges that blow AD towards the lake. In this study, we continued the collection and analysis of AD samples that started in 2017 and 2018, while reporting additional 2019 and 2020 data. We constructed a sampler on Utah Lake itself, which allowed us to better estimate how AD loads were distributed over the lake. An interpolation assumption was made in the previous studies that the amount of AD decreases exponentially as it passes onto the lake from the shore. Results from 5 months of Bird Island AD sampling on Utah Lake indicate that this assumption was incorrect.

We performed statistical comparison tests on 2 variables: (1) the difference in AD between 2 table heights at the same site and (2) the difference in AD between a filtered sample and an unfiltered sample. We were able to statistically conclude that there was no difference in AD between 1-meter and 2-meter tall sample tables and that filtered AD samples had as much as 3 times lower concentration than unfiltered AD samples.

In 2017, the total AD loading was estimated to be, on the high end, approximately 350 tons of total phosphorous (TP) and 460 tons of dissolved inorganic nitrogen (DIN) (Olsen JM, 2018). After making some changes to the interpolation methods, Joshua Reidhead in 2018 estimated AD loads of 153 tons of TP and 505 tons of DIN (Reidhead, 2019). With no changes to the 2018 sampling methods, but using an updated interpolation method, we determined the AD results for Utah Lake in 2019 to be 262 tons of TP and 1052 tons of DIN. After adjustments to the sampling tables, the bucket filters, and incorporating the Bird Island sampler results, we calculated the 2020 AD loading totals to be 133 tons of TP and 482 tons of DIN on the lake.

Keywords: Utah Lake; atmospheric deposition; total phosphorus; dissolved inorganic nitrogen; eutrophic; harmful algal blooms

ACKNOWLEDGEMENTS

I express my gratitude to Dr. Wood Miller, Dr. Gustavious Williams, and Dr. Brett Borup for the opportunity of a lifetime to study under their tutelage and implement their expertise; South Davis Sewer District and BYU for funding this research; Dr. Theron Miller for his unceasing patience and assistance in suggesting improvements that I would have never been able to conjure on my own; for Dr. LaVere Merritt and others for planting a small seed of an idea in the beginning and helping it growing into a groundbreaking full-fledged study of Utah Lake's ecology; to Marty Marsine and his talented crew at the South Davis Sewer District shop for building practical solutions from mere ideas; to the BYU Environmental Analytical Laboratory for their unfailing consistency in processing the collected samples; my parents David and Sharon for encouraging me to go as far as possible in my education; and to my incredible wife, Noelle, whose support and patience was crucial throughout.

TABLE OF CONTENTS

Table of Contents.....	iv
List of Tables	v
List of Figures	vi
1 Introduction & Background.....	1
2 Materials and Methods	4
2.1 High vs Low Tables	5
2.2 Filter vs No Filter	7
2.3 Bird Island Sampler.....	8
2.4 Total Utah Lake Atmospheric Deposition	10
2.5 Other Modified Sample Table Items.....	12
2.5.1 Solar Panel Locations	12
2.5.2 Miners Moss Installation.....	13
3 Results	14
3.1 High vs Low Tables Comparison.....	14
3.2 Filter vs No Filter	17
3.3 Bird Island Prediction.....	22
3.4 Scope of Inference.....	25
3.5 Total Utah Lake Atmospheric Deposition Results.....	25
3.6 Yearly Sample Comparison	29
4 Further Research.....	33
4.1 Atmospheric Deposition.....	33
4.2 Site Local Soil Comparison.....	34
4.3 Wind Patterns or Other Weather Analysis	34
5 Analysis and Conclusions.....	35
References.....	37
Appendix.....	38

LIST OF TABLES

Table 1 – 2019 vs 2020 TP and DIN Average Weekly Concentration Comparison (mg/l)	17
Table 2 – Average Percentage Difference between TP and DIN for 2020 and 2019	18
Table 3 – Summary of Statistical Results for Filter vs Unfiltered Comparison	21
Table 4 – Bird Island Sampler Monthly TP Results	22
Table 5 -- Bird Island Sampler Monthly DIN Results	23
Table 6 – Full Model TP Results from JMP	24
Table 7 – Reduced Model DIN Results from JMP	25
Table 8 – 2019 and 2020 Yearly Tons of AD.....	27
Table 9 – Comparison of Average Monthly TP For All Sites(mg/m ²)	29
Table 10 – Comparison of Average Monthly DIN for All Sites (mg/m ²).....	31
Table 11 – Summary of 2017-2020 AD Data on Utah Lake (tons/year)	36
Table 12 – Weekly TP Comparison Table Between High and Low Samplers.....	38
Table 13 – Weekly DIN Comparison Table Between High and Low Samplers.....	39
Table 14 – Weekly TP Comparison of Filtered vs Unfiltered Tables.....	40
Table 15 – Weekly DIN Comparison of Filtered vs Unfiltered Tables	41
Table 16 – 2020 Weekly AD Interpolation Results.....	43
Table 17 – 2019 Weekly AD Interpolation Results.....	44

LIST OF FIGURES

Figure 1 – Bird Island Sampler, Winched Halfway Down.....	3
Figure 2 – Utah Lake Sampling Sites	4
Figure 3 – The two AD sampling locations around Farmington Bay.....	6
Figure 4 – High vs Low tables at the Ambassador Duck Club near Farmington Bay, Utah.....	6
Figure 5 – Mosida Sample w/o Filter After 2 Days. Mosida Sample w/ Filter After 1 Week	8
Figure 6 – Bird Island Sampler (Left) July 2020 (Right) September 2020	9
Figure 7 – Tables with Solar Panel Attached and Table with Solar Panel 5 m away.....	13
Figure 8 – TP Graphical Comparison Between High and Low Samplers	14
Figure 9 – TP Box and Whisker Plot Comparison Between High and Low Samplers	15
Figure 10 – DIN Graphical Comparison Between High and Low Samplers.....	15
Figure 11 – DIN Box and Whisker Plot Comparison Between High and Low Samplers	16
Figure 12 – TP Graphical Comparison Between Filtered and Unfiltered Samplers.....	18
Figure 13 – TP Box and Whisker Plot Comparison Between Filtered and Unfiltered Samplers .	19
Figure 14 – DIN Graphical Comparison Between Filtered and Unfiltered Samplers	19
Figure 15 – DIN Box and Whisker Plot Between Filtered and Unfiltered Sampling Tables.....	20
Figure 16 – 8/23/2020 DIN Interpolation Results Map	26
Figure 17 – 2020 Weekly AD Interpolation Results	28
Figure 18 – 2019 Weekly AD Interpolation Results	28
Figure 19 – Average Monthly TP for All Sites Comparison	30
Figure 20 – Average Monthly TP for All Sites Comparison	31
Figure 21 – 1/7/2020 DIN Interpolation Results Map	42
Figure 22 – 7/23/2020 DIN Interpolation Results Map	42

Figure 23 – 8/10/2020 DIN Interpolation Results Map	43
Figure 24 –Filtered vs Nonfiltered Scatterplot of TP and DIN	46
Figure 25 – Difference and Log Difference of TP Between Filtered and Nonfiltered	46
Figure 26 – Original and Transformed Distributions of DIN Difference Filtered vs Nonfiltered	47
Figure 27 – TP Scatterplot Matrix (Log Transformed Data).....	47
Figure 28 – TP Scatterplot Matrix Before Transformation	48

1 INTRODUCTION & BACKGROUND

It is generally assumed that the loading of nutrients to a lake ecosystem occurs mainly through point sources like wastewater treatment plants effluent, ground water, and surface water or non-point water sources such as overland flow and runoff. Most point sources are easy to identify and sample, while non-point sources can be estimated. Atmospheric Deposition (AD) has proven to be a difficult nutrient source to measure. Most of the research on AD has been associated with other elements associated with acidic deposition such as sulfur, mercury, and chloride (Hicks, 1986). Recently, research has been performed regarding other nutrient components of AD such as Phosphorus and Nitrogen in an attempt to understand how they impact algae growth on bodies of water. Utah Lake is a eutrophic freshwater lake that sustains a rich and nutrient heavy ecosystem, which often leads to algal blooms and cyanobacteria growth. Recent studies have shown that AD provides significant nutrient loads to the lake (Olsen JM, 2018, Reidhead, 2019).

The National Atmospheric Deposition Program (NADP) has 5 AD monitoring stations throughout Utah, but none in Utah Valley, where Utah Lake is located. NADP, however, is more focused on measuring and understanding global atmospheric deposition. Because of this, their stations are sited to minimize AD loads from local sources, focusing on long-range transport. Since this study is focused on any potential AD that could enter Utah Lake, all

sources, both global and local, are considered legitimate contributions to AD. Thus, our stations were sited to measure AD loads locally on the lake.

A study measuring the atmospheric deposition of total phosphorus (TP) and dissolved inorganic nitrogen (DIN) on Utah Lake began in 2017. That study originated from questions over the feasibility and necessity of reducing the nutrient loadings from wastewater treatment plants (Olsen JM, 2018). These questions led to studies being performed to better understand all the potential nutrient sources that could enter the Utah Lake ecosystem and be used for algal growth. With help from the South Davis Sewer District, Jacob Olsen constructed AD sampling tables and set them up at various locations around Utah Lake (Olsen JM, 2018). These tables were constructed with guidance from the NADP (Lehmann, 2011) and were used from 2017 to 2019 with no changes. Feedback from the Utah Science Panel (USP) about the samplers used for data collection raised several questions about the validity of the data. Three of the concerns raised by the panel are (1) does the height of the table holding the sample buckets bias the measurements, (2) does using a filter, which protects the samples from bugs and debris, make a significant difference on the measurements, and (3) how well do these measurements from the shores of the lake represent the actual deposition across the water surface? These questions are of interest to the USP, NADP, and other AD research projects moving forward because it will help determine the validity of the previously collected data and provide guidelines for future AD sampling methods.

To address these concerns, we made modifications to the sampling tables to determine the effect of changing the height of the sampler and the effect that a filter inside the sampling buckets would have on measured AD. Additionally, we installed a sampler on Bird Island (Figure 1), which is located in the southern portion of Utah Lake. This station was constructed

in an effort to evaluate interpolation methods and analyze the correlations that might exist among the samplers around the lake. Previous studies (Olsen JM, 2018, Reidhead, 2019) had assumed different distribution patterns for AD on the lake. Since this new sampler measures AD on the lake itself, we were able to use these data to perform better spatial interpolations in estimating total AD loads. The Bird Island sampler data also helped determine the accuracy of previous years' data interpolation methods.



Figure 1 – Bird Island Sampler, Winched Halfway Down

This report will present a statistical analysis of the data collected to compare the effect of (1) sampler table heights and (2) filters in the sample buckets, as well as (3) an analysis of potential correlations among the existing sampler locations and the Bird Island sampler. An estimate of the total amounts of AD for 2019 and 2020 will also be provided to remain consistent with previous years' research.

2 MATERIALS AND METHODS

In this section, I will discuss the changes made to the tables and sampling methods in 2020.

The sampling procedure followed the same NADP protocols outlined in Jacob Olsen's publication (Olsen JM, 2018). During my regular weekly sample runs, I procured a wet-deposition sample and dry-deposition sample from each site. In order to simulate the collecting properties of a wet lake surface, the dry-deposition sample bucket at each site was loaded with 3 liters of deionized water (Jassby AD, 1994, Anderson KA, 2006). During the weekly sampling, all buckets were replaced with clean ones. I collected samples at 5 sites around and in Utah Lake seen in Figure 2. I then allocated 500 mL of each sample into clean bottles that then could be analyzed by the Environmental Analytical Laboratory on the campus of Brigham Young University.

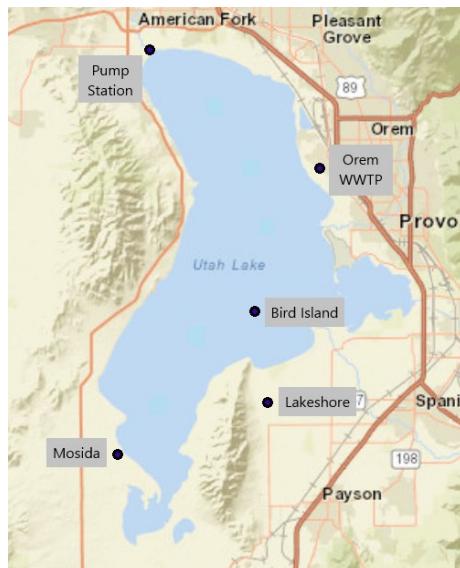


Figure 2 – Utah Lake Sampling Sites

I followed the same calculation process as has been followed in previous years' work: I multiplied the nutrient concentration of each sample (mg/L) by the volume of the sample (L) which resulted in mg of nutrients deposited in the sample bucket (Olsen JM, 2018, Reidhead, 2019). Deionized water was added to bring samples up to analytical volume if necessary, but any measurable nutrient concentration in the distilled, deionized water was subtracted. After receiving the results from the lab, I calculated unit area deposition rates by dividing the total deposition mass in milligrams by the surface area of the sample bucket (0.0615 m^2) and the time represented by the sample (usually 1 week).

2.1 High vs Low Tables

One of the requirements for official NADP samplers is that the table should be 1 to 2 meters from the ground. Tables previously constructed have steel legs which meet this requirement but are only about 1-meter tall. I installed four 1-meter tall steel legs to each of the existing tables using four bolts, washers, and nuts which gave the tables approximately a 2-meter height. The goal of doing this was to provide greater probability that all the nutrients in each sample resulted from AD only, and not from local vegetation or windswept dust from around the tables.

In order to understand the effectiveness of the higher tables, while also minimizing the impact of geographical variability, I set up two tables, one with the original 1-meter table legs and one with the new 2-meter table legs, at the Central Davis Wastewater Treatment Plant location and the Ambassador Duck Club location. Both sites are located near Farmington, Utah for a similar study underway on Farmington Bay, part of the Great Salt Lake. Figure 3 shows the

location of those samplers and Figure 4 shows a tall sampler next to a short sampler at the Ambassador Duck Club location.



Figure 3 – The two AD sampling locations around Farmington Bay



Figure 4 – High vs Low tables at the Ambassador Duck Club near Farmington Bay, Utah

2.2 Filter vs No Filter

One of the major challenges of direct AD measurement involves contamination by insects, plant matter, or bird excrement (Newman, 1995, Ahn H, 2001). Attempts have been made in other AD studies to solve this problem by installing additional samplers at one location to increase the chance of collecting enough uncontaminated samples for analysis (Anderson KA, 2006). Our study is primarily focused on amounts of AD being deposited on Utah Lake per year. Therefore, installing multiple samplers at a location to try to obtain uncontaminated samples would not be cost or time efficient. Other attempts have been made (Tamatamah, 2005) to limit the impact of large outlier samples by removing contaminated samples, but this strategy leads to frequent missing data. Ultimately, there is still not a universal agreement on whether or not to include these local contaminants as part of the deposition (Graham, 1979). Olsen and Reidhead included these sources as they reasoned these contaminated samples still represented contributions to the nutrient load on the lake (Olsen JM, 2018, Reidhead, 2019).

Within the last three years of AD sampling around Utah Lake, large amounts of bugs, both terrestrial and aquatic, have been found in the samples, especially at the Mosida location. We attempted to answer the question: are the bugs found in the samples an accurate representation of bugs falling and dying in the lake, or just an anomaly? For example, during the 2019 sampling year, from July to August, I counted approximately 100+ bugs per sample at the Mosida location for 5 weeks, mostly the terrestrial bee *Halictidae Lasioglossum*.

We installed stainless steel, 500-micron mesh filters in each of the buckets as shown in Figure 5. We observed the results to determine the impact of filters on the samples. Immediately, the Mosida site had zero bugs the first week the filters were installed and resulted in zero bugs or vegetation in the sample the following weeks. We installed filters at each of the

locations and every sample at each site proceeded to show no indication of large bug or plant contamination.



Figure 5 – Mosida Sample w/o Filter After 2 Days (left). Mosida Sample w/ Filter After 1 Week (right).

Our hypothesis was that the buckets without a filter would have more AD nutrients than the buckets with a filter. We performed a statistical analysis on the difference over 7 months between filtered and unfiltered samples in Section 3.2.

2.3 Bird Island Sampler

After a year's worth of discussion, planning, and fabricating, we installed an AD sampler in the south end of Utah Lake, about 50 m east from the middle of Bird Island. We placed the frame with spikes into the gravelly soil, screwed the 10-foot tall poles with the wrenches onto the frame, and slid the raising frame onto the apparatus. We installed about 15 meters worth of

dynamic rope from each corner of the sampler onto 2 cinder blocks connected to a chain and an anchor. For extra support, we shoveled gravel and large rocks on top of the frame for foundational stability. We bolted a standard 1-meter sampling table on top of the frame that gets winched up. We then bolted a steel L-bracket to the side of the table with the solar panel on one end to charge the electronics' battery and a beacon light on the other end for boater safety at night. Pictures of the sampler can be seen in Figure 6 below.



Figure 6 – Bird Island Sampler (Left) July 2020 (Right) September 2020

Having results from a known point inside Utah Lake greatly assisted in the interpolation of total AD on the lake, as will be discussed later in Section 3.3. We also wanted to answer the question of whether or not we could predict the nutrient content at the Bird Island location based on some combination of the other 4 sites (Lakeshore, Mosida, Pump Station, and Orem). The statistical analysis we performed can be found in Section 3.3.

2.4 Total Utah Lake Atmospheric Deposition

The purpose of the research in 2017 began as an attempt to quantify the amount of AD being deposited on Utah Lake per year. In 2017, Olsen simply interpolated between the shoreline samplers to 5 hypothetical points inside the lake and reported the total. An assumption made was that the AD deposition rate at these hypothetical Utah Lake points was at background levels of $0.019 \text{ mg m}^{-2} \text{ day}^{-1}$ (Olsen JM, 2018). A second assumption he made was that the deposition distribution rate decreased as he interpolated across the lake. His report indicated that sampling sites near the lake center would be required to answer the question about deposition patterns on the lake.

Reidhead did more research into the interpolation methods used by other studies and settled on using a geometrical interpolation method with the conservative assumption that the AD values were zero at the center of the lake (Reidhead, 2019).

After a 5-month period of sampling on Bird Island in 2020, the AD results at this location were consistently higher or about the same as the shoreline samplers. More samplers would need to be set up throughout the lake in order to truly understand the spatial and temporal variation from the shoreline to Utah Lake. However, having this known data point gives an idea of the AD throughout the lake so we used the results when performing the interpolation needed to determine the total amount of AD on Utah Lake in 2020.

With the understanding that the AD distribution pattern across the lake does not decrease, but without having a sampler in the lake for 2019, we interpolated using simple kriging among the four sample sites for 2019. In order to get a clearer idea of the spatial and seasonal fluctuations over Utah Lake, there would need to be multiple samplers set up in the lake, as well

as a statistical analysis during each seasonal period, to have strong confidence that interpolations over the lake are more accurate.

I only had sample results from the Bird Island location for 5 months of 2020 (July to November). The values for the other 7 months 2020 (January to May and the month of December) were created from the TP and DIN regression equations generated from the 5-month statistical analysis.

I used simple kriging with a standard variogram to interpolate between the 5 sample points for 2020. While the interpolation method performed here is the same as performed by Olsen (Olsen JM, 2018), the understanding of deposition distribution rates is different. Our method used on the 2020 data means that the estimated deposition rate generally increased or remained the same as the AD progressed towards the center of the lake. In 2017, Olsen used a decreasing distribution pattern rate as the AD progressed towards the center of the lake from the shore. I used the geostatistical software found in ArcGIS Pro for the spatial analysis.

For the 2019 results, I did not use the regression equations from 2020 to create a hypothetical 2019 data point at the Bird Island site. Rather, I just interpolated using simple kriging among the 4 sample sites.

For sites that had missing values for a given week, I used the mean of the remaining sites for that week. If one of the sites had a high outlier, I excluded the high outlier and used the mean of the remaining sites. I loaded the sampling results for each site to each point around the lake in ArcGIS Pro. I then created a random raster within the extents of the Utah Lake layer. I used the Kriging tool within ArcGIS Pro, following the kriging steps described earlier, to load interpolated values onto the Utah Lake raster. I then extracted just the cells within the Utah Lake

layer using the “Extract by Mask” tool. I finally summed every cell within the Utah Lake raster to compute the total nutrient loading for the whole lake in milligrams for that week. I repeated this part of the interpolation process for each week in 2019 and 2020 for both TP and DIN. I then converted the results from milligrams to tons.

2.5 Other Modified Sample Table Items

2.5.1 Solar Panel Locations

One of the critiques regarding the previous sampling table design was that the solar panel used to charge the battery was too close in proximity to the samplers. The reasoning behind this criticism was that the solar panels and steel L-bracket it was attached to could leach off nutrients from the steel during a rain event and fall into the sample, resulting in a contaminated AD sample. I retrofitted the samplers at each location by removing the solar panel and the L-bracket post attached to the table, moving the panel 5 meters away from the table, and then bolting the panel down to a T-post that was pounded into the ground. I heat shrank the ends of 10-gauge wire and spliced them to the existing wires from the solar panel to ensure a distance of 5 meters from the table and that proper electrical powering of the battery could still be accomplished. The solar panels were attached to the T-posts using a circular steel base welded to a cylindrical pipe that would fit around a T-post as seen in Figure 7 below.



Figure 7 – Tables with Solar Panel Attached (left) and Table with Solar Panel 5 m away (right)

2.5.2 Miners Moss Installation

Along the same idea of minimizing contamination when there is a rain event, there was a question from the USP about contamination that could occur from rain that bounced off the top of the tabletop covering, and into the wet deposition sample bucket. We glued green miners moss on top of the tabletop coverings after we performed some basic experiments to see how well the miners moss absorbed the energy of raindrop impact and eliminated the ricochet of droplets that previously could have entered the wet sample buckets.

3 RESULTS

3.1 High vs Low Tables Comparison

We performed a paired t-test on 38 pairs of table height sample data over 8 months, collected from the Central Davis and Ambassador locations. We had 21 pairs from the Central Davis site and 17 from the Ambassador site.

Figure 8 and Figure 9 below show the graphical comparison and the box and whisker plot comparison of TP between the heightened tables and the original lower tables over the course of 8 months in 2020. The data table used to create these figures can be found in the Appendix in Table 12.

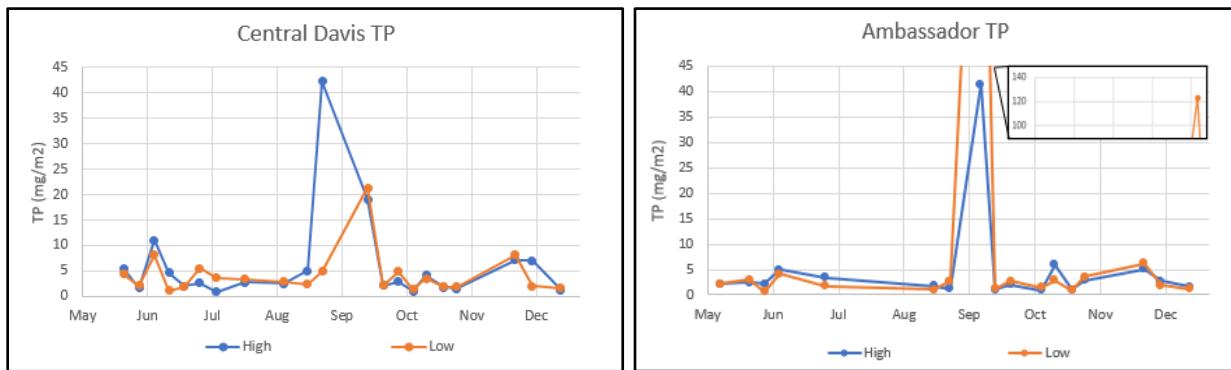


Figure 8 – TP Graphical Comparison Between High and Low Samplers

*Note – No outliers were removed for these graphs.

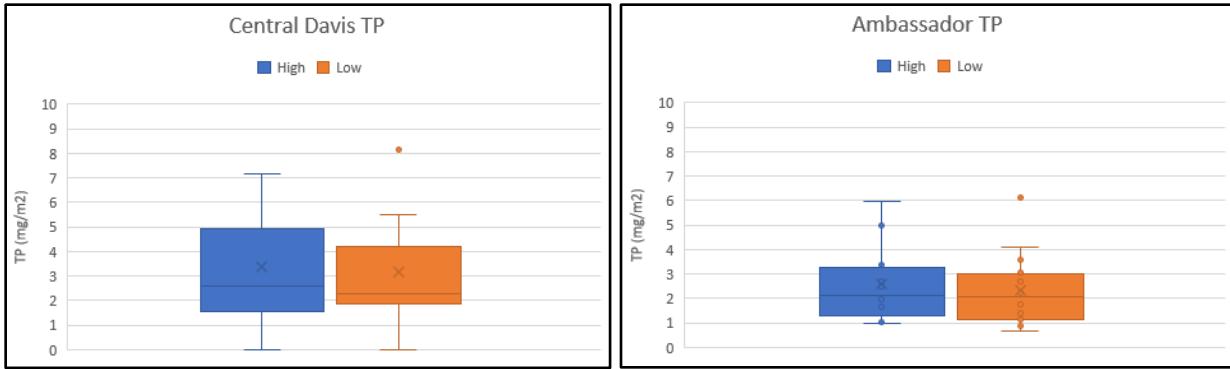


Figure 9 – TP Box and Whisker Plot Comparison Between High and Low Samplers
**Note – The 3 outlier values above 40 have been removed to see the difference better between tables.*

Figure 10 and Figure 11 below show the graphical comparison and the box and whisker plot comparison of DIN between the heightened tables and the original lower tables over the course of 8 months in 2020. The data table used to create these figures can be found in the Appendix in Table 13.

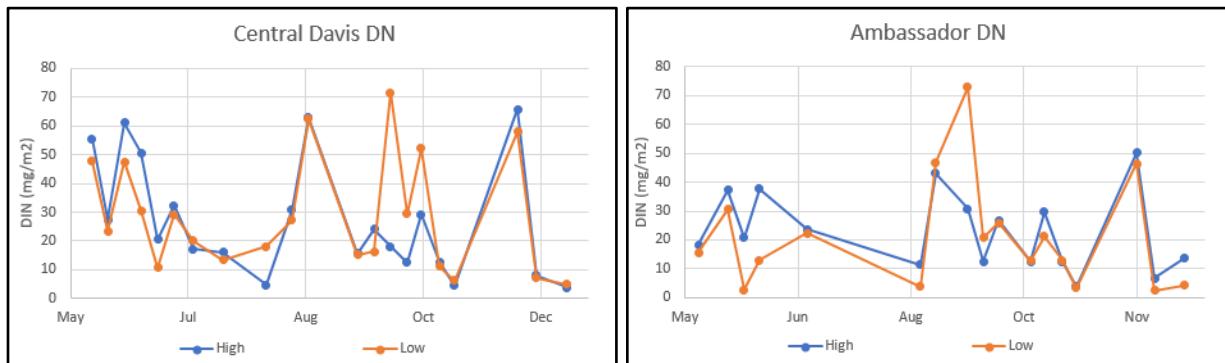


Figure 10 – DIN Graphical Comparison Between High and Low Samplers
**Note – No outlier samples were removed from the data for this plot.*

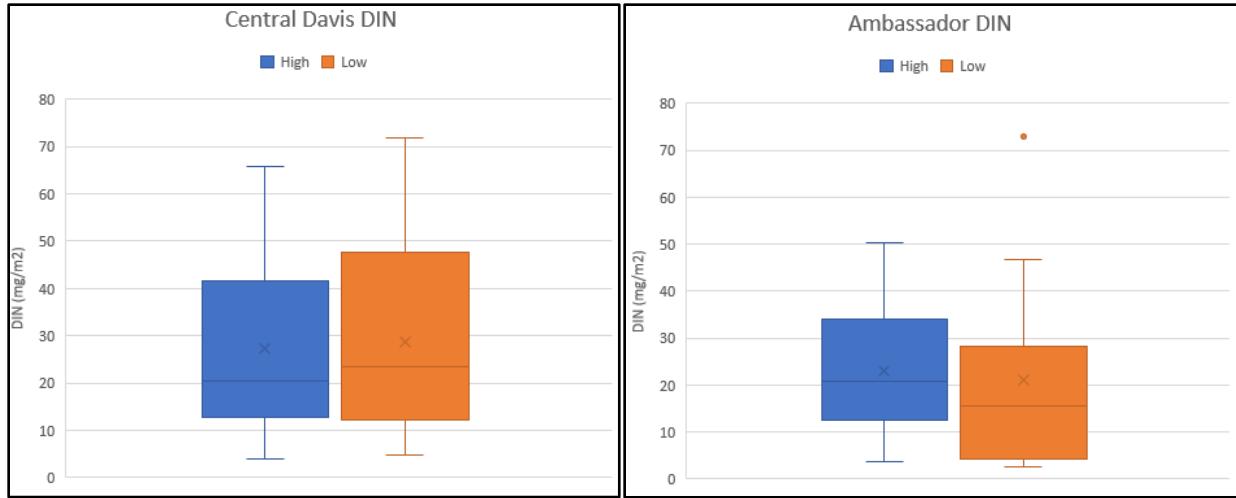


Figure 11 – DIN Box and Whisker Plot Comparison Between High and Low Samplers

*Note – No outlier samples were removed from the data for this plot.

The distribution of data collected was significantly skewed and had a few measurements that came back as zero, so the data were transformed with a $\text{Ln}(x+1)$ transformation. After the back transformation, the TP measurements had an average median difference of 1.09 mg/m^2 , a 95% confidence interval of $(0.85, 1.34)$, and a 1 tailed p-value of 0.264. Because of the transformation, the average difference and confidence interval values represent a multiplicative difference. Thus, the low samplers for TP, on average, were 8% lower than the high sampler's value. The low table DIN measurements were, on average, 12% lower than the high table AD results and a 1 tailed p-value of 0.116.

The low p-values for both TP and DIN indicate that there is not strong evidence that higher tables result in lower AD loadings. However, these results do not prove that there is no difference between low and high tables. Further experiments will need to be performed in order to have more evidence that table height does not have an impact on AD. For the purposes of this study, the data we retrieved and analyses performed indicate that the tables built previously are sufficient at the 1-meter height.

3.2 Filter vs No Filter

In previous years' sample data, a question we have had was how much the bugs found in the samples contributed to the AD nutrient totals in the samples. We decided to do a comparison between 2019 and 2020 and see if installing filters had any effect on the AD concentration outliers. I considered a value an outlier if it was greater than 1 mg/l for TP or 8 mg/l for DIN. Both of these outlier values are about 3 standard deviations above the mean for each respective nutrient. I recorded the number of outliers and average weekly concentration with and without the outliers for 2019 and 2020 in Table 1. As discussed above, we installed bucket filters at the beginning of May 2020. As seen in Table 1, there were 6 TP outliers at all the sites for the 2020 samples. Of these 6 outlier samples, 3 of them occurred before the filter installation. The remaining 3 outliers occurred during high wind days with large amounts of visible dust in the sample. The 2019 TP data returned 13 outliers. Also, there were 2 outliers in the 2020 DIN data, which occurred prior to the filter installation, compared to 9 outliers in the 2019 DIN data.

Table 1 – 2019 vs 2020 TP and DIN Average Weekly Concentration Comparison (mg/l)

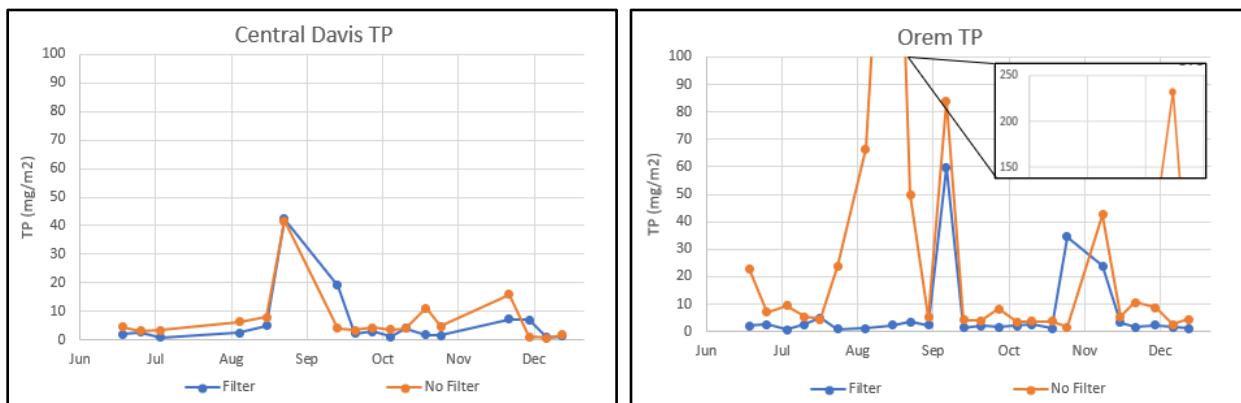
2020 TP Data					2020 DIN Data				
Location	Avg w/ Outliers	Avg w/o Outliers	# of Samples	# of Outliers	Location	Avg w/ Outliers	Avg w/o Outliers	# of Samples	# of Outliers
Lakeshore	0.181	0.120	35	2	Lakeshore	0.785	0.451	35	0
Mosida	0.532	0.088	39	2	Mosida	1.935	0.458	39	2
Pump Station	0.120	0.120	40	0	Pump Station	0.398	0.320	40	0
Orem	0.150	0.113	32	1	Orem	0.553	0.352	32	0
Bird Island	0.376	0.255	18	1	Bird Island	0.820	0.642	18	0
2019 TP Data					2019 DIN Data				
Location	Avg w/ Outliers	Avg w/o Outliers	# of Samples	# of Outliers	Location	Avg w/ Outliers	Avg w/o Outliers	# of Samples	# of Outliers
Lakeshore	0.219	0.137	35	2	Lakeshore	2.070	0.590	35	1
Mosida	3.130	0.129	35	9	Mosida	10.097	0.489	35	6
Pump Station	0.155	0.155	36	0	Pump Station	1.134	0.432	36	0
Orem	0.265	0.154	36	2	Orem	1.572	0.575	36	2

Including the outliers for all data, the average concentration for 2020 TP was approximately 78% lower than the 2019 TP while the average concentration for DIN for 2020 was about 81% lower than the 2020 DIN (Table 2). There is evidence that the lack of high outlier AD concentrations can be attributed to the installation of these filters.

Table 2 – Average Percentage Difference between TP and DIN for 2020 and 2019

	TP (mg/l)	DIN (mg/l)
2020	0.272	0.898
2019	0.942	3.718
% Diff	78%	81%

Figure 12 and Figure 13 below show the graphical comparison and the box and whisker plot comparison of TP between the filtered samplers and the unfiltered samplers over the course of 6 months in 2020 at the Central Davis and Orem sites. It is important to note that the comparison between filtered and unfiltered samplers occurred with 2-meter tall tables. The data table used to create these figures can be found in the Appendix in Table 14.



*Figure 12 – TP Graphical Comparison Between Filtered and Unfiltered Samplers
Note – No outlier samples were removed for these graphs.

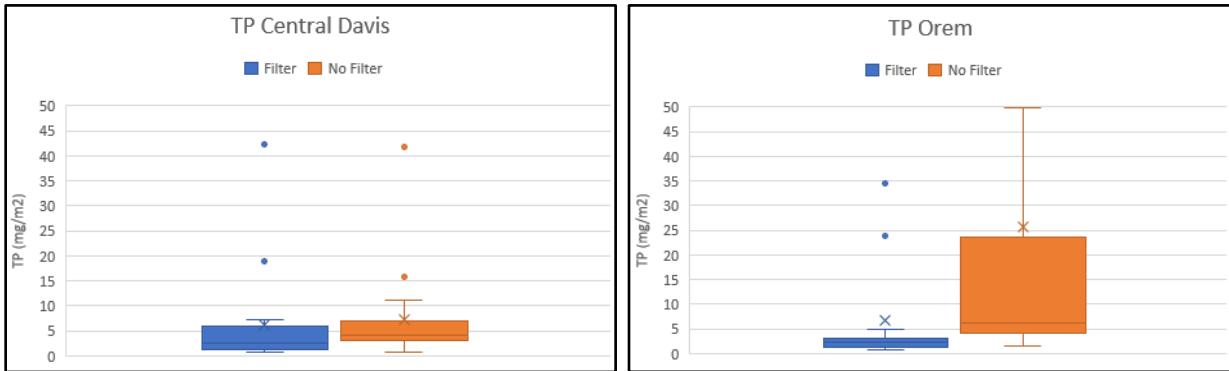


Figure 13 – TP Box and Whisker Plot Comparison Between Filtered and Unfiltered Samplers

*Note – 4 outlier samples were removed from the Orem data to see the difference more clearly.

Figure 14 and Figure 15 show the graphical comparison and the box and whisker plot comparison of DIN between the filtered samplers and the unfiltered samplers at the Central Davis and Orem sites over the course of 6 months in 2020. The data table used to create these figures can be found in the Appendix in Table 15.

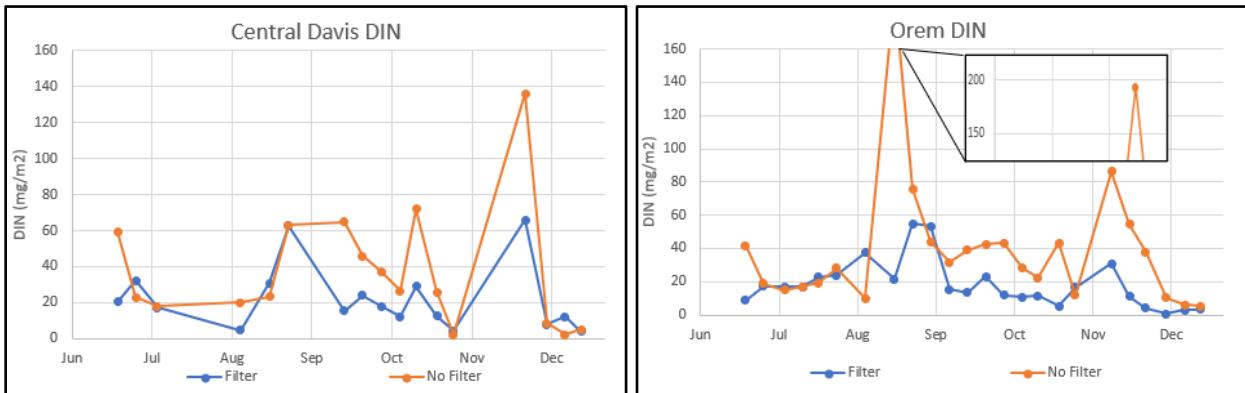


Figure 14 – DIN Graphical Comparison Between Filtered and Unfiltered Samplers

*Note – No outlier samples were removed from the data for these graphs.

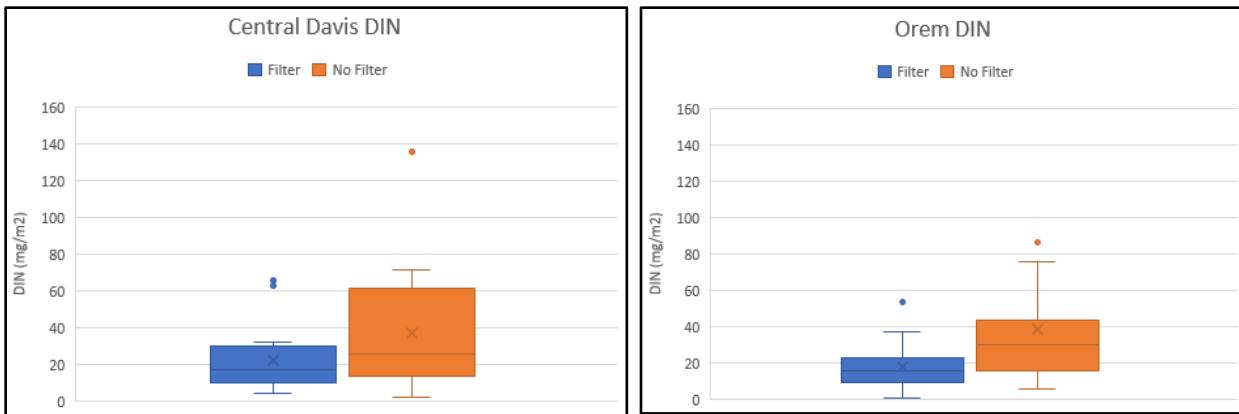


Figure 15 – DIN Box and Whisker Plot Comparison Between Filtered and Unfiltered Sampling Tables

*Note – 1 outlier sample was removed from the No Filter Orem DIN data.

The unfiltered data sites generally had higher nutrient concentrations than the filtered data. There are a few times when that is not the case; for example, the TP results from 10/29/2020 showed the filtered Orem data to be 34.498 mg/m^2 while the unfiltered sampler at Orem for the same day was only 1.606 mg/m^2 . Other individual weekly data comparisons can be seen in Table 14 and Table 15. The reason for this big of a discrepancy for this week is not apparent. However, the results for most other samples showed the filtered data to be lower in AD concentration than the unfiltered data.

Between the two sites, Orem and Central Davis, there were 41 different pairs of samples collected, 17 at the Central Davis site and 24 at the Orem site. I compared the differences in concentrations of TP and DIN using a paired t-test. The distributions of the differences for the two nutrients were skewed, so a natural log transformation was performed on each sample value. I used the one-sided p-value since the hypothesis was directional.

I statistically analyzed the paired data using a statistical software program called JMP and for TP, the average difference between filtered and unfiltered data on the log scale was 0.823, with a 95% confidence interval of 0.398 to 1.249 and a p-value of 0.0004. Back-transforming

these values (e^x) gives a multiplicative difference in the medians of 2.488, with a 95% confidence interval of 1.488 to 3.488. For DIN, the average difference on the log scale was 0.555 with a 95% confidence interval of 0.266 and a p-value of 0.0116. The multiplicative difference in the medians was 1.816 with a 95% confidence interval of 1.305 to 2.326. Table 3 below summarizes the statistical difference between filtered and unfiltered samples. See Figure 24 and Figure 25 in the Appendix for JMP difference scatterplots.

Table 3 – Summary of Statistical Results for Filter vs Unfiltered Comparison

Nutrient	Log Scale			p-value	Multiplicative Difference		
	Diff.	95% Conf. Int.			Diff.	95% Conf. Int.	
TP	1.112	0.405	1.819	0.0018	3.04	1.50	6.17
DIN	0.412	0.062	0.763	0.0116	1.51	1.06	2.14

The low p-value of 0.0018 indicates that there is a statistically significant difference between the filtered and unfiltered samples for TP. The unfiltered samples in mg/m² had on average 3 times the amount of TP as the filtered samples. There is moderate evidence for a difference in the amount of DIN, with the unfiltered samples having 1.5 times the amount of the filtered samples.

Overall, it appears that the filters installed in the samplers provided a barrier that previous contamination (insects, vegetation, etc.) could not get through. Whether or not this means that filtered samples are the most accurate report of AD is still debatable. However, filtered samples provide a conservative estimate of AD at a location.

3.3 Bird Island Prediction

Results from 2020 show that the Bird Island samples were generally higher in AD content than the other samplers. Bird Island usually had a higher or about the same AD value as the other samplers on the shores of Utah Lake for the 5 months that the sampler was available (July to November), except for one data point from the Pump Station on 9/4/2020. These results run contrary to previous years' assumption that the amount of AD would be much less on the lake interior compared to the shore samplers (Brahney, 2019). All previous years' interpolations by Olsen and Reidhead assumed a decreasing distribution pattern from the shore samplers to the middle of the lake. Table 4 and Table 5 show this phenomenon of the Bird Island sampler recording higher amounts of AD than the shoreline samplers (Olsen JM, 2018, Reidhead, 2019). The only instance where the Bird Island site was lower in TP than the average of the shoreline samplers was in October of 2020, and it was only about 64% lower than the average of that month. The only time when the Bird Island sampler for DIN was lower than the DIN for the shoreline samplers for was in August of 2020, and it was only 19% lower than the August 2020 average.

Table 4 – Bird Island Sampler Monthly TP Results

2020 Total Phosphorus (mg/m ²)						
Month	Bird Island	Lakeshore	Mosida	Pump Station	Orem	Avg of 4 shore sites
Jul	5.35	6.62	7.40	2.56	3.73	5.08
Aug	9.37	2.55	3.13	4.36	2.31	3.09
Sep	36.25	3.75	6.17	19.91	16.45	11.57
Oct	1.73	4.70	3.36	2.49	8.42	4.74
Nov	33.34	6.01	2.89	3.34	9.51	5.44

Table 5 -- Bird Island Sampler Monthly DIN Results

2020 Dissolved Inorganic Nitrogen (mg/m ²)						
Month	Bird Island	Lakeshore	Mosida	Pump Station	Orem	Avg of 4 shore sites
Jul	31.93	24.91	21.25	17.28	19.84	20.82
Aug	28.87	35.50	38.31	30.02	37.94	35.44
Sep	52.29	35.47	25.28	20.21	26.40	26.84
Oct	16.39	16.84	15.37	9.58	11.14	13.23
Nov	27.17	14.51	13.24	2.62	15.36	11.43

To answer the question of whether or not we could predict the nutrient content at the Bird Island location based on the other 4 sites (Lakeshore, Mosida, Pump Station, and Orem), I performed a general linear F-test on the data from the 5 Utah Lake sample sites. The TP results were log-transformed because the nutrient data formed a cluster and seemed random (Figure 28 and Figure 27 in the Appendix).

I performed a general linear F-test on the data to determine whether or not the Bird Island results could be predicted by the shoreline samplers. The full model in this F-test refers to the model created by using all 4 shoreline sample sites in an attempt to predict the Bird Island sampler results (Ramsey, 2012). The reduced models in the F-test refer to the models created by removing each of the parameters (sample sites) sequentially in an effort to create the best model to predict the Bird Island site results (Ramsey, 2012). This test, performed in JMP, produced sets of equations for the full model and reduced models, along with p-values to help determine which model was best at determining the linear prediction equation. Each model was compared using the extra sum of squares test. In this instance, I ran a comparison among the resulting reduced models, removing sites sequentially to see which model had more of a correlation with the Bird Island sampler.

A full model ended up being the best model for TP. The AD content at the Bird Island location compared to the other four sites around Utah Lake was calculated to determine the regression equation between shoreline samples and the AD content on the lake. The analysis showed some influential outlier observations; however, considering that there are only 16 samples recorded over this time, I did not remove any points.

The TP analysis from the full model indicated that there is non-conclusive evidence for Lakeshore (p-value 0.0308) and for Orem (0.0323) being related to Bird Island TP. However, there is more convincing evidence that the Pump Station TP is related to Bird Island TP (0.0124) even though those two sites are the furthest apart. The Mosida site did not indicate any strong statistical evidence for a linear relationship to Bird Island TP (0.0880).

In the case of DIN, the analysis showed that the best model was a reduced model including Orem and Lakeshore. There is not strong evidence that any of the sites are linearly related for DIN with Bird Island, with p-values greater than 0.450. The extra sum of squares test has a high p-value so there is not strong evidence that the full and reduced models are different. There is no strong statistical evidence that Lakeshore, Orem, Pump Station, and Mosida are linearly related for DIN to Bird Island.

Table 6 – Full Model TP Results from JMP

Indicator Function Parameterization						
Term	Estimate	Std Error	t Ratio	Prob> t	Lower 95%	Upper 95%
Intercept	2.1952956	0.213912	10.26	0.0094*	1.2749082	3.115683
Log[Orem]	0.7870785	0.144942	5.43	0.0323*	0.1634416	1.4107153
Log[Lakeshore]	-0.99595	0.179052	-5.56	0.0308*	-1.766349	-0.225551
Log[Mosida]	-0.5499934	0.17492	-3.14	0.0880	-1.302556	0.2026871
Log[Pump Station]	0.5818599	0.065296	8.91	0.0124*	0.3009135	0.8628063

Table 7 – Reduced Model DIN Results from JMP

Indicator Function Parameterization						
Term	Estimate	Std Error	t Ratio	Prob> t	Lower 95%	Upper 95%
Intercept	11.100706	15.95262	0.70	0.5175	-29.90682	52.108228
Orem	-0.209478	0.355154	-0.59	0.5810	-1.122432	0.703475
Lakeshore	1.0071501	0.39013	2.58	0.0493*	0.0042888	2.0100113

Even though the statistical results do not indicate that we can confidently and accurately predict the AD at the Bird Island site based on the shoreline sites, I used the reduced linear regression equations from this exercise to give an approximate value for the other 7 months of 2020 for Bird Island. More samplers on Utah Lake itself will need to be constructed and more data over the next few years will need to be collected before a more accurate distribution and prediction model can be created.

3.4 Scope of Inference

Each of these analyses was based on observational studies. The experiments were not randomized. Thus, causality cannot be established, and the conclusions may not confidently apply to other AD sampling locations or times.

3.5 Total Utah Lake Atmospheric Deposition Results

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 proceeded to use the results from the regression analysis for 2020 because it provided a better picture of the AD on the lake than previous years. We used the results from the

full model in Table 6 above while determining the Bird Island TP values for the remaining 5 months, and we used the reduced model in Table 7 when determining the Bird Island DIN values for the other 5 months. In situations where either the full or reduced model resulted in a negative value or a value that did not fit with the rest of the data when creating the weekly values for the interpolation, I entered a mean value that fit within the rest of that week's AD results.

Following the interpolation explained in Section 2.4, I performed a weekly AD interpolation in ArcGIS Pro for each of the weeks in 2020. I then summed each of the weeks' total AD to report the yearly TP and DIN for 2020. Figure 16 shows a map of interpolated DIN for the week of 8/23/2020. Other examples of weekly interpolated maps throughout 2020 can be seen in Figure 21, Figure 22, and Figure 23 in the Appendix. The interpolation and calculation for 2019 followed the same process, except with only 4 sample points around the lake being used for the interpolation, removing the Bird Island site.

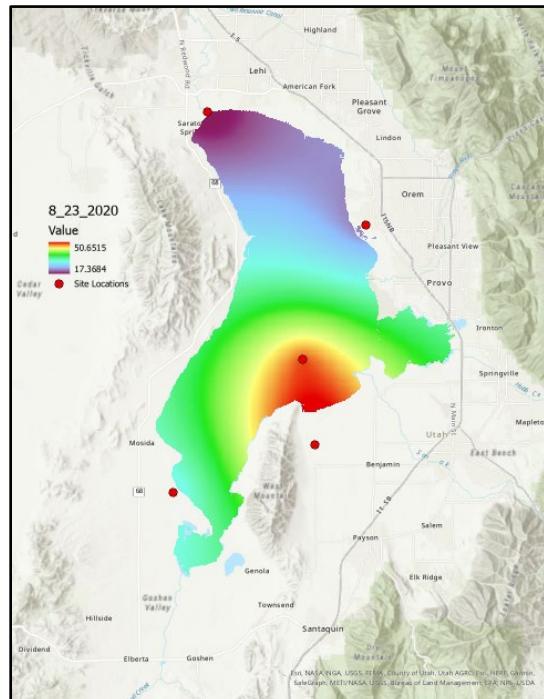


Figure 16 – 8/23/2020 DIN Interpolation Results Map

Each week's interpolation resulted in a different spatial interpolation map, making it difficult to notice any clear pattern of AD distribution on the lake over time. Some weeks showed each of the sites having more of a linear relationship to the Bird Island site. Another sampler on the west side of the lake would be helpful with this spatial interpolation. The interpolation could be better since there is only one sampling point in Utah Lake, but it provides a better picture of the AD on the lake than previous years.

The interpolation resulted in a total 2020 TP loading estimation of 133 tons and a total 2020 DIN loading estimation of 482 tons (see Table 8). The 2019 interpolation resulted in a TP loading estimation of 262 tons and a total 2019 DIN loading estimation of 1052 tons. It is important to remember than the 2019 data resulted from samples that did not have the same filters installed on the 2020 samplers.

Table 8 – 2019 and 2020 Yearly Tons of AD

Yearly Tons of AD		
Year	TP	DIN
2019	262	1052
2020	133	482

Figure 17 shows the weekly loading of TP and DIN for 2020 while Figure 18 shows the 2019 weekly AD loading. Data used to create these figures can be found in the Appendix (Table 16 and Table 17). There is much seasonal variation in both the 2019 and 2020 data. The winter months were generally distributed so that they correlated with the minimum amounts of AD for their respective year. The summer months generally related to the maximum amounts of AD for the year. It is important to remember that the spike in the 2020 data occurred in May prior to the installation of filters. As explained in Section 3.2, there is strong evidence that suggests that the

number of bugs that usually found their way into the sample would be filtered out and the peaks would most likely not reach 87 tons of DIN and 27 tons of TP like it does in this instance.

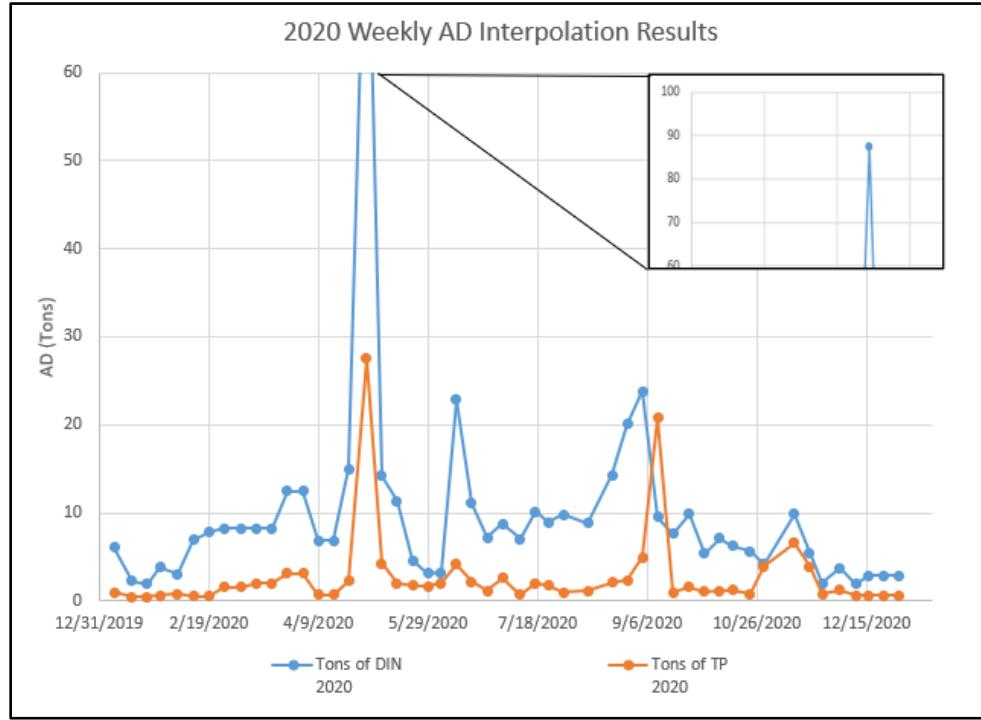


Figure 17 – 2020 Weekly AD Interpolation Results

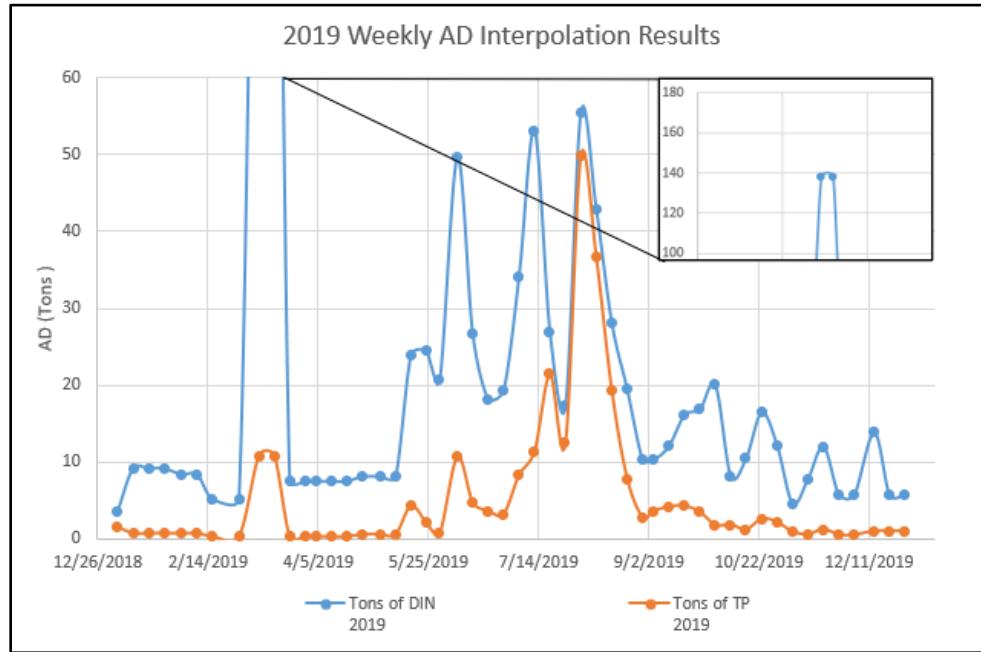


Figure 18 – 2019 Weekly AD Interpolation Results

3.6 Yearly Sample Comparison

There has been a question of what other AD weekly loading totals look like on Utah Lake over the course of several years. I compiled average monthly AD sample data from 2017 and 2018 and then incorporated monthly AD data I collected from 2019 and 2020 in an effort to get an idea of the AD monthly variation. I did a simple average calculation for TP from each site for each month and then took the average of those results to get a total monthly average for all the sites. These monthly averages for TP are shown in Table 9 and Figure 19 below.

It is apparent that the changes to the sampling apparatus in 2020 had an impact on the summer data. In 2017 and 2019, Figure 19 shows spikes of TP occurring in May and July respectively. The 2020 data never showed a spike as high as that in any of the months.

Table 9 – Comparison of Average Monthly TP For All Sites(mg/m²)

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

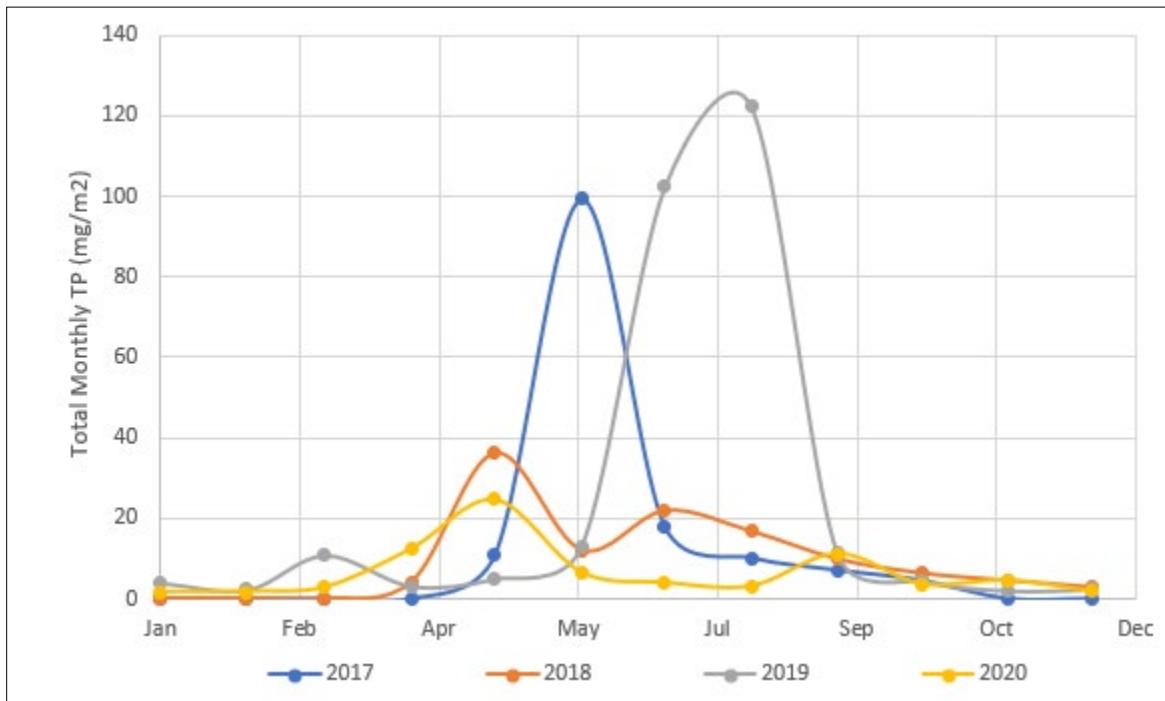


Figure 19 – Average Monthly TP for All Sites Comparison

I performed the same analysis on DIN data for 2017 to 2020. While 2020's average DIN data did peak around the middle of April, Figure 20 and Table 10 show that it did not reach the same crest as any of the other years. This has more to do with the sampling changes to the tables, adding bucket filters specifically, rather than stating that 2020 was a low monthly AD loading year for Utah Lake. The general trend of increasing AD during the summer months and decreasing AD during the winter months was confirmed with this analysis.

Table 10 – Comparison of Average Monthly DIN for All Sites (mg/m²)

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

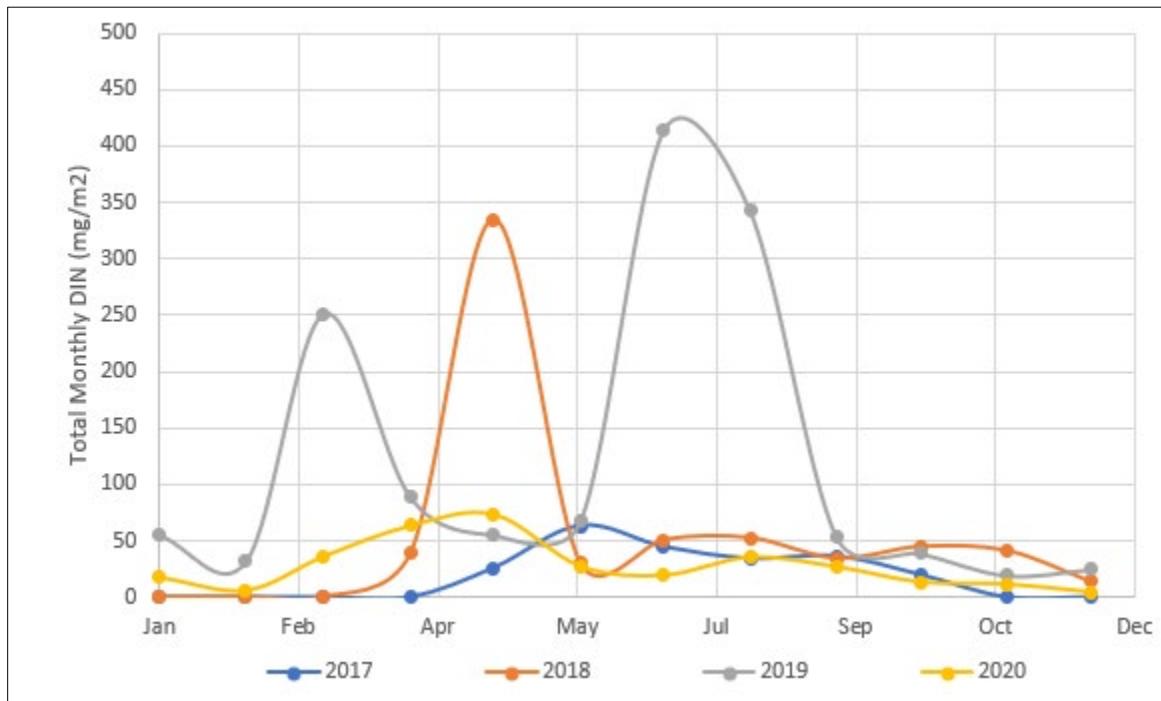


Figure 20 – Average Monthly TP for All Sites Comparison

The same trends found for monthly TP are true for DIN as shown in Figure 20. The DIN peaks for 2017-2019 were, respectively, 250, 330, and 415 mg/m², while the 2020 peak was about 75 mg/m². It is important to remember that some of the 2017 data was removed due to an

incorrect understanding of sample contamination. The general trend of increasing DIN during the summer months and decreasing DIN during the winter months was again confirmed with this analysis, except for a smaller DIN peak of 250 in 2019 that occurred in February.

4 FURTHER RESEARCH

4.1 Atmospheric Deposition

As more sites are added, there will be better representation of the AD on Utah Lake. Specifically, constructing a sampler somewhere on the west side of Utah Lake, perhaps near the old Pelican Point site (called Saratoga Springs in previous studies), could provide a better interpolation for the AD among the sites. The previous studies showed that the Pelican Point site had more local contribution from dust (Olsen JM, 2018) likely due to the large gravel pit and agricultural practices on that side of the lake. A better understanding of the total deposition could be determined with a site on the west side combined with the analysis results from this study that the distribution of AD across Utah Lake does not decrease, but rather in some situations, increases.

The comparison tests of having two tables at a few sites performed as part of this research have been informative and enlightening, but the extra tables might be more useful at new sites.

A comparison of the different types of interpolation could also be performed and could provide a range of AD weekly values depending on the type of interpolation (kriging, IDW, or Thiessen Polygons) and the different variograms (Gaussian, exponential, semivariate, or linear).

4.2 Site Local Soil Comparison

An unquantified variable surrounding this research is that the samplers are not exactly on the Utah Lake shoreline. Some sites are 50 meters away from the closest shoreline and some samplers are 5 meters away. The reason some samplers are further away is just logistical as we could not find a more secure or a more accessible property to place the sampler at the time. Something that could be done to assist in stating more confidently that the results are representative of actual AD would be to perform a serial extraction on the soil around each of the sampler tables. Dust samples from the top of the tables could be collected and be compared to the results of the soil extraction and analyzed.

4.3 Wind Patterns or Other Weather Analysis

We set up two weather stations in 2020: one at the Mosida site and the other at the Orem WWTP site. These weather stations measure rainfall, temperature, humidity, wind velocity, and wind direction. Wind roses could be built from the wind velocity and direction data. If data were collected over the entire year, analyses could be performed in an effort to determine the relationship between wind patterns and AD. The relationship between AD and other weather variables (rain, temperature, or humidity) could be investigated also.

5 ANALYSIS AND CONCLUSIONS

First, this analysis provides statistical evidence that there is not a difference between high and low tables for both TP and DIN. The lower buckets had, on average, smaller concentrations of both nutrients than the higher buckets; the opposite of what our original hypothesis stated. Additional trials with much taller tables, e.g. 3 to 4 meters, could further test this hypothesis.

Second, filtered samples had significantly less nutrients than the unfiltered samples. A monthly comparison from samples with filters and without filters in 2020 demonstrated that the 500-micron mesh filters prevented contamination (bugs, local vegetation, etc.) in the samples. However, this analysis did not address whether the filtered or the unfiltered sample is the most accurate representation of Atmospheric Deposition. The filters might be filtering out larger particles of AD that would result in a representative sample. It is plausible that the actual value of AD is higher than the reported filtered value in 2020.

The 2017 through the 2019 data showed a period of time when the concentrations would “spike” to 10 times the average AD values. Filters reduced the spike to about 3 times the yearly average of AD. For example, the Central Davis unfiltered sample in November indicated a DIN value of approximately 135 mg/m^2 while the Central Davis filtered sample for the same date returned a DIN value of about 60 mg/m^2 , a 225% reduction.

Third, there is not strong evidence that the AD nutrients at the four shoreline sites are related to the nutrients at Bird Island for both reduced and full statistical regression models.

However, it is worth pointing out that there are only 16 observations associated with this exercise. One unexplored variable is that each sample site is influenced by different wind patterns which affect the transport of AD. Early preliminary analysis of the wind roses at the Mosida site indicate that the majority of the winds come from the southwest, which is the direction that leads almost directly to the Bird Island site. Further research on site-specific wind patterns that likely influence the AD on Utah Lake should be conducted.

Finally, the results from interpolating the sample values across Utah Lake can be seen in Table 11. The total AD from 2017 and 2018 can also be seen in Table 11. There was approximately 262 tons of TP added to Utah Lake in 2019 and 133 tons of TP in 2020, while 1052 tons of DIN were added in 2019 and 482 tons of DIN in 2020. Dry TP deposition represents the majority of deposition that occurs seasonally.

Table 11 – Summary of 2017-2020 AD Data on Utah Lake (tons/year)

Year	TP	DIN
2017	350	460
2018	153	505
2019	262	1052
2020	133	482

The algal growth is greatest during the summer, so it is important to note that elevated Utah Lake AD correlates with this season. To reaffirm, it takes about 17 tons of phosphorus per year and 200 tons of nitrogen per year to support algal growth on Utah Lake (Merritt LB, 2016). The amount of TP and DIN determined by this study and previous years' studies is enough AD alone to support eutrophic conditions on the lake. While this study was specific to Utah Lake, this analysis should be a foundation on which water managers at other locations could use as reason to start their own AD monitoring project.

REFERENCES

- Ahn H, J. T. (2001). "Variability, Uncertainty, and Sensitivity of Phosphorus Deposition Load Estimates in South Florida." *Water, Air, and Soil Pollution* 126: 37-51.
- Anderson KA, D. J. (2006). "Dry and wet atmospheric deposition of nitrogen, phosphorus and silicon in an agricultural region." *Water, Air, and Soil Pollution* 176: 351–374.
- Brahney, J. (2019). "Estimating Total and Bioavailable Nutrient Loading to Utah Lake from the Atmosphere." *Watershed Sciences Faculty Publications Paper* 1094.
- Graham, W. F., and Duce, R. A. (1979). "Atmospheric Pathways of the phosphorus cycle." *Geochimica et Cosmochimica Acta* 43: 1195-1208.
- Hicks, B. B. (1986). "Measuring dry deposition: a re-assessment of the state of the art." *Water, Air and Soil Poll* 30: 75-90.
- Jassby AD, R. J., Axler RP, Goldman CR, Hackley SH (1994). "Atmospheric deposition of nitrogen and phosphorus in the annual nutrient load of Lake Tahoe (California-Nevada)." *Water Resources Research* 30: 2207-2216.
- Lehmann, C. M. B., Gay, D. A. (2011). "Monitoring long-term trends of acidic wet deposition in US precipitation: results from the National Atmospheric Deposition Program." *Power Plant Chemistry* 13: 378-385.
- Merritt LB, M. A. (2016). "Interim Report on Nutrient Loadings to Utah Lake." Jordan River, Farmington Bay & Utah Lake Water Quality Council.
- Newman, E. (1995). "Phosphorus inputs to terrestrial ecosystems." *Journal of Ecology*: 713-726.
- Olsen JM, W. G., Miller AW, Merritt LB. (2018). "Measuring and Calculating Current Atmospheric Phosphorous and Nitrogen Loadings to Utah Lake Using Field Samples and Geostatistical Analysis." *Hydrology* 5: 45-65.
- Ramsey, F. S., Daniel (2012). *The Statistical Sleuth: A Course in Methods of Data Analysis*, Cengage Learning.
- Reidhead, J. G. (2019). "Significance of the Rates of Atmospheric Deposition Around Utah Lake and Phosphorus-Fractionation of Local Soils." *Theses and Dissertations* 7685.
- Tamatamah, R. A., R. E. Hecky, and H. C. Duthie (2005). "The atmospheric deposition of phosphorus in Lake Victoria (East Africa)." *Biogeochemistry* 73: 325-344.

APPENDIX

Table 12 – Weekly TP Comparison Table Between High and Low Samplers

<u>Total Phosphorus (mg/m²)</u>				
Date	Central Davis High	Central Davis Low	Ambassador High	Ambassador Low
5/15/2020	N/A	N/A	2.1019	2.2019
5/28/2020	5.5211	4.3844	2.4699	3.0559
6/4/2020	1.6591	2.1910	2.1392	0.6789
6/11/2020	11.0077	8.1681	4.9910	4.1117
6/18/2020	4.6052	1.1592	N/A	N/A
6/25/2020	1.9736	1.8912	N/A	2.0518
7/2/2020	2.6770	5.5142	3.3861	1.7758
7/10/2020	0.8675	3.6073	N/A	N/A
7/17/2020	N/A	N/A	N/A	N/A
7/23/2020	2.7951	3.3811	N/A	N/A
7/30/2020	N/A	N/A	6.3890	N/A
8/10/2020	2.4922	2.9497	N/A	N/A
8/21/2020	5.0232	2.3520	1.7534	1.0470
8/28/2020	42.2723	4.8558	1.1744	2.7162
9/11/2020	N/A	95.0565	41.4456	122.9775
9/18/2020	19.0458	21.3333	1.0806	1.2422
9/25/2020	2.1758	2.2004	1.9871	2.7481
10/2/2020	2.9420	4.8666	N/A	N/A
10/9/2020	1.0739	1.3719	0.9570	1.4054
10/15/2020	4.0970	3.5867	5.9876	2.8122
10/23/2020	1.7816	1.8972	1.0262	0.8696
10/29/2020	1.5314	1.8779	2.8117	3.5793
11/25/2020	7.1850	8.1438	5.1187	6.1318
12/3/2020	6.9812	2.0605	2.7071	1.9200
12/10/2020	0.9690	1.3493	N/A	N/A
12/16/2020	1.2232	1.6993	1.6509	1.1216

Table 13 – Weekly DIN Comparison Table Between High and Low Samplers

Dissolved Nitrogen (DIN) (mg/m²)				
Date	Central Davis High	Central Davis Low	Ambassador High	Ambassador Low
5/15/2020	N/A	N/A	18.3505	15.6802
5/28/2020	55.5805	47.8516	37.1800	30.5609
6/4/2020	27.3853	23.4786	20.6964	2.6625
6/11/2020	61.0313	47.5235	37.7698	12.9051
6/18/2020	50.7340	30.5800	N/A	N/A
6/25/2020	20.4300	10.6777	N/A	30.8692
7/2/2020	32.4111	29.1291	23.6510	22.3738
7/10/2020	17.1983	20.0588	N/A	N/A
7/17/2020	N/A	N/A	N/A	N/A
7/23/2020	16.0371	13.3301	N/A	N/A
7/30/2020	N/A	N/A	37.6854	N/A
8/10/2020	4.6574	18.1426	N/A	N/A
8/21/2020	30.7045	27.1392	11.4268	3.9072
8/28/2020	62.8473	62.5003	43.1570	46.8427
9/11/2020	N/A	60.0307	30.7545	72.9678
9/18/2020	15.6639	15.0998	12.5794	20.8336
9/25/2020	24.0713	16.2298	26.8603	25.9990
10/2/2020	18.1224	71.7225	N/A	N/A
10/9/2020	12.4450	29.4181	12.4538	12.8069
10/15/2020	29.1751	52.1308	29.5834	21.2767
10/23/2020	12.8071	11.2148	12.4538	12.9849
10/29/2020	4.5165	6.3549	3.7474	3.3032
11/25/2020	65.8802	57.9917	50.2586	46.3789
12/3/2020	8.0681	7.1911	6.6332	2.4917
12/10/2020	12.1626	11.6605	N/A	N/A
12/16/2020	3.8923	4.8168	13.5444	4.3525

Table 14 – Weekly TP Comparison of Filtered vs Unfiltered Tables

<u>Total Phosphorus (mg/m²)</u>				
Date	Central Davis Filter	Central Davis Unfiltered	Orem Filter	Orem Unfiltered
6/25/2020	1.9736	4.4820	2.0095	22.9642
7/2/2020	2.6770	3.0465	2.6660	7.0593
7/10/2020	0.8675	3.3352	0.6988	9.4431
7/17/2020	N/A	N/A	2.4678	5.4925
7/23/2020	2.7951	N/A	4.9859	4.5119
7/30/2020	N/A	N/A	0.9500	23.7307
8/10/2020	2.4922	6.2892	1.0434	66.5338
8/21/2020	5.0232	7.9270	2.3631	232.5352
8/28/2020	42.2723	41.6804	3.5383	49.7937
9/4/2020	N/A	N/A	2.4220	5.2501
9/11/2020	N/A	5.6627	59.9064	83.9371
9/18/2020	19.0458	4.0492	1.2663	4.2267
9/25/2020	2.1758	3.3842	2.1909	4.0811
10/2/2020	2.9420	4.3022	1.6954	8.2823
10/9/2020	1.0739	3.6930	2.1695	3.4091
10/15/2020	4.0970	4.0859	2.5183	3.6299
10/23/2020	1.7816	11.1853	1.2217	3.7653
10/29/2020	1.5314	4.7025	34.4981	1.6064
11/12/2020	N/A	N/A	23.8514	42.5714
11/19/2020	N/A	N/A	3.1592	5.3603
11/25/2020	7.1850	15.9369	1.5063	10.5526
12/3/2020	6.9812	1.1643	2.3049	8.6842
12/10/2020	0.9690	0.6500	1.5589	2.5119
12/16/2020	1.2232	1.8235	1.2048	4.3610

Table 15 – Weekly DIN Comparison of Filtered vs Unfiltered Tables

Dissolved Nitrogen (DIN) (mg/m²)				
Date	Central Davis Filter	Central Davis Unfiltered	Orem Filter	Orem Unfiltered
6/25/2020	20.4300	59.5340	8.8608	41.6556
7/2/2020	32.4111	22.8556	17.4130	18.7116
7/10/2020	17.1983	18.0469	16.8853	15.0733
7/17/2020	N/A	N/A	16.8511	16.9373
7/23/2020	16.0371	N/A	22.8224	19.2995
7/30/2020	N/A	N/A	23.9317	28.0458
8/10/2020	4.6574	20.2561	37.3610	9.8357
8/21/2020	30.7045	23.3195	21.4038	193.4824
8/28/2020	62.8473	62.9133	55.0607	75.6913
9/4/2020	N/A	N/A	53.2993	44.0598
9/11/2020	N/A	40.1728	15.4110	31.7135
9/18/2020	15.6639	64.8115	13.5924	39.1779
9/25/2020	24.0713	45.8080	23.2990	42.4242
10/2/2020	18.1224	37.2950	11.8829	43.3193
10/9/2020	12.4450	26.5728	10.5837	28.3383
10/15/2020	29.1751	71.8249	11.4560	22.3484
10/23/2020	12.8071	25.9082	5.3034	43.1498
10/29/2020	4.5165	2.4101	16.4699	11.7305
11/12/2020	N/A	N/A	30.6879	86.2924
11/19/2020	N/A	N/A	11.0848	54.5141
11/25/2020	65.8802	135.9862	4.3066	37.7897
12/3/2020	8.0681	8.8403	0.6518	10.2957
12/10/2020	12.1626	2.2210	2.9760	6.1784
12/16/2020	3.8923	5.3047	3.4658	5.3441

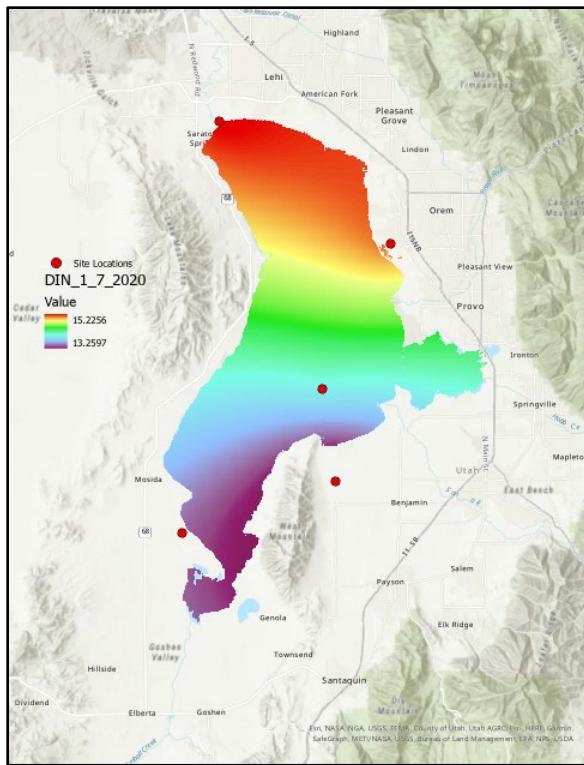


Figure 21 – 1/7/2020 DIN Interpolation Results Map

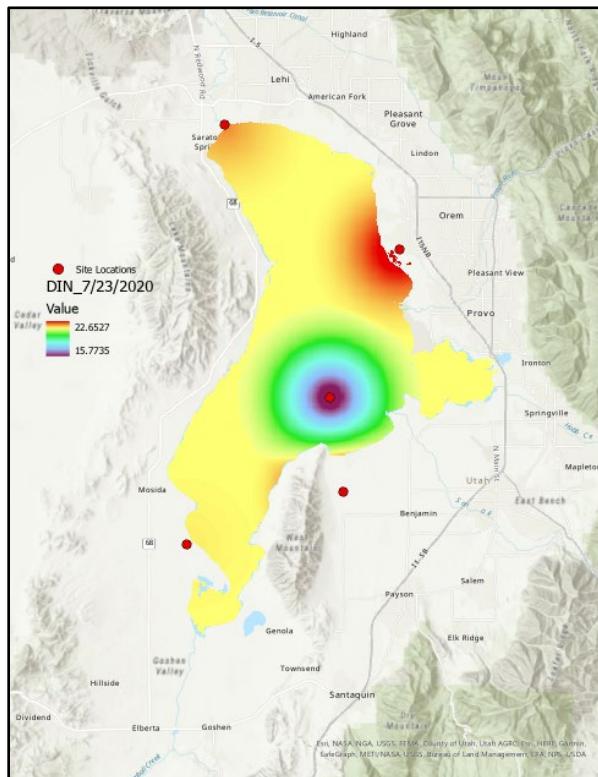


Figure 22 – 7/23/2020 DIN Interpolation Results Map

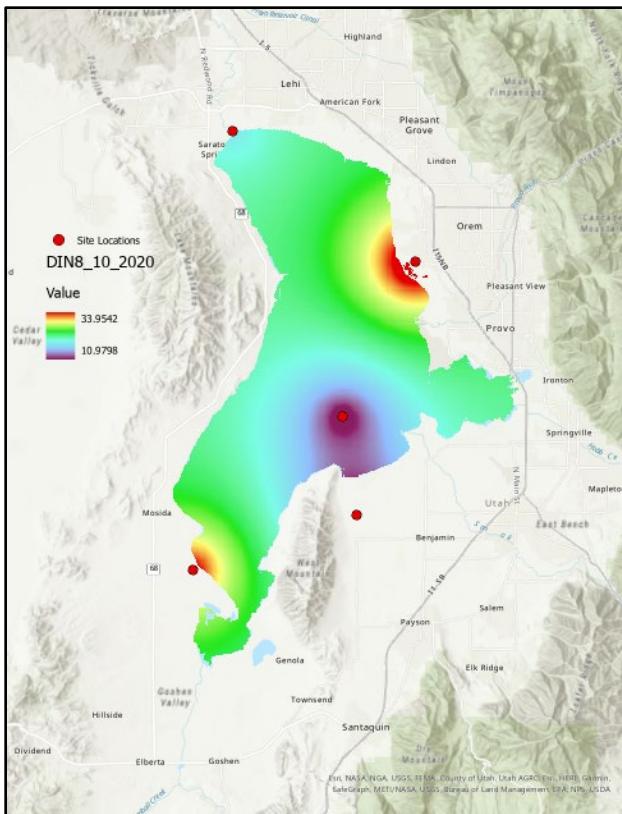


Figure 23 – 8/10/2020 DIN Interpolation Results Map

Table 16 – 2020 Weekly AD Interpolation Results

Date	Tons of DIN 2020	Tons of TP 2020
1/7/2020	6.06	0.95
1/15/2020	2.24	0.48
1/22/2020	1.94	0.48
1/28/2020	3.83	0.60
2/5/2020	3.03	0.76
2/12/2020	6.92	0.57
2/19/2020	7.78	0.57
2/26/2020	8.27	1.53
3/5/2020	8.27	1.53
3/12/2020	8.27	1.96
3/19/2020	8.27	1.96
3/26/2020	12.46	3.09
4/2/2020	12.46	3.09
4/9/2020	6.86	0.74
4/16/2020	6.86	0.73
4/23/2020	14.95	2.28

5/1/2020	87.41	27.49
5/8/2020	14.21	4.28
5/15/2020	11.36	2.04
5/22/2020	4.57	1.76
5/29/2020	3.13	1.65
6/4/2020	3.25	2.02
6/11/2020	22.84	4.14
6/18/2020	11.13	2.19
6/25/2020	7.18	1.16
7/2/2020	8.73	2.65
7/10/2020	7.04	0.69
7/17/2020	10.14	1.97
7/23/2020	8.96	1.75
7/30/2020	9.77	0.97
8/10/2020	8.87	1.11
8/21/2020	14.29	2.10
8/28/2020	20.07	2.32
9/4/2020	23.81	4.94
9/11/2020	9.50	20.79
9/18/2020	7.62	0.92
9/25/2020	9.84	1.55
10/2/2020	5.37	1.03
10/9/2020	7.06	1.12
10/15/2020	6.28	1.26
10/23/2020	5.64	0.76
10/29/2020	4.20	3.91
11/12/2020	9.88	6.60
11/19/2020	5.46	3.91
11/25/2020	1.98	0.82
12/3/2020	3.74	1.26
12/10/2020	1.95	0.65
12/16/2020	2.84	0.60
12/23/2020	2.84	0.60
12/30/2020	2.84	0.60
TOTALS	482.29	132.96

Table 17 – 2019 Weekly AD Interpolation Results

Date	Tons of DIN 2019	Tons of TP 2019
1/4/2019	3.64	1.50
1/11/2019	9.20	0.72
1/18/2019	9.20	0.72

1/25/2019	9.20	0.72
2/2/2019	8.41	0.69
2/9/2019	8.41	0.69
2/16/2019	5.21	0.31
2/28/2019	5.21	0.31
3/9/2019	138.08	10.80
3/16/2019	138.08	10.80
3/23/2019	7.53	0.28
3/30/2019	7.53	0.28
4/4/2019	7.53	0.28
4/11/2019	7.53	0.28
4/18/2019	7.53	0.28
4/25/2019	8.14	0.57
5/3/2019	8.14	0.57
5/10/2019	8.14	0.57
5/17/2019	23.93	4.26
5/24/2019	24.55	2.08
5/30/2019	20.63	0.69
6/7/2019	49.68	10.65
6/14/2019	26.65	4.72
6/21/2019	18.22	3.65
6/28/2019	19.39	3.24
7/5/2019	34.20	8.31
7/12/2019	53.15	11.38
7/19/2019	26.96	21.43
7/26/2019	17.31	12.48
8/2/2019	55.42	49.81
8/9/2019	42.98	36.73
8/16/2019	28.21	19.41
8/23/2019	19.51	7.85
8/30/2019	10.33	2.77
9/4/2019	10.33	3.62
9/11/2019	12.12	4.17
9/18/2019	16.16	4.30
9/25/2019	16.87	3.48
10/2/2019	20.03	1.80
10/9/2019	8.15	1.83
10/16/2019	10.55	1.21
10/23/2019	16.49	2.61
10/30/2019	12.19	2.16
11/6/2019	4.62	0.92
11/13/2019	7.83	0.59
11/20/2019	12.03	1.24

11/27/2019	5.79	0.52
12/4/2019	5.79	0.52
12/13/2019	13.87	1.03
12/20/2019	5.71	1.04
12/27/2019	5.71	1.04
TOTALS	1052.08	261.88

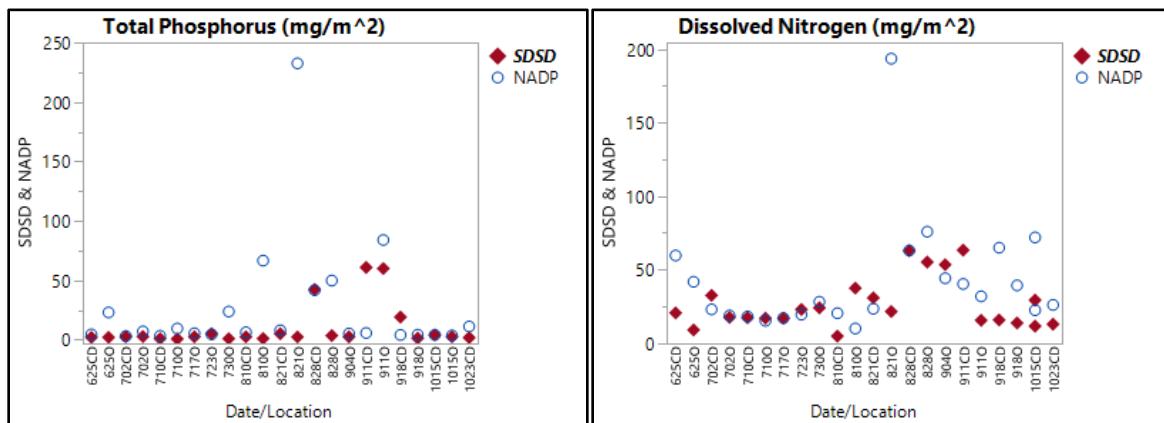


Figure 24 –Filtered vs Nonfiltered Scatterplot of TP and DIN

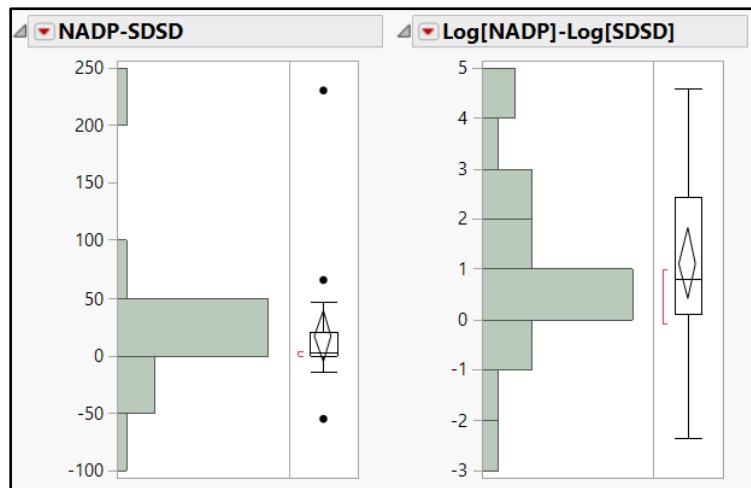


Figure 25 – Difference and Log Difference of TP Between Filtered and Nonfiltered

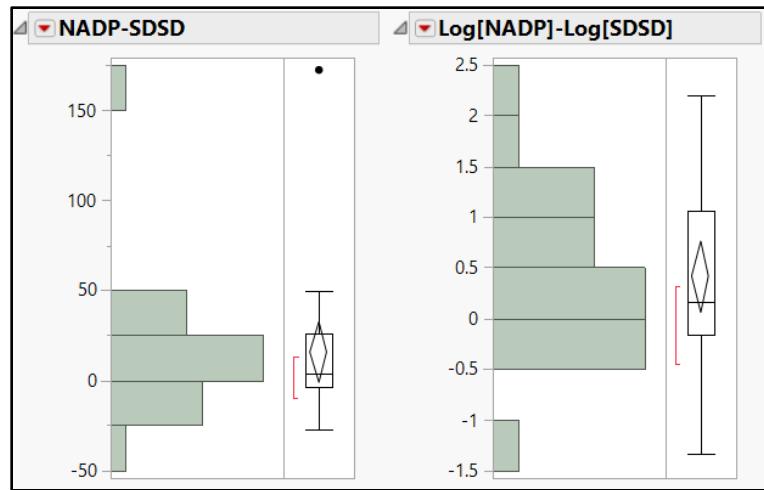


Figure 26 – Original and Transformed Distributions of DIN Difference Filtered vs Nonfiltered

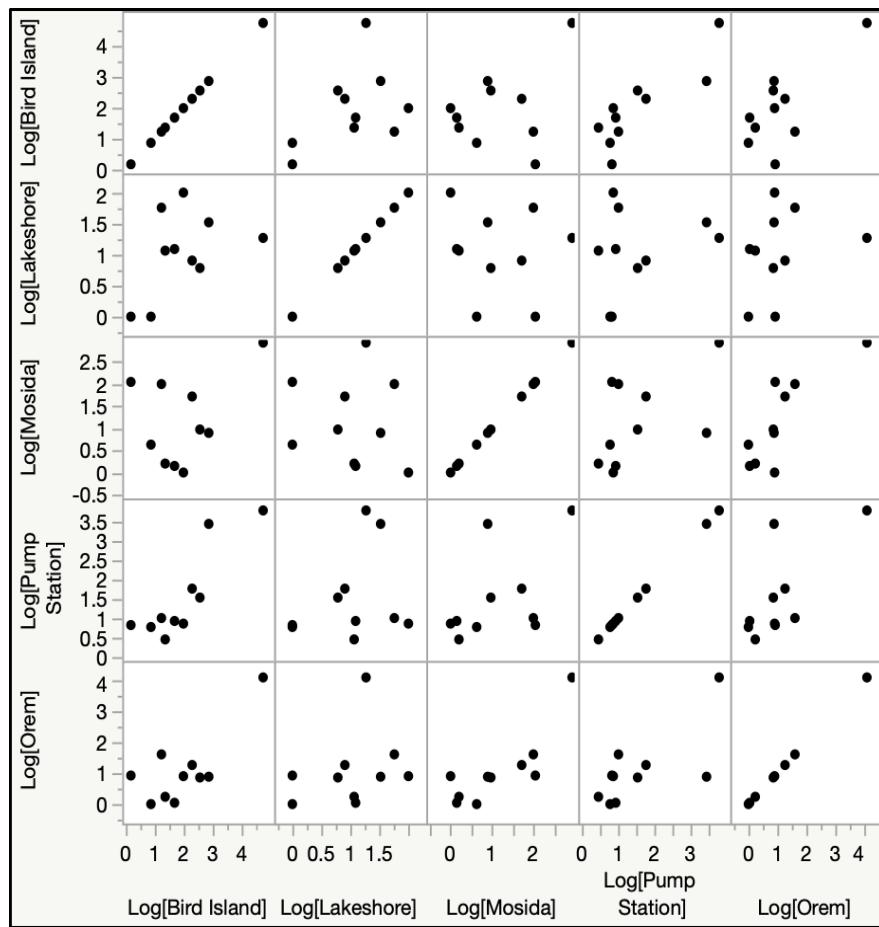


Figure 27 – TP Scatterplot Matrix (Log Transformed Data)

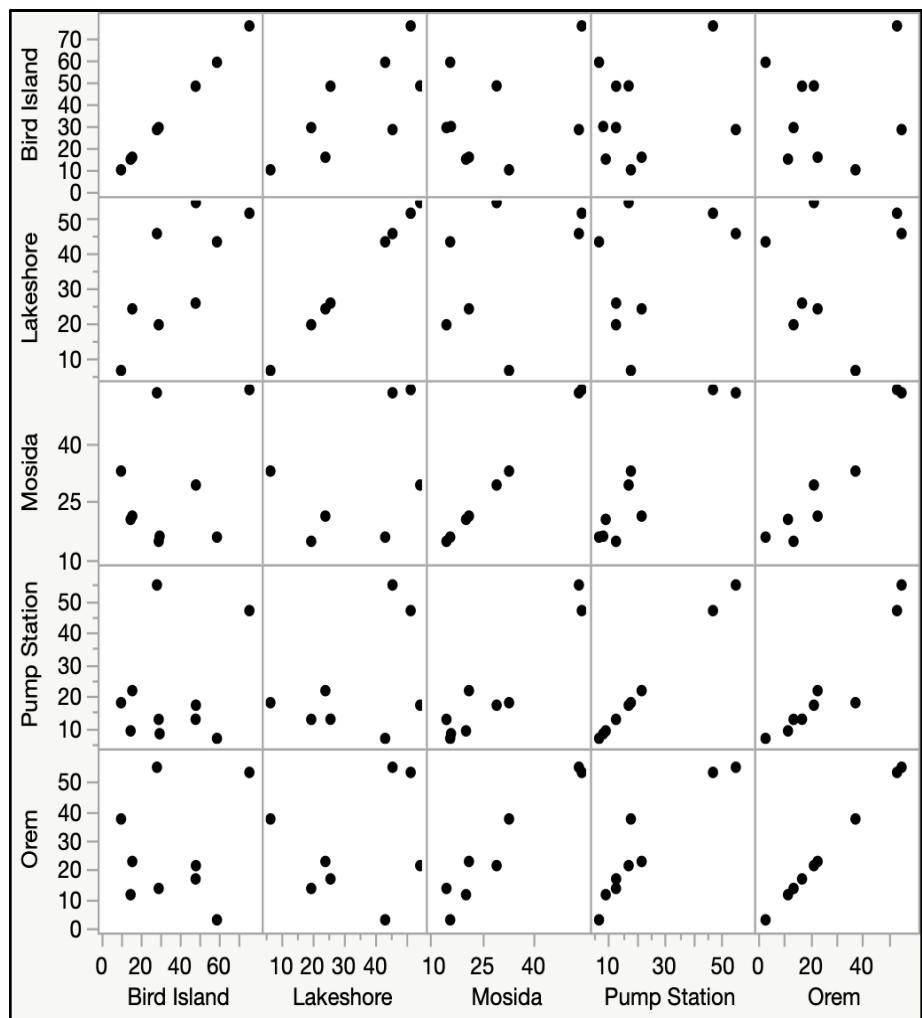


Figure 28 – TP Scatterplot Matrix Before Transformation

ProQuest Number: 28538364

INFORMATION TO ALL USERS

The quality and completeness of this reproduction is dependent on the quality
and completeness of the copy made available to ProQuest.



Distributed by ProQuest LLC (2021).

Copyright of the Dissertation is held by the Author unless otherwise noted.

This work may be used in accordance with the terms of the Creative Commons license
or other rights statement, as indicated in the copyright statement or in the metadata
associated with this work. Unless otherwise specified in the copyright statement
or the metadata, all rights are reserved by the copyright holder.

This work is protected against unauthorized copying under Title 17,
United States Code and other applicable copyright laws.

Microform Edition where available © ProQuest LLC. No reproduction or digitization
of the Microform Edition is authorized without permission of ProQuest LLC.

ProQuest LLC
789 East Eisenhower Parkway
P.O. Box 1346
Ann Arbor, MI 48106 - 1346 USA