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Measuring and Calculating Current Atmospheric Phosphorous and Nitrogen Loadings on Utah Lake Using Field Samples, Laboratory Methods, and Statistical Analysis: Implication for Water Quality Issues

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Brigham Young University

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Measuring and Calculating Current Atmospheric Phosphorous and Nitrogen Loadings on
Utah Lake Using Field Samples, Laboratory Methods, and Statistical
Analysis: Implication for Water Quality Issues

Jacob Milton Olsen

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

Measuring and Calculating Current Atmospheric Phosphorous and Nitrogen Loadings on Utah Lake Using Field Samples, Laboratory Methods, and Statistical Analysis: Implication for Water Quality Issues

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Master of Science

Atmospheric nutrient loading and transport through precipitation and dry deposition is one of the least understood yet one of the most important pathways of nutrient transport into many lakes. These nutrients, phosphorus and nitrogen, are essential for aquatic life and often play major roles in algae blooms that occur in lakes and reservoirs. Often heavy algal growth intensifies a variety of water quality problems. Utah Lake may be even more susceptible to atmospheric deposition due to its large surface area to volume ratio and proximity to Great Basin dust sources.

In this study, eight months of atmospheric deposition data were collected and analyzed from five locations near Utah Lake. Geospatial maps were created to show the temporal distribution of phosphorus and nitrogen. Evaluation of the atmospheric deposition results indicate that between 8 to 350 tons of total phosphorus and 46 to 460 tons of dissolved inorganic nitrogen were deposited onto the surface of Utah Lake over an eight-month period. Both estimates were based on assuming that the deposition decreased exponentially from the sampling station to the middle of the lake. The large difference results from using only samples with no visible particles or insects present to give the low estimate and all samples to give the high estimate.

These nutrient loading values are very significant in that it has been estimated that only about 17 tons year⁻¹ of phosphorus and about 200 tons year⁻¹ of nitrogen are needed to support a eutrophic level of algal growth in Utah Lake. Atmospheric deposition was found to be a major contributor in providing a eutrophic nutrient load to Utah Lake. Further, it is likely that the actual deposition loading is much higher than 8 tons per 8 months thus indicating that deposition alone adds a eutrophic phosphorus loading to the lake. Since conditions are similar in much of the Great Basin and other areas of Western United States, this seems to be a very significant finding relative to nutrient evaluation and feasible management scenarios.

The results also indicate that one might expect to see more cyanobacteria blooms (Harmful Algal Blooms) in shallow ponds in this area if atmospheric deposition is the main source of nutrients, since N to P ratios are low and thus more situations arise where a shortage of ionic nitrogen favors these nitrogen-fixing cyanobacteria.

Keywords: Utah Lake, phosphorus, nitrogen, atmospheric deposition, eutrophication, harmful algal blooms

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1 INTRODUCTION

Nutrients have been the focus of considerable scientific research in relation to eutrophication and also the growth of harmful algal blooms (HABs) (Anderson et al. 2002; Heisler et al. 2008). Nutrients can enter an aquatic ecosystem in a variety of ways; surface tributaries, municipal wastewater discharge, groundwater and the atmosphere. Of these different avenues, atmospheric deposition is commonly neglected during the formation of a nutrient budget. However, since increased eutrophication of water bodies by nitrogen (N) and phosphorus (P) is a growing problem in many areas, atmospheric deposition is being recognized as an important part of the total nutrient budget for many aquatic ecosystems (Cole et al. 1990; Jassby et al. 1994; Lewis 1981; Schindler et al. 1976).

Shallow lakes such as Utah Lake might be even more susceptible to the atmospheric deposition, given their large surface area to volume ratios. Despite these characteristics, atmospheric deposition is commonly neglected with respect to the nutrient budgets of Utah Lake (PSOMAS 2007). The objective of this work is to evaluate: (1) spatial variability of total phosphorus (TP) and dissolved inorganic nitrogen (DIN) loads over the surface of Utah Lake, and (2) temporal variability of TP and DIN loads among seasons.

2 BACKGROUND AND LITERATURE REVIEW

Recently, there has been increased interest in nutrients in Utah Lake because of controversy about the feasibility of reducing its very large nutrient loadings to a degree that phosphorus actually could be made limiting to overall algal growth, as well as to limit HABs (DWQ 2016; Merritt and Miller 2016; PSOMAS 2007). Among well-understood factors that contribute to HABs are abundant light, water clarity, warm water temperatures, slow-moving or stagnant waters, and high nutrient levels. Of these factors, nutrients are usually the only possibly controllable factors. Utah Lake exhibits many of these characteristics, or all, depending on climatology and seasonal effects.

In 2004, Utah Lake was listed on Utah's §303(d) list for exceedance of state criteria for total phosphorus TP and total dissolved solids (TDS) concentrations. The State of Utah's Division of Water Quality conducted a study to calculate total phosphorus loadings to Utah Lake, shown in Figure 2-1. The sources that were included in this study were tributaries, groundwater, springs, and miscellaneous surface flows. Of the total phosphorus loading, the tributaries were found to contribute 97.2% (PSOMAS 2007). Atmospheric deposition was not considered mainly since essentially no information was available for this area. In addition, other research has been performed to determine the effect of historic phosphorus sediments on Utah Lake's water quality (Abu-Hmeidan et al. 2018). Results found sediment reflux for Utah Lake alone can contribute anywhere between 0.24 to 19 mg/L of TP to a water column.

Merritt and Miller (2016) completed the most intensive nutrient balance to date for Utah Lake. In addition to confirming about the same P loading as the earlier DWQ and PSOMAS studies, they evaluated the impact of the loading using the Larsen and Mercier Trophic State model and the Carlson Trophic State Index model (Carlson 1977; Larsen and Mercier 1975). They concluded that the actual lake state is currently moderately eutrophic, but that the P and N loading to the lake are some 15 to 20 times larger than needed to support a eutrophic level of algal growth. For the total loadings the N/P ratio was found to be about 8, which indicates that if nutrients were limiting then one might expect nitrogen to be more limiting than P. This fact may have some impact, though tenuous, on the presence of HABs in the lake at times. Overall Merritt and Miller concluded that the evidence was very strong that phosphorus and nitrogen could not be reduced enough to make nutrients the overall limiting factors to algal growth and reported that light limitation via the high natural turbidity of the lake was likely the overall limiting factor. They also pointed out the importance of more accurately quantifying atmospheric deposition of nutrients as the feasibility of nutrient control programs are considered. Based on the Larsen-Mercier model, they concluded that only 17 tons year⁻¹ of phosphorus was needed to supply the moderately eutrophic actual state of the lake. Using a N/P ratio of 12 for the algae, this means about 200 tons year⁻¹ of nitrogen would be needed by Utah Lake algae. Current loadings are much higher than this and it would not be feasible to reduce them to this level.

The National Atmospheric Deposition Program (NADP), the primary atmospheric deposition monitoring program in the United States, does not measure TP in precipitation

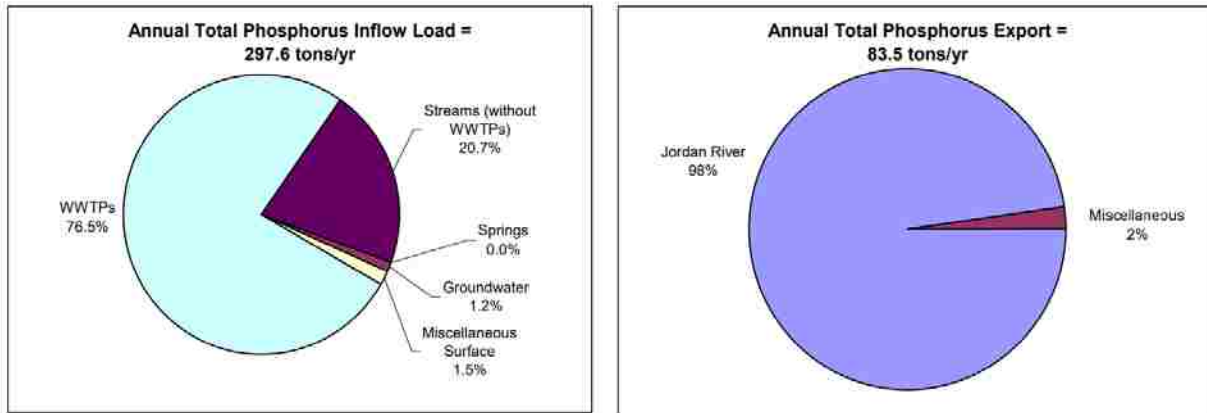


Figure 2-1: Total Phosphorous Loading Summary (PSOMAS 2007)

samples. As a result, little data are available for atmospheric deposition of TP in Utah. However, there have been several studies performed in the Western United States with regard to nitrogen deposition. In these studies, nitrate deposition in the Utah Wasatch Front produced concentrations as high as 2.00 – 2.05 kg/ha N (Nanus et al. 2003).

2.1 Deposition

This section provides information related to the collection of both wet and dry depositions as well as specific considerations for collection methods.

2.1.1 Types of Deposition

There are three main classifications of atmospheric deposition; bulk deposition, wet deposition, and dry deposition. Bulk deposition has been the most common form of atmospheric collection for decades (Uttormark et al. 1974; Welch and Legault 1986). The bulk deposition has

no provision to exclude dry deposition during dry periods. Thus, gases and particulate matter may influence the chemical composition of precipitation passing the contaminated funnel (Slanina et al. 1983). Recently, it has become increasingly more common to collect both wet and dry deposition.

Wet deposition is defined as the process by which atmospheric pollutants become associated with cloud and precipitation droplets (or particles) and are subsequently delivered to the earth's surface during precipitation. The quantity of compounds that are received per unit area of the surface is considered wet deposition. Wet deposition is equal to the amount of precipitation per unit area of the collection basin multiplied by the measured concentration of the pollutant in the sample. Wet deposition is considered to be independent of receptor surface. Despite the apparent simplicity of measuring wet deposition, there can be some sources of error. To minimize error, it is recommended that wet deposition samples only be exposed to the atmosphere during collection. In addition, shorter exposure periods are recommended when sample deterioration is expected due to biological and/or chemical action.

Dry deposition is the process whereby gases and aerosols are deposited directly from the atmosphere to surfaces. Dry deposition is governed by the concentration in the air, turbulent transport processes in the atmospheric boundary layer, gravitational settling, molecular diffusion, and by the capability of the surface to capture or absorb gases and particles (Willem Erisman et al. 1994). Dry deposition sources principally include particulates from the burning of fossil fuels, forest fires, wind erosion of soil, aerosols from agricultural practices, and plant pollen (Ahn and James 2001; Cole et al. 1990; Jassby et al. 1994). The process of dry deposition can contribute greater amounts of nutrients than wet deposition (Ahn and James 2001; Anderson and Downing 2006; Newman 1995).

2.1.2 Deposition Collection

Sampling devices used in the collection of atmospheric deposition vary, depending on the type of deposition to be measured. If researchers are only concerned with bulk deposition, then funnels with a collection basin can be deployed to measure the total deposition for a specific time period. Others may only require wet deposition samples for which the researcher can simply place a rain gage at the sample location before the storm and collect the sample immediately after the storm. Still, others may want to collect both wet and dry deposition thus using a sample collector with two buckets and a moisture sensor. The bucket corresponding to either wet or dry deposition is left open to the atmosphere depending on whether wet deposition or dry deposition data are being collected.

Several techniques have been developed to estimate deposition (Willem Erisman et al. 1994). While wet deposition can be measured with reasonable accuracy, direct measurement of dry deposition proves to be more difficult. This is mostly due to the fact that the dominant mechanisms for dry deposition are turbulence and surficial properties. There is a high variability in measurements of dry deposition to different types of surfaces used in collection devices. When measuring dry deposition to a water body, it is essential to have a wet surface for collection (Anderson 2004; Cole et al. 1990; Gomolka 1975; Peters and Reese 1995). The NADP estimates dry deposition using only a dry plastic surface. Boundary-layer resistance governs depositional velocities, but a dry surface imposes an artificially high aerodynamic resistance and lowers deposition rates (Anderson 2004; Jassby et al. 1994).

2.1.3 Spatial and Temporal Variation

Studies have shown that deposition varies both spatially and temporally. Particular studies comparing TP deposition to lake shorelines and at increasing distance from shore found significantly greater deposition near the shoreline (Cole et al. 1990; Gomolka 1975). This indicates that samplers may only represent localized deposition. Contamination is also a concern although some apparent contaminants might reasonably be considered part of the local deposition. Contamination has been found to be a problem in many studies. There is not general agreement on whether to include these local contaminants as part of the deposition (Ahn and James 2001; Cole et al. 1990; Graham and Duce 1979; Peters and Reese 1995). Much of the controversy comes from the issue of the definition of the appropriate geographic area and the size of the ecosystem that should be used for the lake being considered.

The spatial variance of atmospheric deposition is well illustrated by maps produced by the NADP. The resolution of these maps are quite crude; i.e., there are only 5 active monitoring sites in Utah and none in the Utah Valley. These NADP sites are located in/near Logan, Green River, Bryce Canyon, Canyonlands, and Vernal. The temporal variance of nutrient deposition is also well documented (Linsey et al. 1987; Shaw et al. 1989). These temporal variances are attributed to seasonal biological activities and agricultural processes. It is important to also understand that the NADP seek to measure global atmospheric deposition. This study is concerned with any atmospheric deposition that could potentially come in contact with Utah Lake. Because of this, all sources, both regional and local, are considered legitimate.

2.2 Aquatic Chemistry

This section provides information about the transport of nitrogen and phosphorus through the atmosphere.

2.2.1 Nitrogen

The atmospheric input of DIN can be especially significant to aquatic ecosystems (Larsen et al. 2001; Shaw et al. 1989). The three forms of N (Nitrate, ammonia, and organic nitrogen) are deposited via different routes. The most significant sources of nitrate (NO_3) to the atmosphere occur through combustion processes, the partitioning of HNO_3 to the aerosol phase by ammonia gas in the atmosphere, and microbial oxidation of ammonium in soil and water (Galloway and Likens 1981). Once NO_x is released into the atmosphere, a variety of complex photochemical reactions occur to oxidized nitrogen compounds and ultimately, produce aerosol nitrate and nitric acid. These end products are deposited onto surface waters (EPA 2000).

Ammonia gas (NH_3) enters the atmosphere via volatilization from animal waste, microbial decomposition of organic matter in oceans and soils, losses from the production and application of fertilizer, hydrolysis of urea in fertilized soils, and biomass combustion (Schlesinger and Hartley 1992). NH_3 is highly reactive and reacts in the atmosphere to form ammonium (NH_4^+). NH_4^+ is also formed through microbial transformation of organic nitrogen and microbial fixation in soil and water. NH_3 and NH_4^+ establish an equilibrium in the atmosphere and are dissolved in precipitation (EPA 2000).

Organic N comprises a wide variety of compounds with complex compositions. Generally, organic N comprises urea, pollen, and amino acids. They are primarily released from biological processes as well as from anthropogenic processes. They can be found in various states in the atmosphere.

2.2.2 Phosphorus

Phosphorus is an important nutrient for terrestrial ecosystems (Schlesinger and Bernhardt 2013). The transport of phosphorus through the atmosphere is fundamentally different than carbon and nitrogen in that there is not a stable gaseous phase for phosphorus in the Earth's atmosphere. Because of this, TP on a regional basis is mainly restricted to aerosols (Graham and Duce 1979; Mahowald et al. 2008). Sources of phosphorus that contribute to atmospheric deposition include soil erosion, burning, agricultural practices, and other industrial emissions (Graham and Duce 1979; Redfield 2002). Historically, phosphorus has not been included in atmospheric deposition studies, however, several reports suggest that phosphorus deposition should be included more frequently (Ahn and James 2001; Cole et al. 1990; Gomolka 1975; Jassby et al. 1994; Newman 1995; Peters and Reese 1995). Recent work showed that shoreline soils have high TP levels, on the order of 800 mg/kg. This implies that dust deposits from the shore could be a significant source of TP in Utah Lake (Abu-Hmeidan et al. 2018).

TP is the only form of phosphorus that was measured in this study. TP incorporates the total of all filterable and particulate phosphorus forms. TP was analyzed because of its close association with a wide variety of limnological variables and the link between TP loading estimates and phosphorus content found in many lake studies (Peters 1986).

2.3 Utah Lake

Utah Lake (Figure 2-2) is a shallow, eutrophic, basin-bottom lake in a semi-arid region. It is the third largest freshwater lake west of the Mississippi River in surface area and has the largest surface area of any freshwater lake in Utah. Utah Lake rests in Utah Valley and is generally bounded by several municipal areas on the south, east, and north and a sparsely populated area to the west. It has an average depth of 9 ft. (2.74 m), a max depth of 14 ft. (4.3 m), and a surface area of approximately 88,000 acres (354 km²).



Figure 2-2: Aerial Photograph of Utah Lake

The primary sources of water to the lake are snowpack runoff from the Wasatch and Uinta Mountains and small streams and creeks. Other than precipitation and groundwater, the lake has at least fifteen key tributaries. The major tributaries include the American Fork River, Benjamin Slough, Hobble Creek, Mill Race Creek, Provo River, and the Spanish Fork River. The Provo River, together with the Spanish Fork River, account for approximately 60% of the inflow into Utah Lake (PSOMAS 2007). The Jordan River is the only surface outlet and discharges northward toward the Great Salt Lake.

The area surrounding Utah Lake has an average annual precipitation of approximately 13 inches (NOAA 2016). Approximately 50% of the water flowing into Utah Lake is lost to evaporation each year. This high evaporation rate coupled with the very shallow nature of Utah Lake results in moderately high levels of dissolved solids, averaging about 900 mg/l and ranging from about 500 mg/l during very wet years to about 2000 mg/l during very dry years (Merritt and Miller 2016).

2.4 Collection Consideration

The direct measurement of atmospheric nutrient deposition has several challenges. One major challenge involves the contamination of samples by insects, plant matter, or bird excrement. (Ahn and James 2001; Newman 1995; Peters and Reese 1995). Some investigators have attempted to solve this problem simply by increasing the number of samplers deployed, thus increasing the chance of collecting sufficient uncontaminated samples for analysis (Anderson and Downing 2006; Peters and Reese 1995). While this approach may yield an adequate number of uncontaminated samples, it is also associated with increased costs and time, while only yielding a fraction of the potential data. One study attempted to remove the effect of

contamination by outlier detection and statistical methods. However, the study reported standard errors as large as the mean. Still, other studies removed contaminated samples from analysis altogether (Anderson and Downing 2006; Tamatamah et al. 2005). This strategy commonly leads to frequent missing data, especially during summer months.

An additional challenge of direct measurement of nutrient deposition comes from sample contamination by relatively local dust sources (Pollman et al. 2002). This can artificially inflate estimates of regional deposition. Several studies have indicated sample contamination by local resuspension of material (Jassby et al. 1994; Lewis 1981; Tamatamah et al. 2005). To minimize this form of contamination, collectors have been elevated to greater than 1 meter above the ground surface (Blake and Downing 2009). For this study local nutrient sources are not considered contamination, as they may be a significant source of TP loading to Utah Lake. Although, this paper may refer to local nutrient sources as contamination, this is only done to remain consistent with NADP definitions of contamination. For a complete definition of contamination see Section 3.3.

3 MATERIALS AND METHODS

This section provides the sampling outline, procedure, and an overview of the methods that were used for laboratory analysis.

3.1 Sampling Network

To characterize depositional patterns on Utah Lake I established a network of sampling stations was established (Figure 3-1). I deployed six Automated samplers a several locations. Five of these were situated near the shore of Utah Lake, and the sixth was deployed on Farmington Bay in the Salt Lake Valley. Detailed locations of each site are given in Table A-1. Locations were evenly distributed around Utah Lake to obtain a representative measure of the total atmospheric deposition across the lake surface. I designed six samplers that operate similar to the Aerochem Metrics (ACM) bucket collectors used by the NADP. More information on the design and functionality of these samplers are given in Appendix B. Placement of each sampler followed similar protocols established by the NADP (NADP 2014). Any variation in the NADP protocol and site selection is stated in Table A-1. The Farmington Bay site was chosen to compare deposition rates outside of the Utah Valley.



Figure 3-1: Sample Locations Around the Parameter of Utah Lake

Each automated sampler consisted of two polyethylene buckets on an elevated table with a moveable cover, shown in Figure 3-2. These buckets measured 0.0615 m^2 at the bucket opening and were 35 cm high. Movement of the cover was initiated by a moisture sensor. This moisture sensor was calibrated to ensure that dew would not trigger the movement of the bucket cover. During dry periods the cover shielded the wet-deposition bucket and when activated by rain or snow, the cover shielded the dry deposition bucket and exposed the wet deposition bucket.



Figure 3-2: Automated Sampler at Mosida on May 4, 2017

3.2 Sample Collection

I collected sample at five sites around Utah Lake from May 4, 2017, to December 28, 2017, and from the sixth site near Farmington Bay from May 18, 2017, to December 28, 2017. Samples were collected weekly from each location in accordance with NADP protocol. During the weekly sampling, all buckets were replaced with clean ones. In order to simulate the collecting properties of a wet lake surface, the dry-deposition bucket at each site was pre-loaded with 3 L of deionized water (Anderson and Downing 2006; Jassby et al. 1994). This volume of water was chosen as a compromise between simulating water surface in the context of this standard sampling device while offering low evaporative loss and sample volume small enough to yield detectable concentrations and deposition rates.

3.3 Sample Processing and Analysis

The graduated cylinders, funnels, bottles, buckets, and all equipment in contact with the samples were cleaned with phosphorus-free detergent, acid-washed with 10% HCl solution, and kept in plastic bags until they were used for sample collection. Each batch of deionized water that was added to samplers was analyzed along with the deposition samples and any detectable nutrients were subtracted from deposition estimates. Contaminated samples were determined as overlapped samples (dry buckets that collected some rainwater), bulk deposition samples (a combine wet and dry deposition sample, due to sampler malfunction), samples with contaminants (bird droppings, insects, obvious algal growth) and samples that were collected longer than a week. Both contaminated and uncontaminated samples were used in analysis to describe a possible range of atmospheric loading to Utah Lake.

In the lab, small brushes were used to scrub the sides of the deposition buckets, and the water swirled to ensure that the contents and particles were removed. If needed, the wet sample volume was brought to 500 ml with deionized water to yield sufficient analytical volume. Samples were kept at 4 °C until analyzed. TP was analyzed using inductively coupled plasma (ICP). NH_4^+ was analyzed with the salicylate method and NO_3^- with the cadmium reduction.

Due to the fact that NO_2^- concentrations are commonly small relative to NO_3^- , their sum will simply be referred to as NO_3^- . Similarly, $\text{NH}_3 + \text{NH}_4^+$ will simply be referred to as NH_4^+ . Dissolved inorganic nitrogen (DIN) is here defined as $\text{NO}_3^- + \text{NH}_4^+$. All measurements are expressed as a mass per square meter per time on the basis of collector surface area.

3.4 Geostatistical Analysis of Nutrient Distribution

I used both TP and DIN deposition samples to create a spatial model that showed the nutrient distribution patterns around the lake. I calculated atmospheric nutrient loading rates from the concentration of nutrients in each sample (mg/L) and multiplied it by the amount of sample (L) to give milligrams of nutrients deposited. If distilled, deionized, water was added to bring samples up to analytical volume, any measurable nutrients from the distilled, deionized water were subtracted. Deposition rates were adjusted to unit area and time by dividing deposition by the surface area of the sampler (m^2) and the time represented by the sample. A step by step process for how loading rates were calculated for both dry and wet deposition are shown in Appendix C. All nutrient concentrations were converted to deposition loadings as described in Appendix C. The deposition loadings for each of the five sites were then entered into geostatistical software at each of the eleven points shown in Figure 3-3.

The geostatistical software that was used for spatial interpolation was developed by Aquaveo and is called Groundwater Modeling System (GMS) (AQUAVEO 2018). GMS contains several geostatistical tools useful in interpolation and autocorrelation among measured points. A single coverage was created to represent the boundary of Utah Lake during 2017 and is shown in Figure 3-4. The total area that was used for the lake for all calculations was 88,000 acres (354 km^2). Simple kriging was used as the interpolation method with the default variogram to represent the decrease in the deposition rate as distance increased onto the lake from the shoreline (Cole et al. 1990; Gomolka 1975). The variogram model function that was specified was exponential.

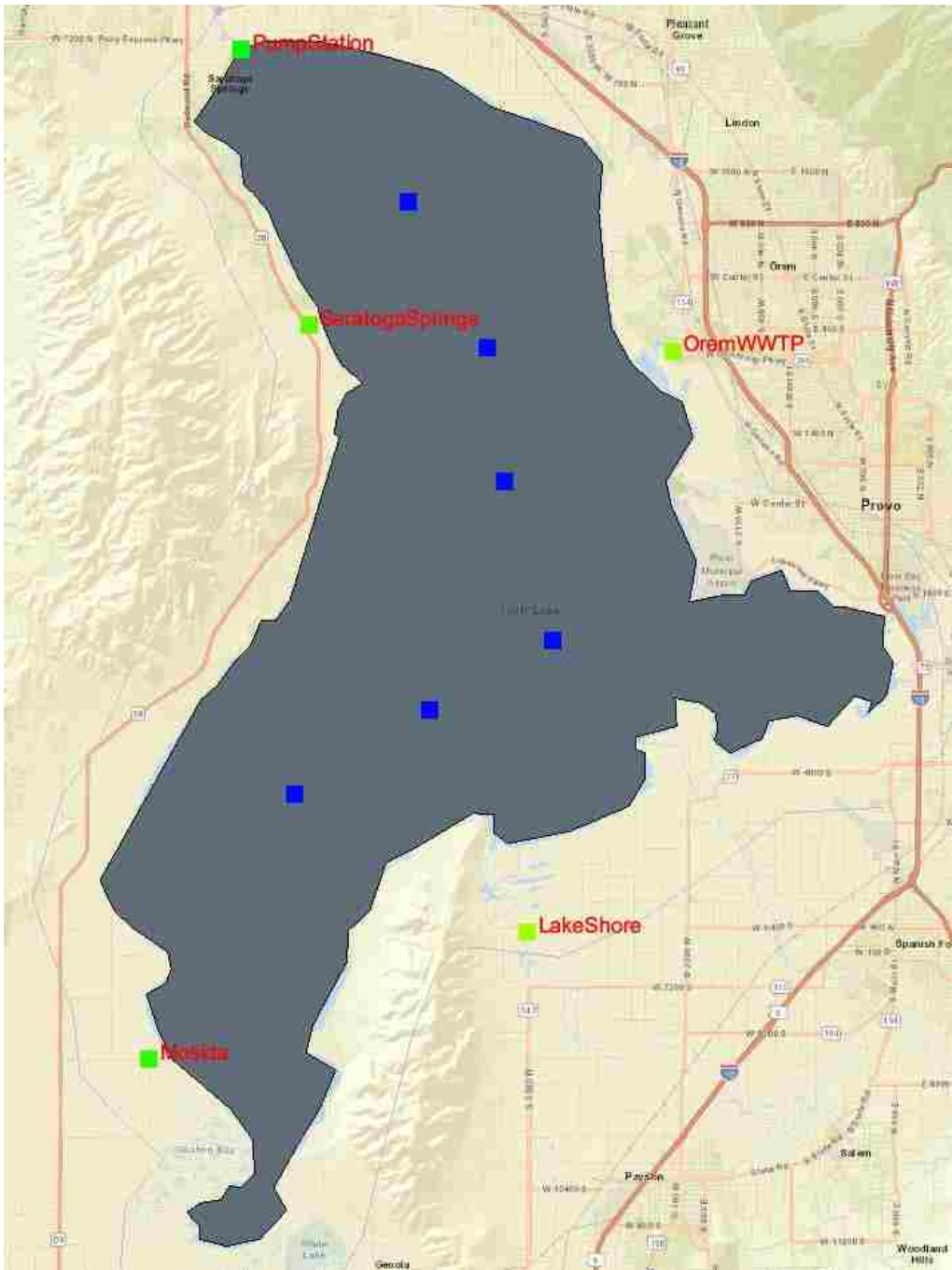


Figure 3-3: Utah Lake Coverage Showing the Eleven Points used in Interpolation



Figure 3-4: Coverage Used to Represent the Surface of Utah Lake

When creating the model to represent atmospheric deposition across the lake, five points were created to represent the five sites where deposition was measured; Lake Shore, Mosida, Saratoga Springs, Pump Station, and Orem WWTP. The weekly deposition loadings for each of the five sites were entered at these five points (Figure 3-3). Six points were also placed on the

lake coverage to divide the lake into six zones. These six points had the background atmospheric deposition assigned to them. For TP the background value used for these six points was 0.019 mg TP m⁻² week⁻¹ (Mahowald et al., 2008). For DIN the background value that was used for these points was 0.112 mg DIN m⁻² week⁻¹ (NADP 2014).

For any given week, the deposition loadings were interpolated across the lake onto a 2D grid with 3,398 cells. Each of the cells had an area of 101,722 m². The grid that was used to spatially interpolate atmospheric deposition rates is shown in Figure 3-5. By using simple kriging, a deposition rate was interpolated onto each cell of the 2D-grid. The deposition rate that was calculated for each cell was then multiplied by the area of that cell to give a nutrient loading (mg cell⁻¹ week⁻¹). All of the atmospheric nutrient loadings for each cell were then summed to yield a total nutrient loading for Utah Lake (mg week⁻¹) for that week. The nutrient loading was then converted into tons week⁻¹. This process was repeated for every week that data were collected.

For sites that had missing values for any week, the average of the remaining sites was used for that week. The nutrient loading for each week (31 weeks) was then summed to yield a total atmospheric nutrient loading for Utah Lake for eight months. For a detailed description of these calculations see Appendix C. This process was used for both the TP and DIN. Figure 3-6 shows an example of the spatial interpolation for TP deposition for May 4, 2017, through May 11, 2017.

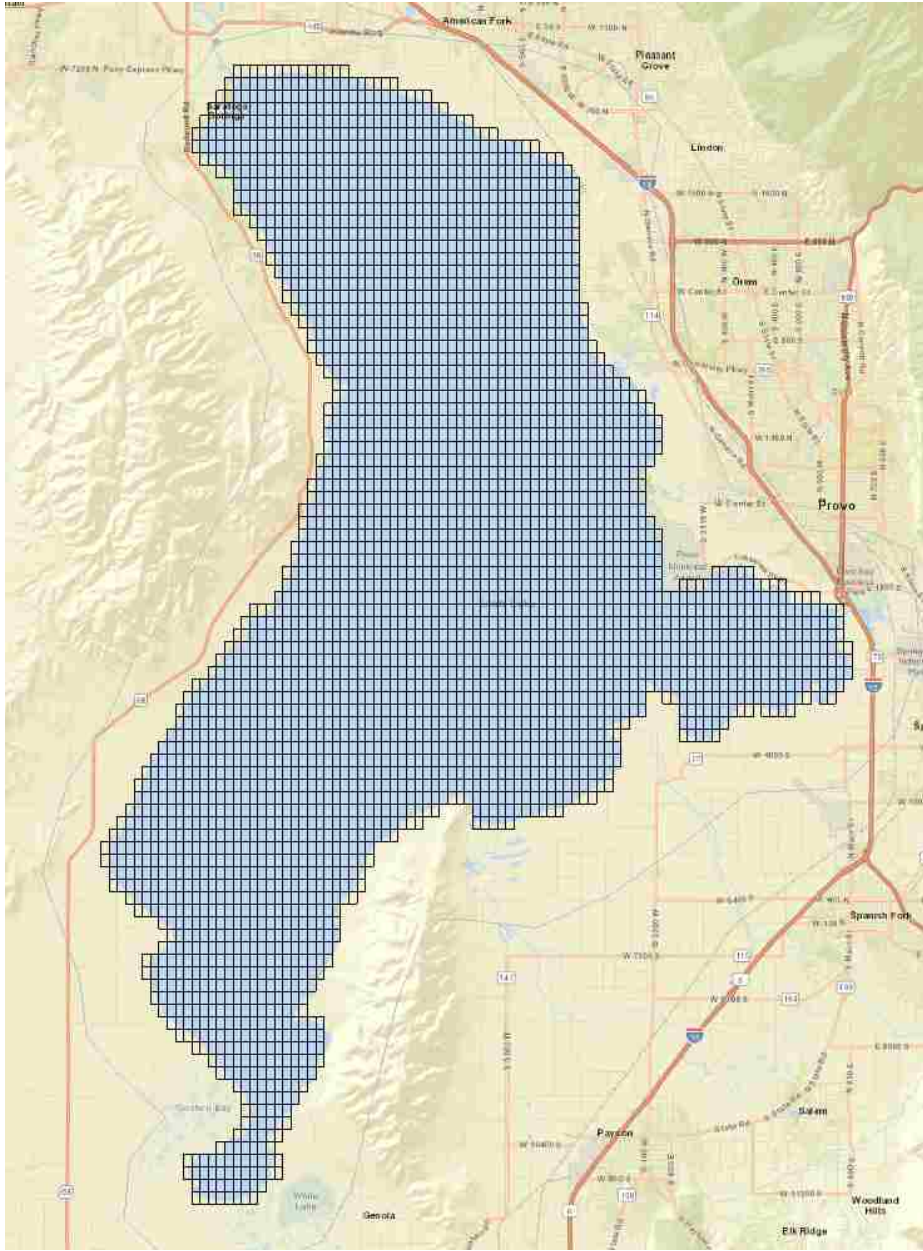


Figure 3-5: 2D-Grid that was used for Spatial Interpolation

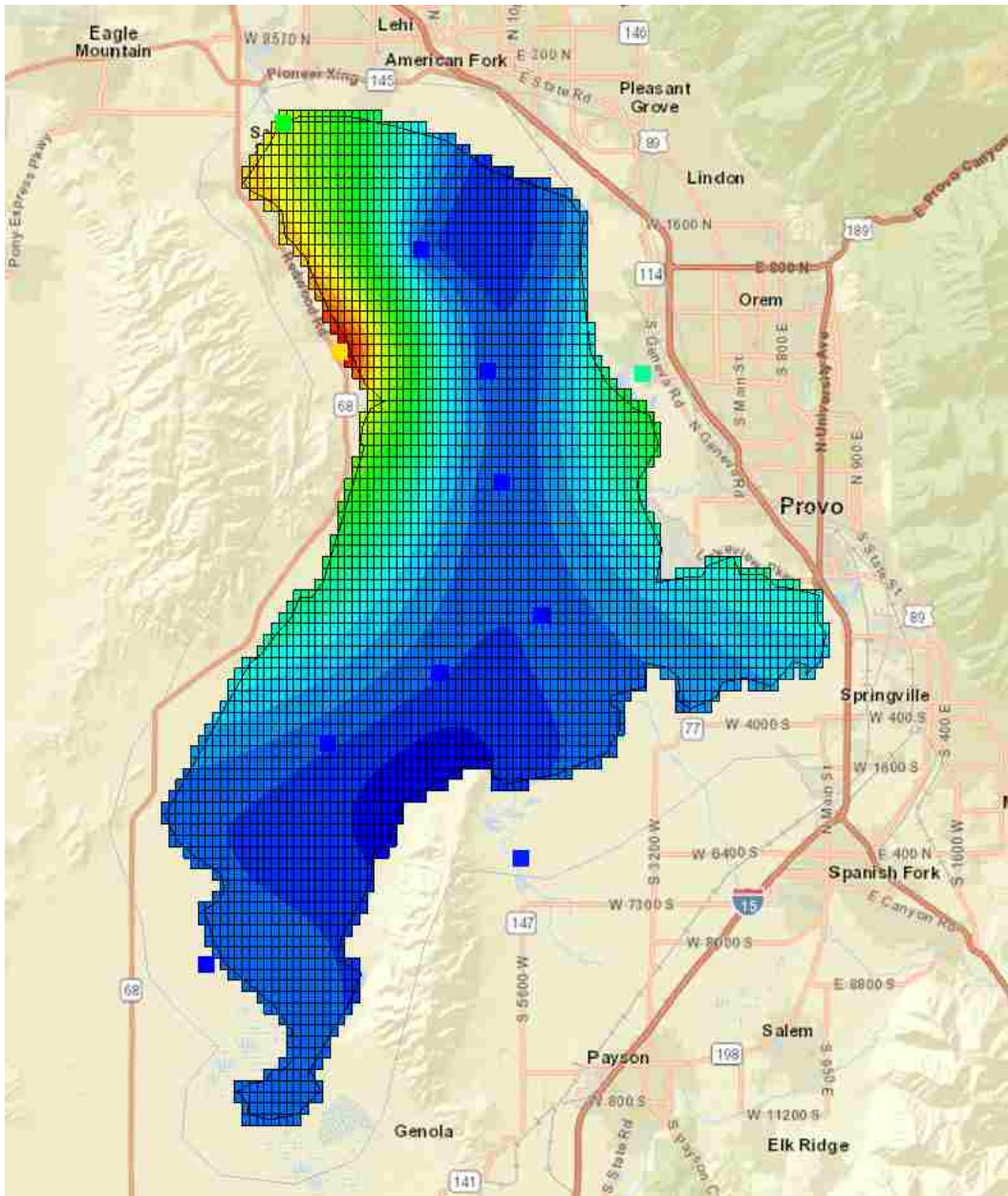


Figure 3-6: TP deposition on Utah Lake for May 4, 2017 through May 11, 2017

4 RESULTS

This section contains results from data that were gathered over a period of eight months (May-December).

4.1 Sampling Results

From May to December, 162 dry deposition samples and 59 wet deposition samples were collected. Table 4-1 shows the number of samples were collected from each site. Some split samples were collected and sent to a licensed laboratory (Chemtech). The comparative values for the analytical results between the licensed laboratory and Brigham Young Universities' Environmental Analytical Laboratory (EAL) for TP are shown in Table A-2 in Appendix A. Analysis on the DIN is not reported due to the samples not having been acidified and the samples being stored for several months before the analysis.

Table 4-1: Number of Dry and Wet Samples Collected at each Location

Location	Dry	Wet	Total
Lake Shore	29	12	41
Mosida	28	10	38
Saratoga Springs	30	14	44
Pump Station	28	10	38
Orem WWTP	22	5	27
Central Davis	25	8	33

4.2 Phosphorus Load Calculation

I computed means and several other statistical measures for the TP loads. These values are shown in Table 4-2. The average loading of all the sites is 7.93 mg of TP m⁻² day⁻¹. The mean values for individual site means range from 1.02 mg of TP m⁻² day⁻¹ at Central Davis to 31.38 mg of TP m⁻² day⁻¹ at the Saratoga Springs site. In addition to a high variability of the mean values, the standard deviation of samples at several sites are quite high, in all cases exceeding the mean. By taking the mean divided by the standard deviation the average coefficient of variation was calculated to be 0.19.

Table 4-2: Summary for TP Deposition Data from May 2017 through December 2017

Site	No. of Data	TP Concentration (mg/L)		Rain in/week	TP Load Rate (mg m ⁻² day ⁻¹)		
		Wet	Dry		Mean	S.D.	Skew
Lake Shore	41	0.68	0.38	0.25	1.33	1.95	0.82
Mosida	38	0.22	1.10	0.12	2.77	5.63	2.55
Saratoga Springs	44	0.60	5.15	0.17	31.38	88.73	2.14
Pump Station	38	0.59	0.85	0.16	3.78	20.14	4.68
Orem WWTP	27	1.62	0.39	0.11	1.26	2.65	3.33
Central Davis	33	0.49	0.37	0.20	1.02	2.60	3.64
Average	37	1.17	1.91	0.17	7.93	41.87	2.86

4.3 Nitrogen Load Calculation

I computed means and several other statistical measures for the DIN loads. These values are shown in Table 4-3. The average loading of all site means is 10.35 mg of N m⁻² day⁻¹. The

mean values for individual site means range from 1.59 mg of N m⁻² day⁻¹ at the Pump Station site to 36.06 mg of N m⁻² day⁻¹ at the Saratoga Springs site. In addition to a high variability of the mean values, the standard deviation of sample at several sites are quite high, in some cases exceeding the mean. By taking the mean divided by the standard deviation the average coefficient of variation was calculated to be 0.18.

Table 4-3: Summary for DIN Deposition Data from May 2017 through December 2017

Site	No. of Data	DIN Concentration (mg/L)		Rain in/week	DIN Load Rate (mg m ⁻² day ⁻¹)		
		Wet	Dry		Mean	S.D.	Skew
Lake Shore	41	4.30	1.15	0.25	4.09	4.06	0.47
Mosida	38	2.29	1.50	0.12	4.17	4.74	1.21
Saratoga Springs	44	4.86	6.00	0.17	36.06	124.62	3.31
Pump Station	38	4.29	0.38	0.16	1.59	2.33	2.31
Orem WWTP	27	7.55	1.33	0.11	5.23	4.60	3.04
Central Davis	33	7.23	1.57	0.20	5.27	5.80	1.30
Average	37	4.76	2.06	0.17	10.35	56.72	1.94

4.4 Site Comparison

Deposition rates varied spatially among sample locations from May through December. The spatial variation for TP and DIN are shown in Figure 4-1 and Figure 4-2, respectively. Precipitation data for all sites showed no significant differences. Dry deposition showed few site-to-site differences aside from the Saratoga Springs site.

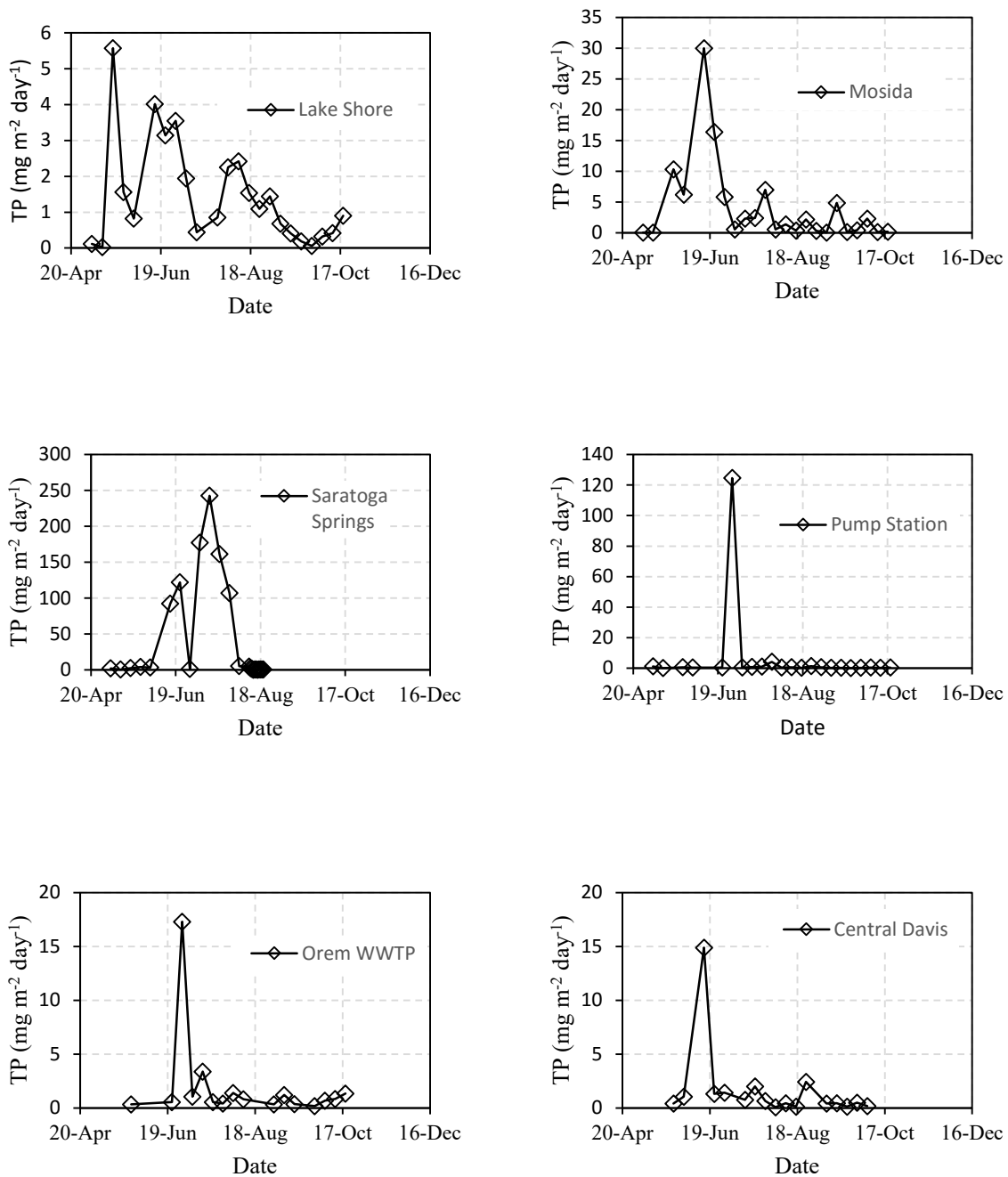


Figure 4-1: Temporal Variations in TP By Sample Locations

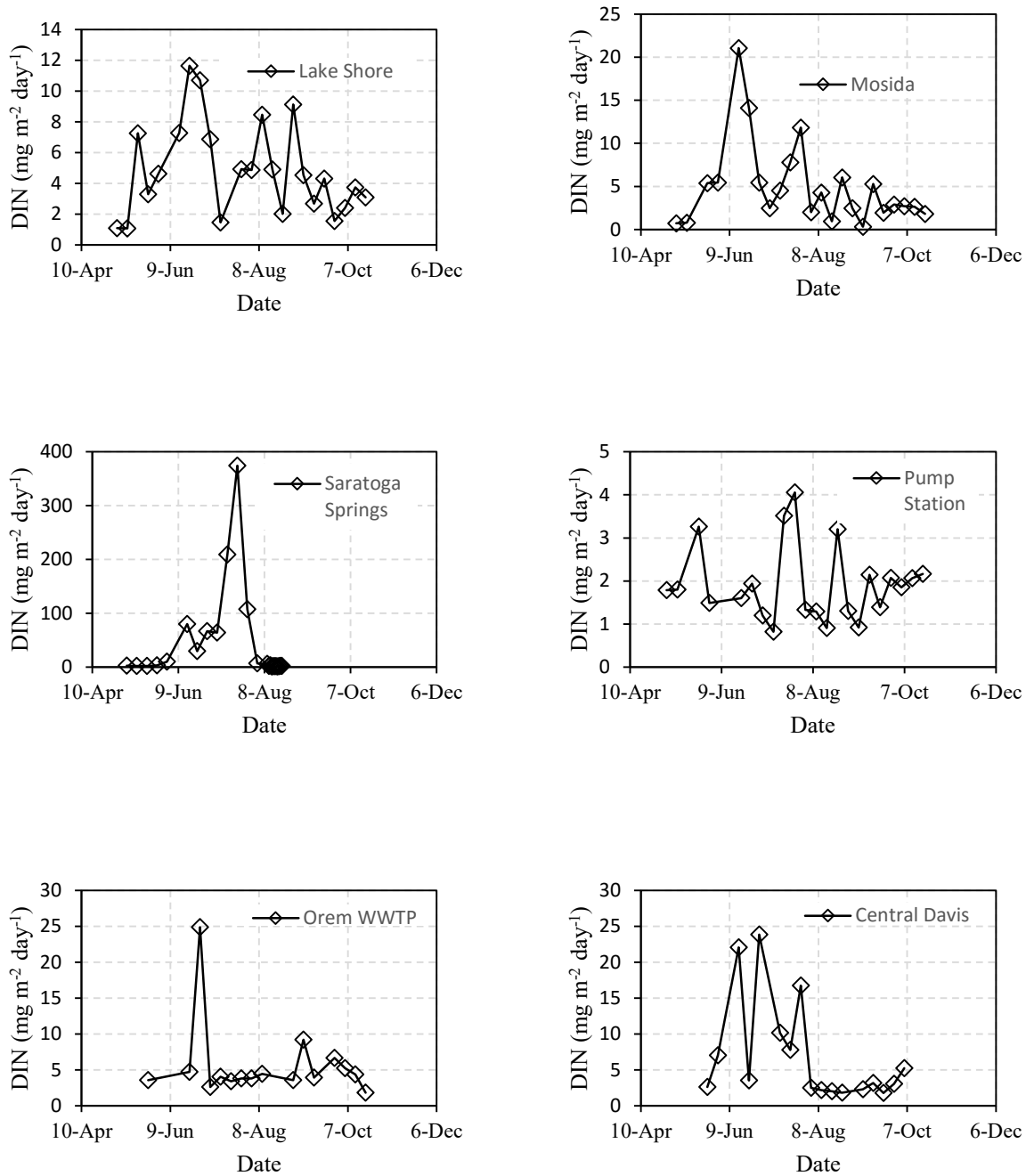


Figure 4-2: Temporal Variations in DIN By Sample Locations

The TP deposition for Saratoga Springs was found to be significantly higher than for all other sites. The differences and p-values of this comparison are shown in Table 4-4. This table shows how different each site is with respect to the Saratoga Springs site. This is thought to be mainly due to the local source of nutrient in the area. Near this site there is high exposure to bare earth with high concentration of TP as well as proximity to both agricultural and industrial practices. Frontal storms also tend to move across the area from desert area to the northwest and west.

Table 4-4: Significantly Different Sites for TP

Site	Site	Difference	p-Value
Saratoga Springs	Central Davis	3.31	0.0017
Saratoga Springs	Lake Shore	3.23	0.0011
Saratoga Springs	Orem WWTP	3.17	0.0025
Saratoga Springs	Pump Station	2.95	0.0034
Saratoga Springs	Mosida	2.84	0.0049

4.5 Total Deposition

As described in Section 3.4, GMS was used to interpolate values to determine a total deposition loading to Utah Lake for the eight months. This process was used for both TP and DIN. Due to the importance of how contamination is defined, a range for the eight-month atmospheric nutrient deposition was calculated. The higher value was determined by including all samples collected through the duration of the study. The lower estimate was determined by excluding all contaminated samples from the analysis.

Based on all of the samples, the deposition loading of TP and DIN to the lake for the eight months were found to be 354 tons and 460 tons, respectively. Excluding all contaminated

Table 4-5: Weekly Loading for TP and DIN

Week Sampled	Date	All Samples		Uncontaminated Samples	
		TP tons/week	DIN tons/week	TP tons/week	DIN tons/week
Week 1	5/11/2017	0.55	0.70	0.80	0.91
Week 2	5/18/2017	0.11	0.91	0.12	0.37
Week 3	5/25/2017	3.36	3.75	0.01	0.43
Week 4	6/1/2017	3.75	2.92	-	-
Week 5	6/8/2017	2.68	4.60	-	-
Week 6	6/15/2017	1.12	0.28	0.06	0.32
Week 7	6/22/2017	59.36	50.39	0.04	0.59
Week 8	6/29/2017	19.36	9.28	-	-
Week 9	7/6/2017	12.82	15.49	-	-
Week 10	7/13/2017	47.51	20.63	0.05	0.47
Week 11	7/20/2017	81.64	71.95	0.07	0.59
Week 12	7/27/2017	79.36	186.33	0.19	1.58
Week 13	8/3/2017	22.81	25.02	-	-
Week 14	8/10/2017	3.38	5.72	0.21	1.12
Week 15	8/17/2017	1.77	4.14	-	-
Week 16	8/24/2017	1.85	3.18	0.05	0.33
Week 17	8/31/2017	2.46	6.02	0.08	0.63
Week 18	9/7/2017	0.41	2.75	-	-
Week 19	9/14/2017	0.50	3.50	0.02	0.31
Week 20	9/21/2017	2.78	4.78	0.09	0.86
Week 21	9/28/2017	0.12	2.68	0.12	2.71
Week 22	10/5/2017	0.19	2.16	0.25	2.40
Week 23	10/12/2017	0.75	1.69	0.75	1.72
Week 24	10/19/2017	0.21	1.85	0.21	1.88
Week 25	10/26/2017	0.43	1.20	0.43	1.22
Week 26	11/2/2017	0.63	6.79	0.63	6.82
Week 27	11/9/2017	0.56	7.08	0.56	7.11
Week 28	11/16/2017	0.17	3.59	0.17	3.62
Week 29	11/30/2017	2.45	7.02	2.45	7.04
Week 30	12/7/2017	0.46	2.14	0.46	1.99
Week 31	12/14/2017	0.16	1.16	0.16	1.19
Total		353.71	459.71	8.01	46.22

samples, the deposition loading of TP and DIN to Utah Lake for the eight months drops to 8 tons and 46 tons, respectively. Table 4-5 shows the weekly atmospheric deposition rates for Utah Lake for all weeks sampled during this study.

The weekly loadings for TP and Din were also plotted and are shown in Figure 4-3 and Figure 4-4, respectively. Because some of the summer months have relatively high values compared to the rest of the sampling period, the weekly loadings for uncontaminated values were also listed and are shown in Figure 4-5 and Figure 4-6. It is easy to see that loadings calculated using only uncontaminated samples had variations that were quite larger over time.

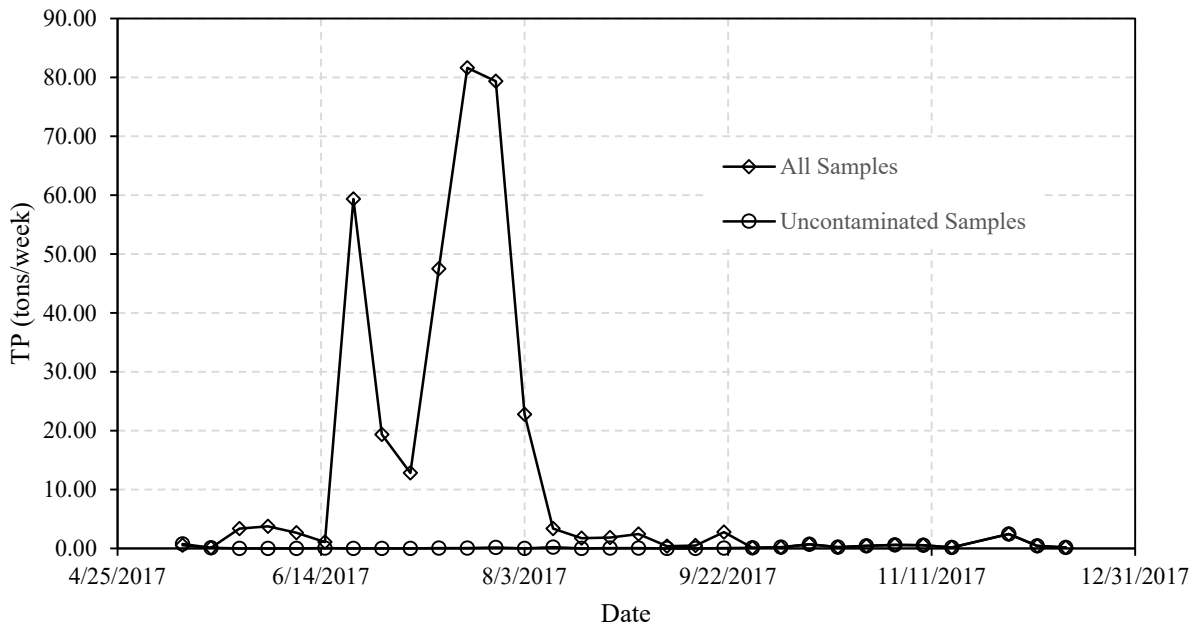


Figure 4-3: Seasonal Loading of TP to Utah Lake for 2017

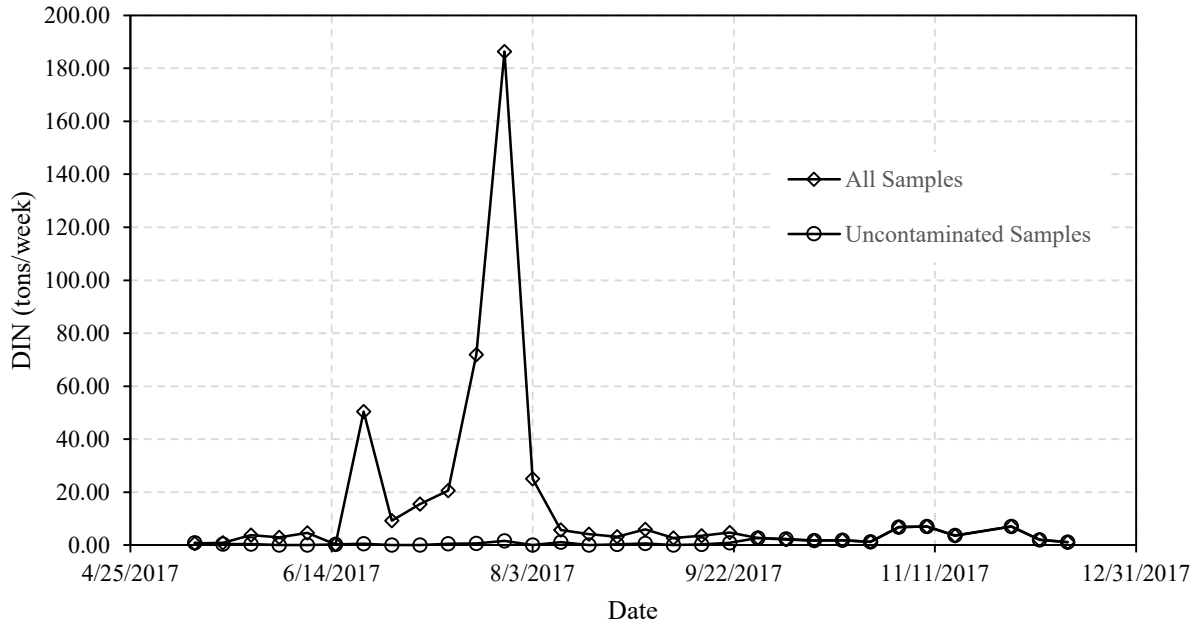


Figure 4-4: Seasonal Loading of DIN to Utah Lake for 2017

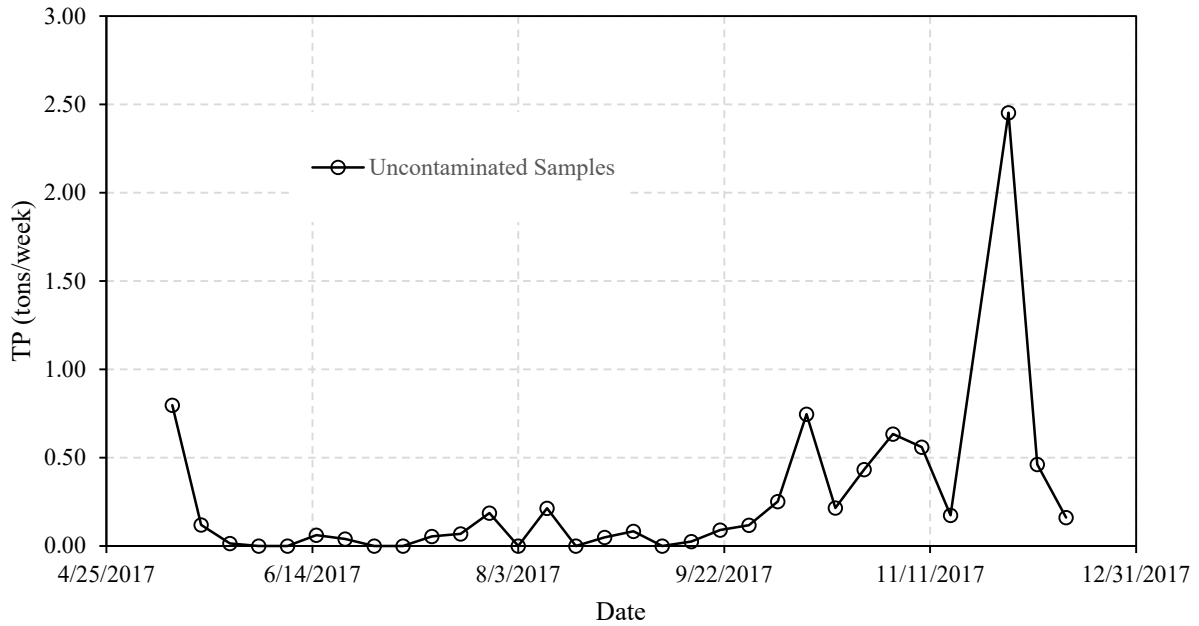


Figure 4-5: Seasonal Loading of TP using Only Uncontaminated Samples

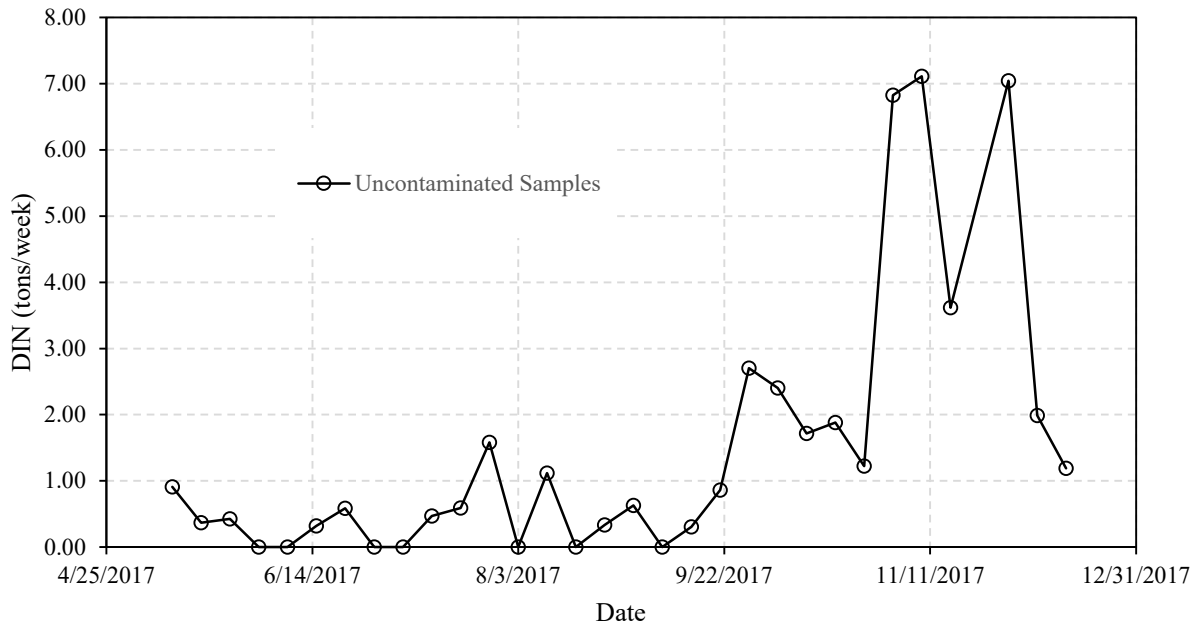


Figure 4-6: Seasonal Loading of DIN using Only Uncontaminated Samples

5 DISCUSSION

5.1 Site Comparison

Wet deposition appears to show large-scale similarity whereas dry deposition may be more influenced by local sources of nutrients such as dust. The data collected for wet deposition for all sites indicate few differences among sites. However, there were some large differences in the deposition of dry samples. For example, the dry deposition at Saratoga Springs was significantly greater than deposition from any other site during the summer months (Figure 4-1). This is most likely due to the influence of the terrestrial bee, Halictidae Lasioglossum, during the summer months. Site differences appeared to be mainly based on site characteristics; high TP deposition rates were found near agricultural areas and industrial areas. The west side of Utah Lake is impacted by a large gravel pit and agricultural practices and these sources are likely contributing to higher levels of TP. This suggests a similar conclusion to what Hendry et al. (1981) found in their study.

5.2 Local Sources

An important issue in this study is whether the sources of TP are local, regional, global, or some combination of these sources. Local sources are seen as possible important contributors to nutrients to Utah Lake due to it being surrounded by urban, industrial and agricultural land uses. The important, impactful area for Utah Lake from atmospheric deposition of nutrients is the lake

itself. The study as set up was to measure the deposition around the lake and as close to the lake as feasible, given the resources available for the study. For this study both regional and local source are valid, local source are not viewed as contaminated samples.

The high spatial variability in TP loads (Table 4-3) suggest that significant portions of the TP is from local sources and affected by local conditions at sampling sites. For example, the maximum average TP load was observed at the Saratoga Springs site ($67.13 \text{ mg of TP m}^{-2} \text{ day}^{-1}$). This site is thought to receive higher nutrient loadings because of its proximity to Great Basin dust sources, industrial and/or agricultural practices. This local dust is suspended during windy storms and impacts the lake, especially when storms approached from a westerly direction. Given that the minimum value of TP loading measured was at the Central Davis site, the regional and global sources are likely less than $1.02 \text{ mg of TP m}^{-2} \text{ day}^{-1}$. By taking $1.02 \text{ mg of TP m}^{-2} \text{ day}^{-1}$ and dividing it by $7.93 \text{ mg of TP m}^{-2} \text{ day}^{-1}$, it can be seen that the Central Davis site contributes 13% of the estimated average value (Table 4-3). Further research might better delineate the phosphorus sources and their impact. However, due to the variability in climatological conditions over time, one might expect even significant differences over multiple years which would result in considerable variations in the atmospheric deposition.

5.3 Total Deposition

Seasonal rates of deposition for both TP and DIN show similar trends. As expected, both forms of nutrients show a seasonal pattern of higher deposition rates during the late spring and summer months. The deposition rates are then lower during the winter months. Phosphorous deposition was dominated by dry deposition; deposition was maximal in July and early August as can be seen in Figure 4-3. Figure 4-3 shows the general seasonal atmospheric nutrient

loading to Utah Lake. Both dry and wet TP deposition declined to lower and similar values in winter. Nitrogen deposition was dominated by dry depositions, with higher rates in summer months. Dry and wet DIN deposition also declined to lower and similar values in winter. This trend can be seen in Figure 4-4.

These seasonal trends agree with those seen by many other studies where deposition increased in early summer and decreased over the remainder of the summer (Delumyea and Petel 1978; Linsey et al. 1987; Shaw et al. 1989). Additionally, significant variability has also been observed in studies of atmospheric TP deposition. In a review of studies on TP deposition, inputs were estimated between 0.007 to 1.7 mg m⁻² year⁻¹ for total deposition to funnels with horizontal orifices (Newman 1995). After interpolation, all values from this study were found to be in the range of observed values except for 7 weeks of data from June 22, 2017, too August 8, 2017. This can be seen in Figure 4-3. All uncontaminated TP samples were found to be within the observed range of values and can be seen in Figure 4-5.

Ranges of nitrogen deposition in other studies were less variable than for those of TP deposition. The DIN data were compared to the NADP wet deposition data for 2014 in Utah. These rates ranged from 2.14 to 8.42 mg m⁻² year⁻¹ (NADP 2014). In comparison, the rates measured by this study had rates that ranged from 0.04 to 24.82 mg m⁻² year⁻¹. These values can be seen in Figure 4-4. When compared with other studies, these values appear to be reasonable (Hendry et al. 1981; Shaw et al. 1989).

5.4 Contamination

Contamination is a problem in deposition studies, mainly due to a lack of agreement as to how to delineate the boundaries for the area being studied. The delineated boundary might vary

depending on the purpose of the study. For a lake and its nutrient load, one would like to identify all of the sources that might represent additional nutrients being added to the lake, especially during the main algal-growth season.

However, it is difficult to obtain sufficient samples to delineate just how much of even a nearby contaminated source might end up going into the lake. Thus, contamination in deposition studies may be viewed as local internal recycling (Ahn and James 2001) because birds and insects use and excrete nutrients on land. These loads were seen as legitimate sources of nutrients and all were taken into account to obtain an upper estimate for atmospheric deposition to Utah Lake. Insects were the main source of contamination in this study. The insect that was the most prominent was the Halictidae *Lasioglossum*. It was found that 43% of all samples collected were contaminated in some way. To give perspective, a range of atmospheric deposition loadings were calculated, to give bounds to the actual value, which is unknown. The higher values were determined by including all samples collected throughout the duration of the study. The lower values were determined by excluding all contaminated samples from the analysis. More samples across many years are needed to narrow down this range.

6 CONCLUSION

Many Studies have indicated that atmospheric deposition can be an important component of the nutrient budget of a lake. Extrapolation of depositions rates found in this study across Utah Lake, using an exponential attenuation from the sampling sites to a background value in the midpoint in the lake, indicates that the atmosphere contributes between 8 to 350 tons of TP per year and 46 to 460 tons of DIN per year. The high values result from using all samples and the low values from eliminating any samples containing visible particle contaminations.

Dry deposition of phosphorus represents the bulk of seasonal deposition and the most important fraction of total deposition. It was verified that the largest loading of atmospheric nutrient deposition occurs during the summer months, as expected. Since the summer is when the algal growth is the greatest, it is important to note that the impact of atmospheric deposition to Utah Lake is even greater than if it were spread evenly during the year.

The study results indicate that atmospheric deposition on Utah Lake is very significant. To put this in perspective, assume that every other source of phosphorus and nitrogen could somehow be eliminated from the lake. Also assume that the lowest deposition values identified in this study were used. Merritt and Miller (2016) determined that about 17 tons of phosphorus per year and 200 tons of nitrogen per year are the values that would be sufficient to support the algal growth that actually is occurring in the lake. The lowest values determined in this study are

8 tons of TP per eight months and 46 tons of DIN per eight months. However, probably these are likely very low estimates of the actual deposition.

All of this considered, atmospheric deposition is a major contributor in supporting a eutrophic state in the lake. If atmospheric nitrogen was the only source of nitrogen, then the lake would likely have far more nitrogen fixing cyanobacteria (HABs) than actually occurs due to a relative shortage of nitrogen relative to phosphorus.

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APPENDIX A

Table A-1: Site Information for Atmospheric Deposition Collectors

Name	Lake Shore	Mosida	Saratoga Springs	Pump Station	Orem WWTP	Central Davis
ID	1	2	3	4	5	6
Latitude	-111.787781	-111.927626	-111.868827	-111.895347	-111.735528	-111.950803
Longitude	40.11229	40.076452	40.283815	40.359414	40.276158	40.99909
County	Utah	Utah	Utah	Utah	Utah	Davis
No Impact from Irrigation Sources	Compliant	Central Pivot irrigation 380 m from collector	Compliant	Central Pivot irrigation 500 m from collector	Wheel line irrigation 500 m from site	Wheel line irrigation 30 m from site
> 5 m from Equipment	Solar Panel	Solar Panel	Solar Panel	Solar Panel	Solar Panel	Solar Panel
>= 5 m from collector	Chain link fence 3 m from collector	Compliant	Compliant	Compliant	Compliant	Compliant
>= 10 m from collector	Access road is 7 m from collector	Compliant	Compliant	Compliant	Compliant	Compliant
>= 20 m from collector	Horse corral 10 m from collector	Compliant	Compliant	Compliant	Compliant	Cultivated field 10 meters from collector
>= 30 m from collector	Farm Shed 15 m from collector	Compliant	Small gravel driveway 25 m from collector	Compliant	Compliant	Compliant
>= 100 m from collector	Compliant	Compliant	Compliant	Compliant	Parking lot 60 m from collector	Compliant
>= 500 m from collector	Compliant	Compliant	Compliant	Compliant	Compliant	Compliant
>= 1 km from collector	Compliant	Compliant	Compliant	Compliant	Compliant	Compliant
Site Classification	R	I	S	S	U	U

Table A-2: Comparison Between ChemTech and EAL for Total Phosphorous

Date Sampled	Site	Wet or Dry	Chemtech Total Phosphorous (mg/L)	EAL Total Phosphorous (mg/L)	Error
7/13/2017	Saratoga Springs	Dry	42	39.2	-0.1
7/13/2017	Saratoga Springs	Wet	0.03	1.2	39.6
8/3/2017	Saratoga Springs	Dry	0.5	11.8	22.6
8/10/2017	Pump Station	Dry	0.11	0.1	0.0
8/10/2017	Pump Station	Wet	0.18	0.7	2.8
8/24/2017	Lake Shore	Dry	38	0.5	-1.0
8/24/2017	Lake Shore	Wet	0.02	1.4	69.7
8/24/2017	Central Davis	Dry	0.01	0.0	1.5
7/27/2017	Saratoga Springs	Wet	0.45	0.6	0.3
9/21/2017	Mosida	Dry	3	2.2	-0.3

APPENDIX B

This appendix contains instructions for sample collection as well as a parts list for all of the needed equipment. Also included are the design drawings for the samplers and other necessary information for operation.

B.1 Instructions for Sample Change-Out

Instructions for sampling change-out are very similar to the NTN sample change-out, Aerochem Metrics Bucket collector document. The link to this document is provided:

http://nadp.slh.wisc.edu/lib/manuals/NTN_Sample_Changeout_ACM_v_1-1.pdf

The only differences in procedure occur on step 20. It is not necessary to weigh the bucket and contents. This information can be calculated later after recording the volume of sample collected.

B.2 Instructions for Sample Decanting

Instructions for sample decanting are very similar to the NTN Sample Decanting SOP. The link to this document is provided:

http://nadp.slh.wisc.edu/lib/manuals/NTN_Sample_Decanting_v_1-7.pdf

The differences in procedure stem from measuring the volume of sample in place of the weight of sample. Steps 1 through 3 should be ignored. On step 5, the bucket should be shaken

six time. On step 7, decant all sample into graduated cylinder. Measure volume of sample and record on FORF. After volume of sample is measured. Decant volume into 500 mL bottle. Insure no headspace is present. Proceed to step 8. Insure the bottle is properly labeled on the side and lid of the bottles with the date, the site name, and the type of sample (wet/dry). Place the samples directly into the refrigerator in CB 395. Keep samples refrigerated until samples are analyzed. Ignore step 9 through 11 and 14 through 15.

B.3 Bucket Cleaning and Preparation

Items needed:

- Bucket
- Lid
- Hard plastic scrubbers
- Lab coat
- Eye protection
- Latex gloves

Instructions for Cleaning and Drying

1. Fill sink with warm tap water. Place 1 tablespoon of Liquinox in sink while it fills. Take discarded buckets and submerge buckets in solution.



2. Take hard plastic scrubbers and scrub all interior and exterior surfaces of the bucket with Liquinox solution. Repeat step for all bucket lids and graduated cylinders.



3. After all buckets and lids have been scrubbed. Drain water from sink and rinse sink with DI water (grey tap).



4. Take bucket and rinse all surfaces with DI water. Insure that no soap suds are present after rinse. Repeat step for all bucket lids and graduated cylinders.
5. Submerge buckets, lids, and graduated cylinders in 10% HCl acid wash for at least 24 hours. Careful with acid wash. The acid wash can burn skin, discolor/burn clothing. Make sure to wear protective equipment.



6. After a minimum of 24 hours, remove buckets and place on counter to air dry with interior surface facing down to minimize contact with laboratory air deposition.

Instructions for Bucket Preparation

1. After the buckets, lids, and graduated cylinder have air dried (Usually about 24 hours). Measure 3 Liters of DI water and place in bucket. One of the two buckets for each sampler should have 3 L of DI water (dry deposition bucket).
2. Place bucket lid on bucket. Insure that the lid is secured and sealed.
3. Place plastic bag on sealed bucket. Twist opening of plastic bag to a close and clamp with plastic label.



4. Repeat steps 2 and 3 for the reaming bucket. This bucket should remain dry (wet deposition sample).

B.4 Parts List

- **Bucket:** 2 Gal bucket Item ID 7595 from BYU Chemical Central Stockroom
- **Bucket lid:** 2 Gal bucket lid Item ID 7595 from BYU Chemical Central Stockroom

- **Field Observer Report Form (FORF):** Page 10 of the NTN Sample Changeout – ACM document.
- **Plastic Bags:** Olympian High Density Can Liner from Amazon
- 500 mL bottles
- **Hydrochloric Acid Reagent:** Item ID 6289 from BYU Chemical Central Stockroom
- **Liquinox:** Item ID 7583 from BYU Chemical Central Stockroom
- **Latex Gloves:** BYU Environmental Laboratory CB 395
- **Lab Coat:** BYU Environmental Laboratory CB 395
- **Kimwipes:** BYU Environmental Laboratory CB 395
- **Graduated cylinder:** BYU Environmental Laboratory CB 395
- **Hard plastic scrubbers:** BYU Environmental Laboratory CB 395
- **Rain gage:** Rain and Snow Gauge- Stratus RG202 Long Term Professional Gauge on Amazon
- **Precipitation Sensor:** SODIAL(R) Snow/Raindrops Detection Sensor Module Rain Weather Module Humidity For Arduino on Amazon
- **Solar Charger:** SunSaver 10 Charge Controller 12V 10A on Amazon
- **Black Zip Ties:** 14” Black Wire Ties from AutoZone
- **Arduino Uno:** NHduino from BYU Electrical Engineering Shop
- **12 V to 5 V H board:** BYU Electrical Engineering Shop
- **Actuator:** Classic Rod Linear Actuators 6” Stroke
- **Bungee Cords:** Home Depot

B.5 Arduino Code

First, insure that Arduino IDE is downloaded and working on a portable field laptop. The sample code for both lid position and rain gage logging is given below (Sampler Code). There is also code that insure the correct data and time is used when logging the data (Correct Data Code). Both codes will need to be uploaded to the microcomputer (Arudino) using the Arduino IDE software using a USB cable.

Sampler Code

```
//Here we go at logging the rain and lid position data to the logger.

// Call a few libraries
#include <SPI.h>
#include "SD.h"
#include <Wire.h>
#include "RTClib.h"

//Set some constants
// A simple data logger for the Arduino analog pins
#define LOG_INTERVAL 1000 // mills between entries(reduce to take more/faster data)

// how many milliseconds before writing the logged data permanently to disk
// set it to the LOG_INTERVAL to write each time (safest)
// set it to 10*LOG_INTERVAL to write all data every 10 datareads, you could lose up to
// the last 10 reads if power is lost but it uses less power and is much faster!
#define SYNC_INTERVAL 1000 // mills between calls to flush() - to write data to the card
uint32_t syncTime = 0; // time of last sync()

#define ECHO_TO_SERIAL 1 // echo data to serial port
#define WAIT_TO_START 0 // Wait for serial input in setup()

////////////////////////////////////

int ledPin = 13;

// lowest and highest sensor readings:
const int sensorMin = 0; // sensor minimum
const int sensorMax = 1024; // sensor maximum

//H_Bridge
```

```

int relay1 = 8;
int relay2 = 10;
int doorStatus = 0; //0 = closed 1 = open

//Next we want to write a few helper functions to make our code easier to read and maintain.

void extendActuator() {
    digitalWrite(relay1, HIGH);
    digitalWrite(relay2, LOW);
}

void retractActuator() {
    digitalWrite(relay1, LOW);
    digitalWrite(relay2, HIGH);
}

void stopActuator() {
    digitalWrite(relay1, LOW);
    digitalWrite(relay2, LOW);
}

////////////////////////////////////

//now we're going to define the pin for the SD card and catch any errors
//in loading the card.
RTC_PCF8523 RTC; // define the Real Time Clock object

// for the data logging shield, we use digital pin 10 for the SD cs line
const int chipSelect = 10;

// the logging file
File logfile;

void error(char *str)
{
    Serial.print("error: ");
    Serial.println(str);

    while (1);
}

```

```

void setup(void) {

    pinMode(ledPin, OUTPUT);// Set up pin 13 as an output.

    pinMode(relay1, OUTPUT);
    pinMode(relay2, OUTPUT);

    Serial.begin(9600); // initialize serial communication @ 9600 baud:
    Serial.println();

    #if WAIT_TO_START
        Serial.println("Type any character to start");
        while (!Serial.available());
    #endif //WAIT_TO_START

    // initialize the SD card
    Serial.print("Initializing SD card...");

    // make sure that the default chip select pin is set to
    // output, even if you don't use it:
    pinMode(10, OUTPUT);

    // see if the card is present and can be initialized:
    if (!SD.begin(chipSelect)) {
        Serial.println("Card failed, or not present");
        // don't do anything more:
        return;
    }
    Serial.println("card initialized.");

    // create a new file
    char filename[] = "LOGGER00.CSV";
    for (uint8_t i = 0; i < 100; i++) {
        filename[6] = i / 10 + '0';
        filename[7] = i % 10 + '0';
        if (!SD.exists(filename)) {
            // only open a new file if it doesn't exist
            logfile = SD.open(filename, FILE_WRITE);

```

```

    break; // leave the loop!
}
}

if (!logfile) {
    error("couldnt create file");
}

Serial.print("Logging to: ");
Serial.println(filename);
////////////////////////////////////

//Here we define the header for the .csv file
Wire.begin();
if (!RTC.begin()) {
    logfile.println("RTC failed");
#ifdef ECHO_TO_SERIAL
    Serial.println("RTC failed");
#endif //ECHO_TO_SERIAL
}

logfile.println("datetime,precip,state");
#ifdef ECHO_TO_SERIAL
    Serial.println("datetime,precip,state");
#endif

////////////////////////////////////

//I commented this code because the program would not compile. Now it does.

//#if ECHO_TO_SERIAL// attempt to write out the header to the file
// if (logfile.writeError || !logfile.sync()) {
//     error("write header");
// }
// #endif
//

```



```

// If you want to set the aref to something other than 5v
//analogReference(EXTERNAL);
}

////////////////////////////////////

int state = 0;

////////////////////////////////////

void loop() {

/*
extendActuator();
delay(3500);
stopActuator();
delay(3500);
retractActuator();
delay(3500);
*/

// delay for the amount of time we want between readings
delay((LOG_INTERVAL - 1) - (millis() % LOG_INTERVAL));

// // log milliseconds since starting
// uint32_t m = millis();
// logfile.print(m);    // milliseconds since start
// logfile.print(", ");
// #if ECHO_TO_SERIAL
// Serial.print(m);    // milliseconds since start
// Serial.print(", ");
// #endif
// fetch the time

//Timestamping
DateTime now = RTC.now();

// log time
// logfile.print(now.unixtime()); // seconds since 2000

```

```

// logfile.print(", ");

int sensorReadingA = analogRead(A0); // read the sensor on analog A0:

if(state == 0) // Waiting for rain
{
  Serial.println("Waiting for rain");
  if(sensorReadingA < 700) // Rain Detected
  {
    state = 1; // Opening
  }
}
else if (state == 1) // Opening
{
  Serial.println("Opening");
  extendActuator();
  delay(5000);
  state = 2; // Stopped
}
else if (state == 2) // Stopped
{
  Serial.println("Stopped");
  if(sensorReadingA > 700) // Rain Not Detected
  {

    state = 3; // Closing
  }

  Serial.println(sensorReadingA);
}
else if (state == 3) // Closing
{
  Serial.println("Closing");
  retractActuator();
  delay(5000);
}

```

```

    state = 0; // Waiting for Rain
}
else
{
    state = 0; // Default
}
logfile.print(now.year(), DEC);
logfile.print("/");
logfile.print(now.month(), DEC);
logfile.print("/");
logfile.print(now.day(), DEC);
logfile.print(" ");
logfile.print(now.hour(), DEC);
logfile.print(":");
logfile.print(now.minute(), DEC);
logfile.print(":");
logfile.print(now.second(), DEC);
logfile.print(", ");
logfile.print(sensorReadingA);
logfile.print(", ");
logfile.println(state);
logfile.flush();
#if ECHO_TO_SERIAL
// Serial.print(now.unixtime()); // seconds since 2000
// Serial.print(", ");
Serial.print(now.year(), DEC);
Serial.print("/");
Serial.print(now.month(), DEC);
Serial.print("/");
Serial.print(now.day(), DEC);
Serial.print(" ");
Serial.print(now.hour(), DEC);
Serial.print(":");
Serial.print(now.minute(), DEC);
Serial.print(":");
Serial.print(now.second(), DEC);
Serial.print(", ");
Serial.print(sensorReadingA);

```

```
Serial.print(", ");
Serial.println(state);
#endif //ECHO_TO_SERIAL
```

```
}
```

Correct Date Code

```
// Date and time functions using a DS1307 RTC connected via I2C and Wire lib
```

```
#include <Wire.h>
```

```
#include "RTClib.h"
```

```
RTC_PCF8523 rtc;
```

```
char daysOfTheWeek[7][12] = {"Sunday", "Monday", "Tuesday", "Wednesday", "Thursday", "Friday", "Saturday"};
```

```
void setup () {
```

```
while (!Serial) {
```

```
    delay(1); // for Leonardo/Micro/Zero
```

```
}
```

```
Serial.begin(57600);
```

```
if (!rtc.begin()) {
```

```
    Serial.println("Couldn't find RTC");
```

```
while (1);
```

```

}

if (! rtc.initialized() {

  Serial.println("RTC is NOT running!");

  // following line sets the RTC to the date & time this sketch was compiled

  // rtc.adjust(DateTime(F(__DATE__), F(__TIME__)));

  // This line sets the RTC with an explicit date & time, for example to set

  // January 21, 2014 at 3am you would call:

  // rtc.adjust(DateTime(2014, 1, 21, 3, 0, 0));

}

}

void loop () {

  DateTime now = rtc.now();

  Serial.print(now.year(), DEC);

  Serial.print("/");

  Serial.print(now.month(), DEC);

  Serial.print("/");

  Serial.print(now.day(), DEC);

  Serial.print(" (");

  Serial.print(daysOfTheWeek[now.dayOfTheWeek()]);

  Serial.print(") ");

  Serial.print(now.hour(), DEC);

  Serial.print(":");

  Serial.print(now.minute(), DEC);

```

```
Serial.print(':');

Serial.print(now.second(), DEC);

Serial.println();

Serial.print(" since midnight 1/1/1970 = ");

Serial.print(now.unixtime());

Serial.print("s = ");

Serial.print(now.unixtime() / 86400L);

Serial.println("d");

// calculate a date which is 7 days and 30 seconds into the future

DateTime future (now + TimeSpan(7,12,30,6));

Serial.print(" now + 7d + 30s: ");

Serial.print(future.year(), DEC);

Serial.print('/');

Serial.print(future.month(), DEC);

Serial.print('/');

Serial.print(future.day(), DEC);

Serial.print(' ');

Serial.print(future.hour(), DEC);

Serial.print(':');

Serial.print(future.minute(), DEC);

Serial.print(':');

Serial.print(future.second(), DEC);
```

```
Serial.println();
```

```
Serial.println();
```

```
delay(3000);
```

```
}
```

B.6 Design Drawings

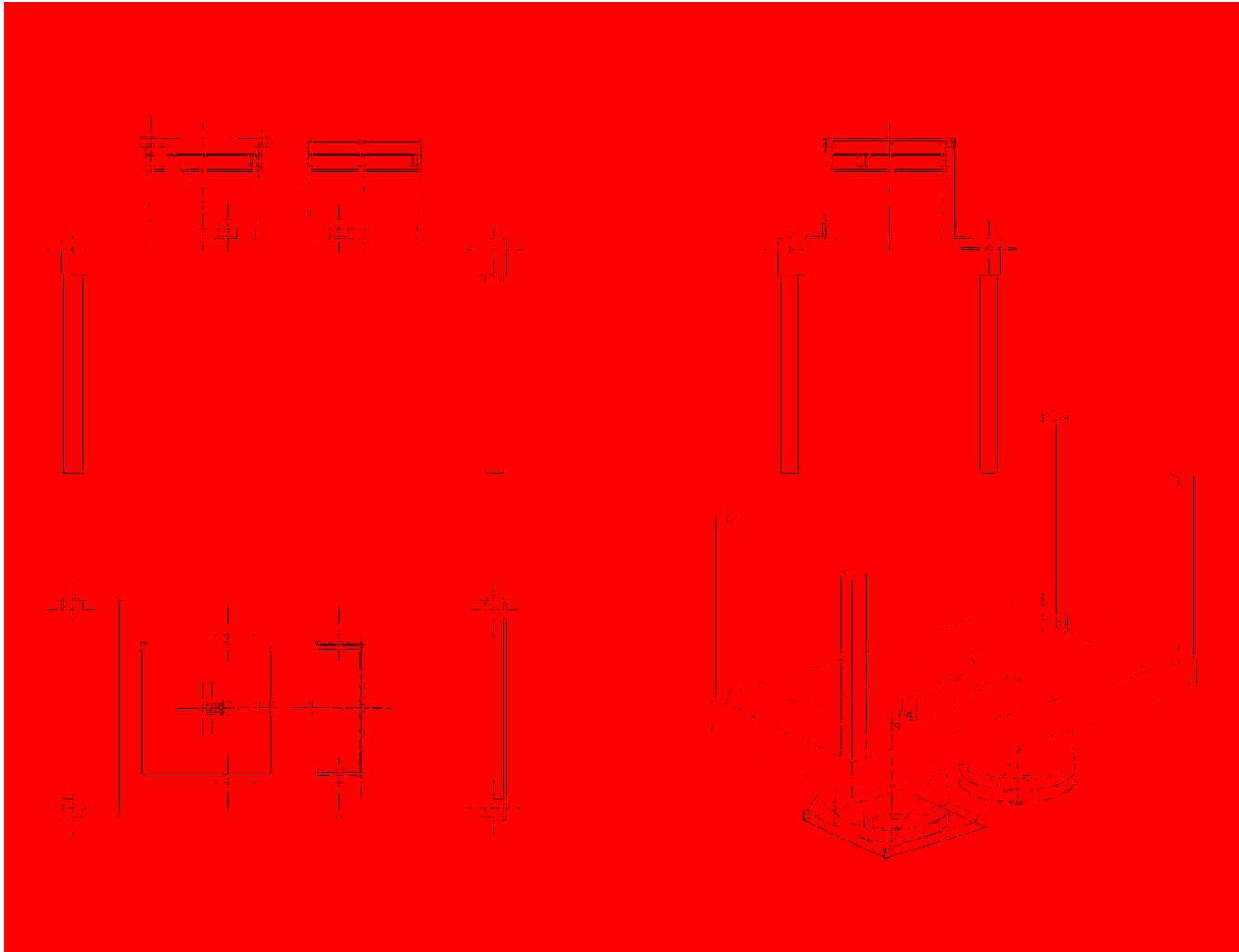


Figure B-1: Complete Sampler Design Drawing

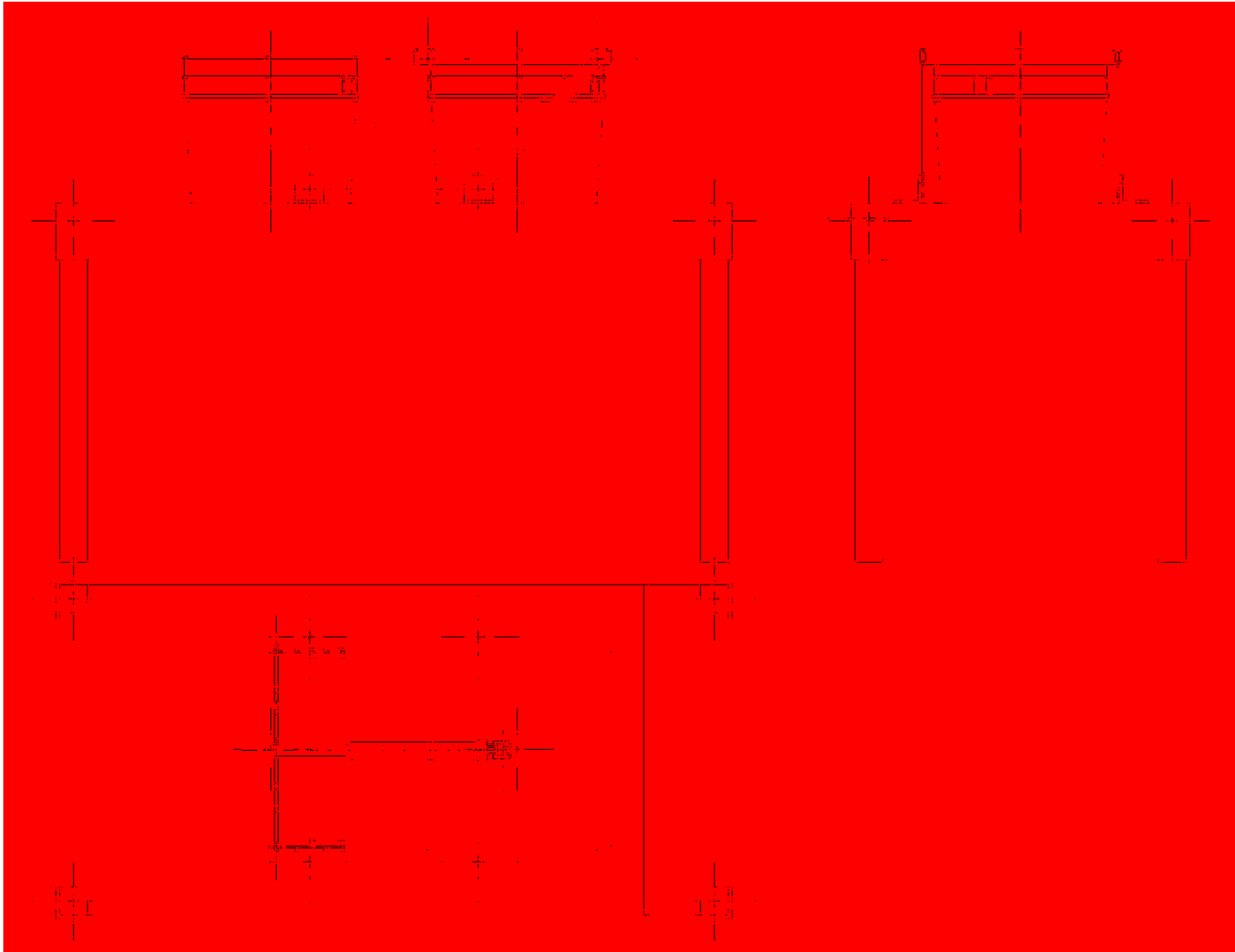


Figure B-2: Front, Side, Bottom View of Sampler Design Drawing

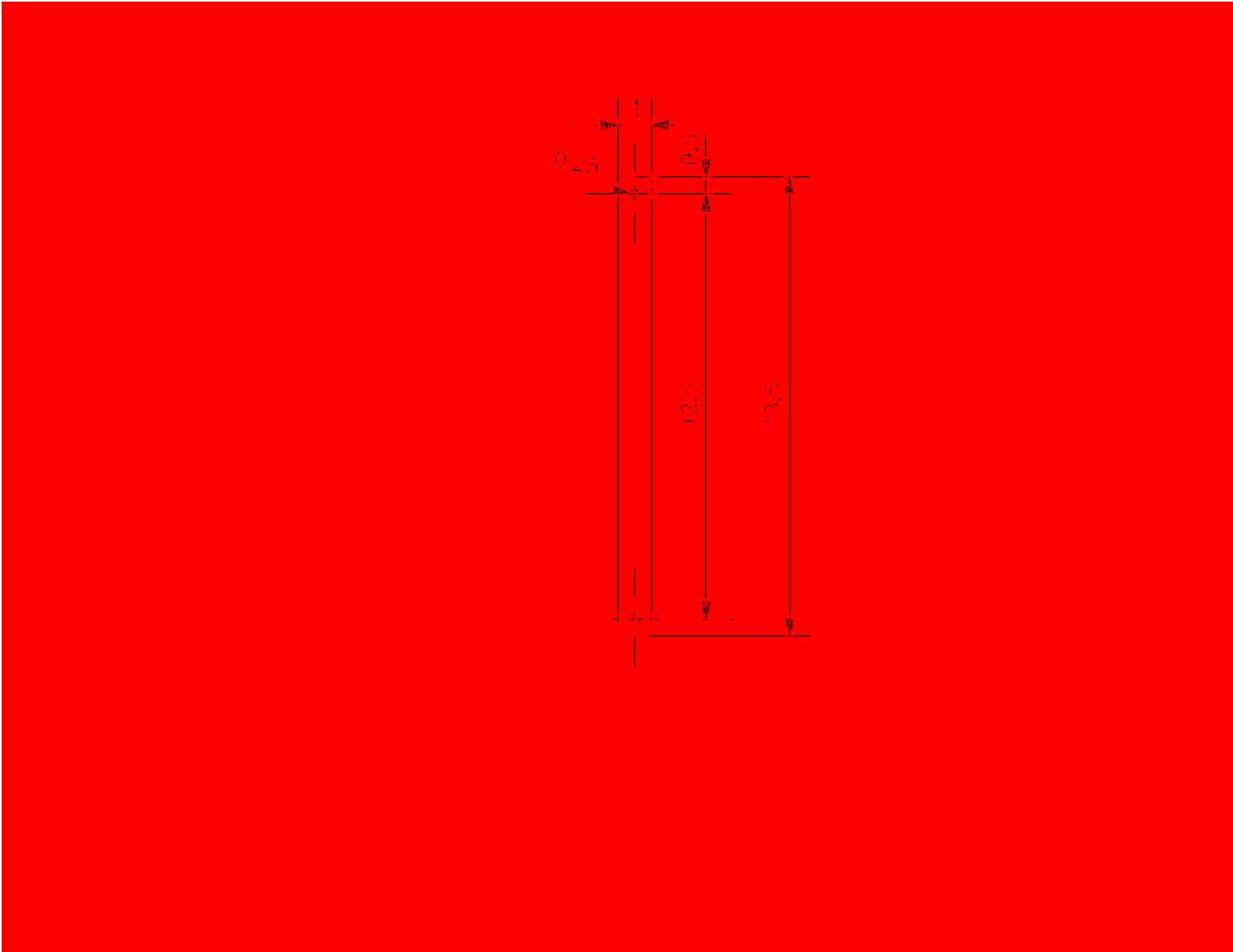


Figure B-3: Short Link

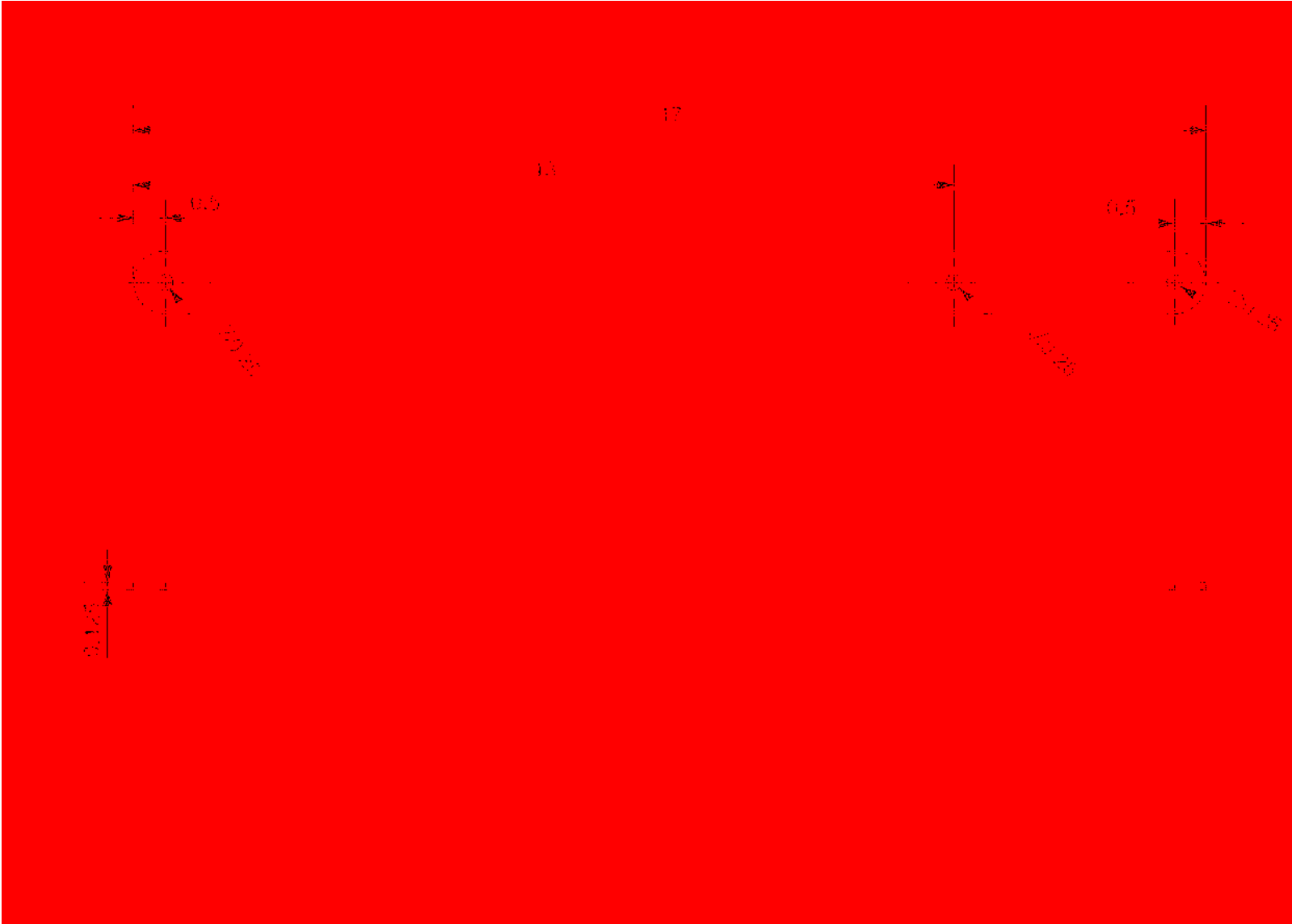


Figure B-4: Long Link

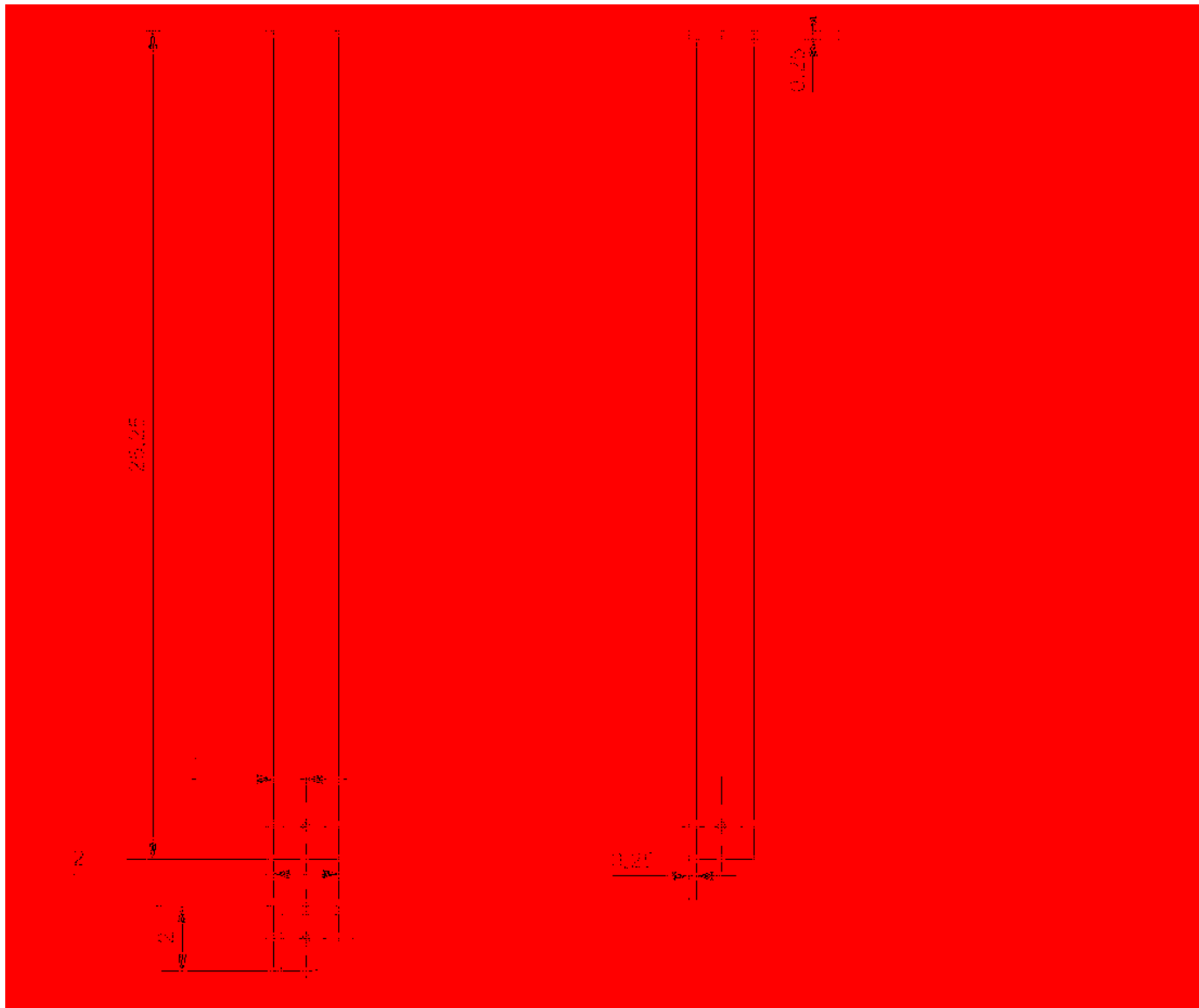


Figure B-5: Sampler Legs

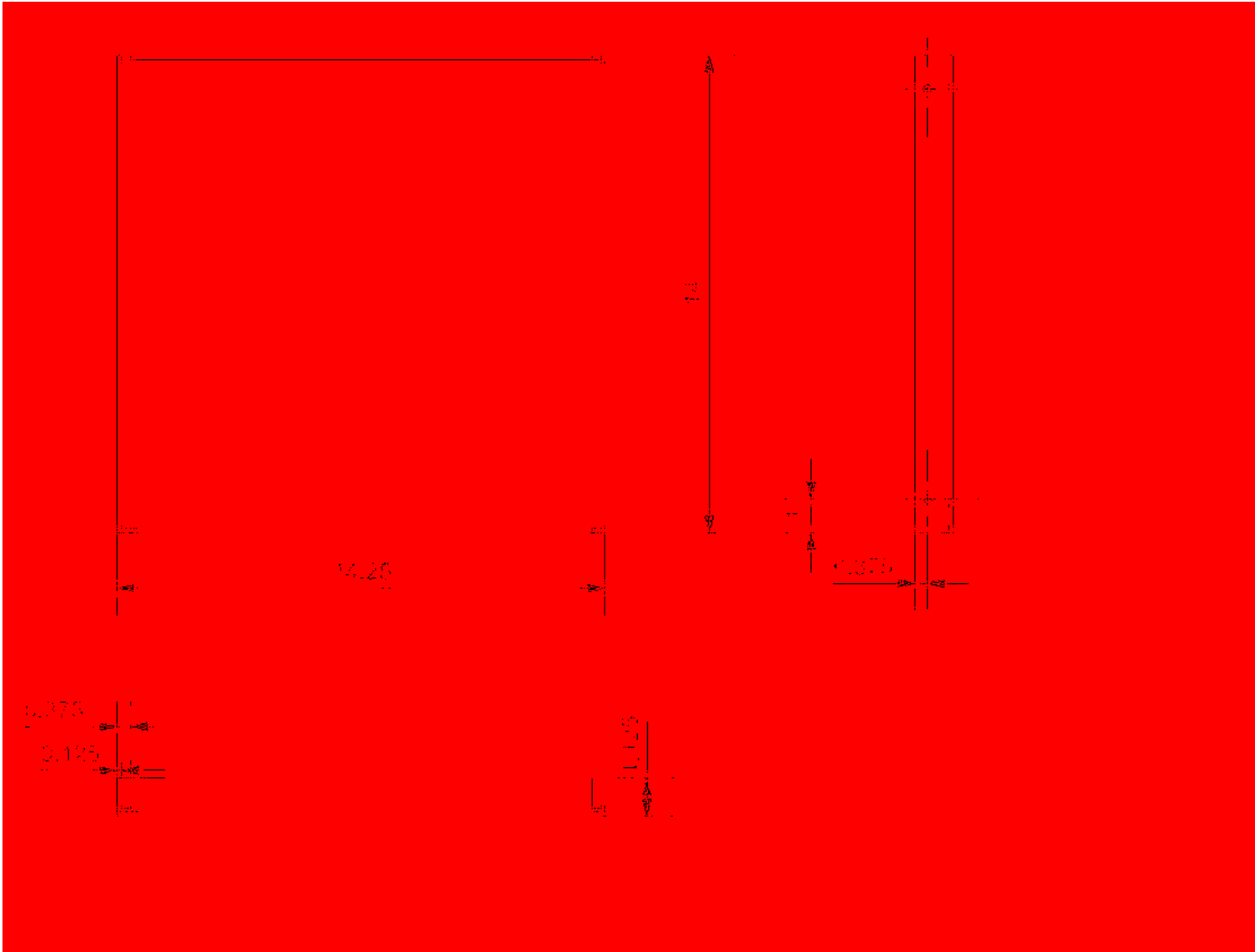


Figure B-6: Sampler Lid

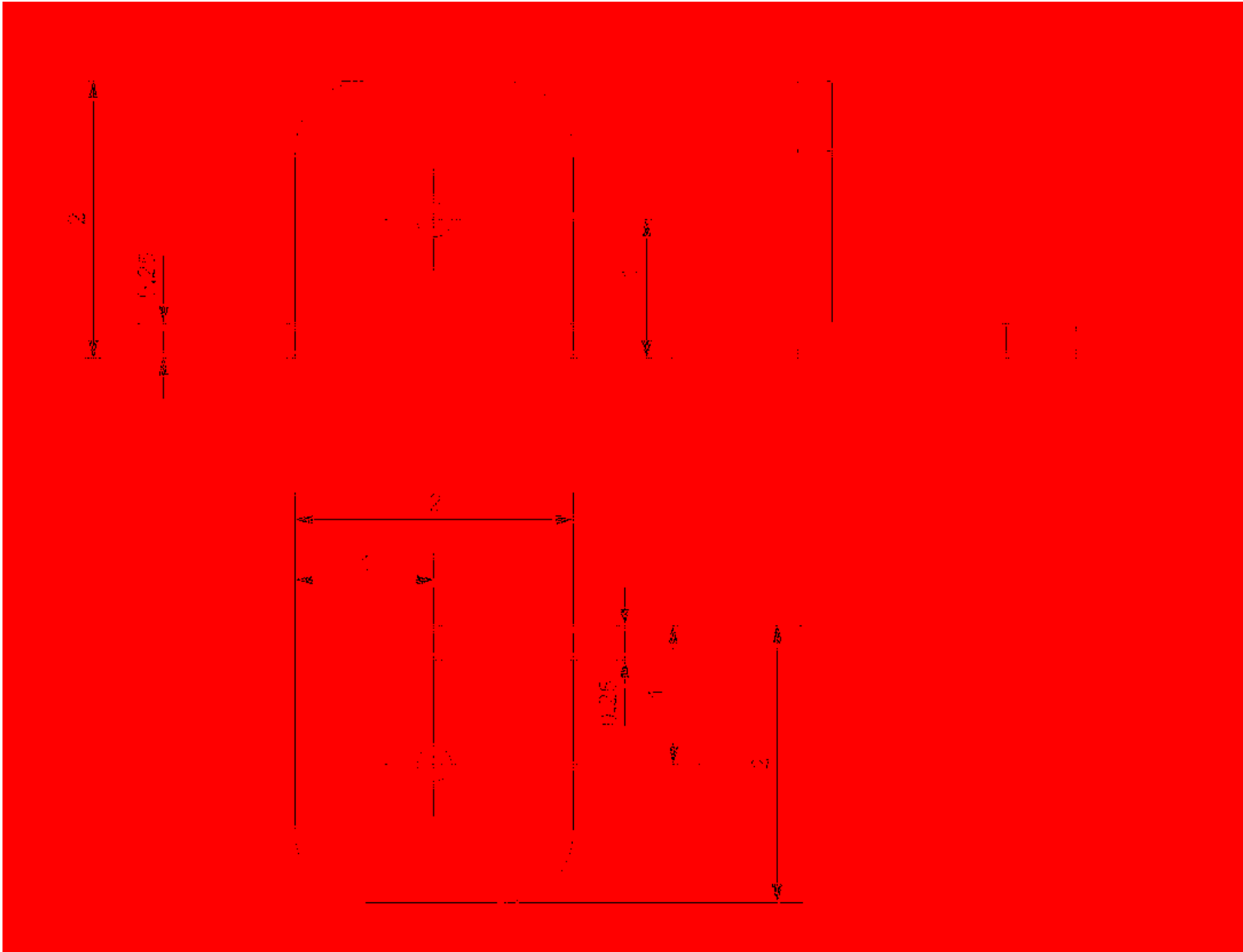


Figure B-7: Sampler Bracket

APPENDIX C

Atmospheric Loading Calculations:

All concentrations values refer to DIN for the third week in July (July 13, 2017 – July 20, 2017)

Defined Variables

V_{sample} - Volume of Sample Collected in the Field (L^3)

V_{lab} - Necessary Volume Required for Analysis (L^3)

V_{added} - Volume of DI water Added to Sample Volume to Obtain a Total Volume of 500 mL (L^3)

C_{lab} - Nutrient Concentration from Lab Analysis

C_{sample} - Nutrient Concentration of Collected Sample (M/L^3)

C_{actual} - Nutrient Concentration of Sample after accounting for Dilution (M/L^3)

A_{bucket} - Area of Bucket that is Used to Collect Samples (L^2)

$\text{DryDeposition}_{\text{rate}}$ - Atmospheric Deposition Rate from Dry Sample ($M/L^2/T$)

$\text{DryDep}_{\text{Rate1}}$ - Atmospheric Deposition Rate from Dry Sample for Location 1 ($M/L^2/T$)

$\text{DryDep}_{\text{Rate2}}$ - Atmospheric Deposition Rate from Dry Sample for Location 2 ($M/L^2/T$)

$\text{DryDep}_{\text{Rate3}}$ - Atmospheric Deposition Rate from Dry Sample for Location 3 ($M/L^2/T$)

$\text{DryDep}_{\text{Rate4}}$ - Atmospheric Deposition Rate from Dry Sample for Location 4 ($M/L^2/T$)

$\text{DryDep}_{\text{Rate5}}$ - Atmospheric Deposition Rate from Dry Sample for Location 5 ($M/L^2/T$)

$\text{WetDeposition}_{\text{rate}}$ - Atmospheric Deposition Rate from Dry Sample ($M/L^2/T$)

$\text{WetDep}_{\text{Rate1}}$ - Atmospheric Deposition Rate from Wet Sample for Location 1 ($M/L^2/T$)

$\text{WetDep}_{\text{Rate2}}$ - Atmospheric Deposition Rate from Wet Sample for Location 2 ($M/L^2/T$)

$\text{WetDep}_{\text{Rate3}}$ - Atmospheric Deposition Rate from Wet Sample for Location 3 ($M/L^2/T$)

$\text{WetDep}_{\text{Rate4}}$ - Atmospheric Deposition Rate from Wet Sample for Location 4 ($M/L^2/T$)

WetDep_{Rate5} - Atmospheric Deposition Rate from Wet Sample for Location 5 (M/L²/T)

TotalDep_{Rate1}- Total Deposition Rate from Both Wet and Dry Sample for Location 1 (M/L²/T)

TotalDep_{Rate2}- Total Deposition Rate from Both Wet and Dry Sample for Location 2 (M/L²/T)

TotalDep_{Rate3}- Total Deposition Rate from Both Wet and Dry Sample for Location 3 (M/L²/T)

TotalDep_{Rate4}- Total Deposition Rate from Both Wet and Dry Sample for Location 4 (M/L²/T)

TotalDep_{Rate5}- Total Deposition Rate from Both Wet and Dry Sample for Location 5 (M/L²/T)

Step 1) Convert Concentration into Deposition Rate for Dry Samples

$$C_{\text{lab}}=0.315 \text{ mg/L}$$

$$V_{\text{lab}}=500 \text{ mL}$$

$$V_{\text{added}}=0 \text{ mL}$$

$$C_{\text{actual}}=\frac{C_{\text{lab}}}{\frac{(V_{\text{lab}}-V_{\text{added}})}{V_{\text{lab}}}} = 0.315 \text{ mg/L}$$

$$V_{\text{actual}}=1250 \text{ mL}$$

$$A_{\text{bucket}}=0.0615 \text{ m}^2$$

$$\text{DryDeposition}_{\text{rate}}=\frac{C_{\text{actual}}*V_{\text{actual}}}{A_{\text{bucket}}} = 6.402 \text{ mg/m}^2$$

Step 2) Repeat Step 1 for all Five Locations

$$\text{DryDep}_{\text{Rate1}} = \text{Deposition}_{\text{rate}}=6.402 \text{ mg/m}^2$$

$$\text{DryDep}_{\text{Rate2}}=53.229 \text{ mg/m}^2$$

$$\text{DryDep}_{\text{Rate3}}=2994.39 \text{ mg/m}^2$$

$$\text{DryDep}_{\text{Rate4}}=0.217 \text{ mg/m}^2$$

$$\text{DryDep}_{\text{Rate5}}=40.316 \text{ mg/m}^2$$

Step 3) Convert Concentration into Deposition Rate for Wet Samples

$$V_{\text{actual}}=8 \text{ mL}$$

$$C_{\text{lab}}=0.005 \text{ mg/L}$$

$$V_{\text{lab}}=500 \text{ mL}$$

$$V_{\text{added}}=492 \text{ mL}$$

$$C_{\text{actual}}=\frac{C_{\text{lab}}}{\frac{(V_{\text{lab}}-V_{\text{added}})}{V_{\text{lab}}}} = 0.312 \text{ mg/L}$$

$$A_{\text{bucket}}=0.0615 \text{ m}^2$$

$$\text{WetDeposition}_{\text{rate}}=\frac{C_{\text{actual}}*V_{\text{actual}}}{A_{\text{bucket}}} = 0.041 \text{ mg/m}^2$$

Step 4) Repeat Step 3 for all Five Locations

$$\text{WetDep}_{\text{rate1}}= \text{Deposition}_{\text{rate}}=0.01 \text{ mg/m}^2$$

$$\text{WetDep}_{\text{rate2}}=0.059 \text{ mg/m}^2$$

$$\text{WetDep}_{\text{rate3}}=7.300 \text{ mg/m}^2$$

$$\text{WetDep}_{\text{rate4}}=0.059 \text{ mg/m}^2$$

$$\text{WetDep}_{\text{rate5}}=0.059 \text{ mg/m}^2$$

Step 5) Add Deposition Rates from Dry and Wet Samples

$$\text{TotalDep}_{\text{rate1}}=\text{DryDep}_{\text{rate1}}+\text{WetDep}_{\text{rate1}}=6.41 \text{ mg/m}^2$$

$$\text{TotalDep}_{\text{rate2}}=\text{DryDep}_{\text{rate2}}+\text{WetDep}_{\text{rate2}}=53.29 \text{ mg/m}^2$$

$$\text{TotalDep}_{\text{rate3}}=\text{DryDep}_{\text{rate3}}+\text{WetDep}_{\text{rate3}}=3001.69 \text{ mg/m}^2$$

$$\text{TotalDep}_{\text{rate4}}=\text{DryDep}_{\text{rate4}}+\text{WetDep}_{\text{rate4}}=0.28 \text{ mg/m}^2$$

$$\text{TotalDep}_{\text{rate5}}=\text{DryDep}_{\text{rate5}}+\text{WetDep}_{\text{rate5}}=40.38 \text{ mg/m}^2$$

Step 6) Enter Deposition Rates into Geospatial Software and Interpolate Values over the Surface of Utah Lake

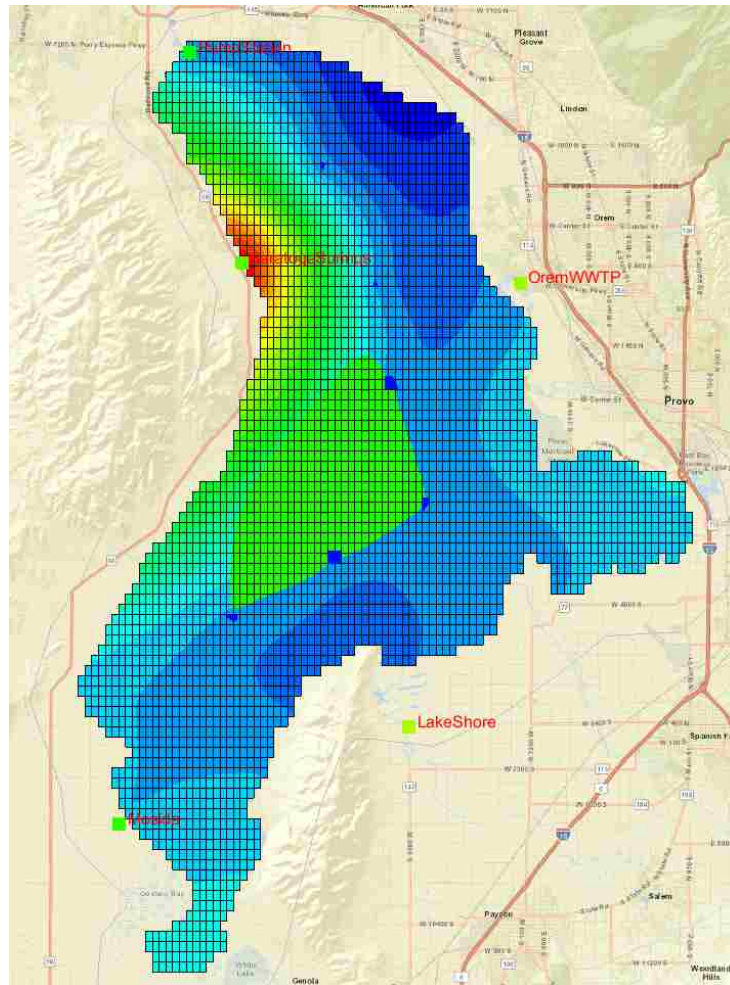


Figure C-1: DIN Deposition Rates Interpolated onto 2D Grid

Step 7) Take Deposition Values for Each Cell and Multiply by the Area of Each Cell and Sum All Loading Values

Table C-1: Table of DIN Deposition Rates for the Third Week in July

Cell ID	X Coordinate	Y Coordinate	Deposition Rate (mg m ⁻² week ⁻¹)	Area (m ²)	Loading (mg week ⁻¹)
1	423890.4	4468270	6.42	101,721.83	652,988.62
2	424164.2	4468270	6.22	101,721.83	632,593.09
3	424438	4468270	5.99	101,721.83	609,459.82
:	:	:	:	:	:
:	:	:	:	:	:
3396	423890.4	4430850	5.35	101,721.83	544,455.50
3397	424164.2	4430850	5.25	101,721.83	534,544.03
3398	424438	4430850	5.15	101,721.83	523,913.59
Total	-	-	-	345,650,770	65,271,960,750

Step 8) Convert Deposition Value from mg week⁻¹ to ton week⁻¹

$$65,271,960,750 \frac{mg}{week} * \frac{1 kg}{1 * 10^6 mg} * \frac{1 ton}{907.185 kg} = 71.95 \frac{ton}{week}$$

Step 9) Sum All Weekly Deposition Loads for the Total Deposition Load to Utah Lake for Eight Months

Table C-2: Weekly Loading for TP and DIN

Week Sampled	Date	All Samples		Uncontaminated Samples	
		TP tons/week	DIN tons/week	TP tons/week	DIN tons/week
Week 1	5/11/2017	0.55	0.70	0.80	0.91
Week 2	5/18/2017	0.11	0.91	0.12	0.37
Week 3	5/25/2017	3.36	3.75	0.01	0.43
Week 4	6/1/2017	3.75	2.92	-	-
Week 5	6/8/2017	2.68	4.60	-	-
Week 6	6/15/2017	1.12	0.28	0.06	0.32
Week 7	6/22/2017	59.36	50.39	0.04	0.59
Week 8	6/29/2017	19.36	9.28	-	-

Week 9	7/6/2017	12.82	15.49	-	-
Week 10	7/13/2017	47.51	20.63	0.05	0.47
Week 11	7/20/2017	81.64	71.95	0.07	0.59
Week 12	7/27/2017	79.36	186.33	0.19	1.58
Week 13	8/3/2017	22.81	25.02	-	-
Week 14	8/10/2017	3.38	5.72	0.21	1.12
Week 15	8/17/2017	1.77	4.14	-	-
Week 16	8/24/2017	1.85	3.18	0.05	0.33
Week 17	8/31/2017	2.46	6.02	0.08	0.63
Week 18	9/7/2017	0.41	2.75	-	-
Week 19	9/14/2017	0.50	3.50	0.02	0.31
Week 20	9/21/2017	2.78	4.78	0.09	0.86
Week 21	9/28/2017	0.12	2.68	0.12	2.71
Week 22	10/5/2017	0.19	2.16	0.25	2.40
Week 23	10/12/2017	0.75	1.69	0.75	1.72
Week 24	10/19/2017	0.21	1.85	0.21	1.88
Week 25	10/26/2017	0.43	1.20	0.43	1.22
Week 26	11/2/2017	0.63	6.79	0.63	6.82
Week 27	11/9/2017	0.56	7.08	0.56	7.11
Week 28	11/16/2017	0.17	3.59	0.17	3.62
Week 29	11/30/2017	2.45	7.02	2.45	7.04
Week 30	12/7/2017	0.46	2.14	0.46	1.99
Week 31	12/14/2017	0.16	1.16	0.16	1.19

Measured Total		353.71	459.71	8.01	46.22
-----------------------	--	---------------	---------------	-------------	--------------