2023-03-09

Nutrient Loadings to Utah Lake from Bulk Atmospheric Deposition

Mitchell Matthew Brown
Brigham Young University

Nutrient Loadings to Utah Lake from Bulk Atmospheric Deposition

Mitchell Matthew Brown

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

Master of Science

Gustavious P. Williams, Chair
A. Woodruff Miller
Robert B. Sowby

Department of Civil and Construction Engineering

Brigham Young University

Nutrient Loadings to Utah Lake from Bulk Atmospheric Deposition

Mitchell Matthew Brown
Department of Civil and Construction Engineering
Master of Science

BYU ENGINEERING

Abstract

Atmospheric deposition is a marginally understood source of nutrient loadings to waterbodies. Atmospheric deposition occurs via wet (rain, snow) and dry (gaseous and particulate transport) pathways. Bulk atmospheric deposition is defined as the total deposition from both wet and dry pathways. Utah Lake is a shallow eutrophic freshwater lake located in central Utah, USA. Recent studies have shown atmospheric deposition to be a significant contributor to the nutrient budget of Utah Lake. This study presents the analysis using three different methods of six years' worth of wet atmospheric deposition samples from nine locations around the lake, though these samples do include some contribution from dry deposition. We present and compare nutrient loads and nutrient loading rates for total phosphorus, total inorganic nitrogen, and ortho-phosphorus. We conclude that wet atmospheric deposition contributed between 309 to 529 tons of total phosphorus, 1,166 to 2,078 tons of total nitrogen, and 106 to 201 tons of ortho-phosphorus to the lake during the study period. We extracted loading rates for the calendar year (in tons per year) and winter/summer month (in tons per month) from the data from each of the three methods of analysis. We show that wet atmospheric deposition is a significant pathway in which nutrients are transported to Utah Lake.

Keywords: atmospheric deposition; Utah Lake; total phosphorus; total inorganic nitrogen; ortho-phosphorus; nutrient loading rates

Acknowledgments

I express my gratitude to Dr. Gustavious Williams, Dr. Woodruff Miller, and Dr. Robert Sowby for their expertise and guidance in this work; The Wasatch Front Water Quality Council and Brigham Young University for supporting this work; Chem-tech Ford Laboratories for donating their work associated with the sample analysis; my parents, Matt and Cheryl Brown for their constant support and allowing me to use resources through their company, MW Brown Engineering Inc.; and to my incredible wife, Tori Brown, whose patience, encouragement and love was crucial throughout.

Table of Contents

List of Figures

List of Tables

1. Introduction

Utah Lake, a remnant of Pleistocene Lake Bonneville, is a shallow eutrophic freshwater lake approximately 50 km (30 miles) long and 10 km (6 miles) wide [1] located in Utah County, Utah. When full, the surface area of the lake is roughly 40,000 hectares (95,000 acres) with an average depth of 2.8 meters (9.2 feet) [1]. Due to its large surface-area-to-volume ratio, the lake is susceptible to atmospheric deposition of nutrients [2]. The lake is considered highly eutrophic by the Larsen-Mercier Tropic State model and moderately eutrophic by the Carlson Trophic State Index model [1]. The lake is commonly used for recreation but has been temporarily closed at times due to the presence of harmful algal blooms [3].

The Utah Division of Water Quality (DWQ) has recently elevated its interest in the nutrient loadings to the lake. DWQ is currently looking at reducing wastewater treatment plant (WWTP) nutrient discharge limits and other mitigation efforts [1, 4]. The proposed mitigation efforts assume that phosphorus loadings from anthropogenic sources significantly contribute to the lakes overall nutrient budget [5]. Abu-Hmeidan, Williams [5] found that "natural phosphorous loadings could be a significant factor, and that the impaired state of the lake may be relatively insensitive to external anthropogenic loadings".

Nutrients, such as phosphorus (P) and nitrogen (N), are generated, transported, and deposited into waterbodies in a variety of ways. Zheng, Cao [6] found that N and P are the major nutrients transported to waterbodies and limiting factors in most aquatic ecosystems. Atmospheric deposition (AD) can occur via wet (rain/snow) or dry (gaseous and particulate transport in the air) pathways and is one of the least understood nutrient transport pathways [7]. Previous studies have neglected or omitted AD nutrients onto Utah Lake [4], while recent studies have shown that AD is a significant source of nutrients [2, 8, 9]. Methods and procedures for studying atmospheric deposition are improving as more data are collected and analyzed [10].

The purpose of this study is to quantify total loads and loading rates for bulk atmospheric deposition of phosphorus and nitrogen onto the surface of Utah Lake with a focus on wet deposition. Bulk atmospheric deposition is deposition from both wet and dry pathways. However, over water, there is significantly more dry deposition that occurs than over land. This deposition consists of fine materials (less than 10 μm) that do not settle readily due to gravity and are removed from the atmosphere by contact rather than by settling. However, dry surfaces only retain a limited amount of these fine particles, as they adhere by static electricity and are easily resuspended to not captured. Contact with water, such as a lake surface, captures these fine particles. Conversely, any of these fine particles that touch the wet surface of the lake are captured. The measurements described in this paper focus on precipitation collections. The rainfall gauges did capture some dry deposition, but dry deposition of dust is a relatively minor component of nutrient deposition to Utah Lake.

Particulate matter less than 10 μm (PM10) and less than 2.5 μm (PM2.5) in diameter are monitored as indicators of air quality. Kuprov, Eatough [11] studied atmospheric pollution in Utah and noted that Utah Valley, the location of Utah Lake, is a non-attainment area for PM_{10} and $PM_{2.5}$ which means that particulate levels are high for these particle sizes.

The way particulates settle in the atmosphere depends on their size and weight, with larger particulates settling faster than smaller particulates. For example, dust particles may settle within a few hours, while smaller particles, like PM2.5, can stay in the atmosphere for days to weeks.

Hinds and Zhu [12] state that particle size is the most important parameter for characterizing aerosol behavior. They show that particles with equivalent diameters of 0.1, 1.0, 10, and 100 μm settle in perfectly calm air at $8.8x10^{-7}$, $3.7x10^{-5}$, and $3.1x10^{-3}$, and $2.5x10^{-1}$ meters per second (m/s), respectively. In terms of time, this means that the 0.1, 1.0, 10, and 100 μm particles require 315 hours, 7.5 hours, 5 minutes, and 4 seconds to settle 1 meter in perfectly calm air, respectively. This means that for particles smaller than about 10 μm (PM10) a light breeze can keep the particle from settling. While PM2.5 particulates such as photochemical smog (mostly nitrogen particles), smokes, and fine dust essentially do not settle from the atmosphere, but are kept aloft by Brownian motion and wind currents [12]. For these particles, gravity is not an effective removal mechanism, but they are removed from the atmosphere by contact with a surface or by washout from precipitation. Contact can either by a dry surface where static charges capture the particle, or wet surfaces. Static surfaces soon fill, and subsequent particles either are not captured or displace an existing particle which is resuspended. Wet surfaces, such as Utah Lake, capture any of the fine particles that touch the surface.

This report presents three methods of analysis on six years of precipitation samples collected at nine locations around the lake. Total loads and loading rates for total phosphorus (TP), total inorganic nitrogen (TIN), and ortho phosphorus (OP) are presented.

2. Materials and Methods

2.1. Sample Collection

Beginning in January 2017, nine bulk atmospheric deposition measuring stations were placed around the perimeter of Utah Lake. More than 850 precipitation samples have been collected after storm events over the past six years (January 2017 through December 2022). Six of the nine stations use a precipitation sampler which consists of a collection tube connected to a larger funnel, placed approximately 2 meters (7 feet) above the ground, depicted in Figure 2.1. The other three stations (BYU, Lehi Pump Station, and Spanish Fork) are standard precipitation gauges on weather stations. Figure 2.2 shows a map of the measuring station (MS) locations around the lake. These samplers are designed to collect precipitation, rather than dry deposition. While they do collect dust, especially larger particulates that settle due to gravity, they do not efficiently capture fine particulate matter. They are also not designed to capture and retain even the larger particles. The large funnel is relatively flat and does collect dust, but the dust is easily resuspended from the open surface, the dust is only transported into the collection sampler during a precipitation event. So while we call this "bulk" deposition, it is heavily skewed toward only the wet portion.

Figure 2.1 Pelican Point bulk atmospheric deposition measuring station

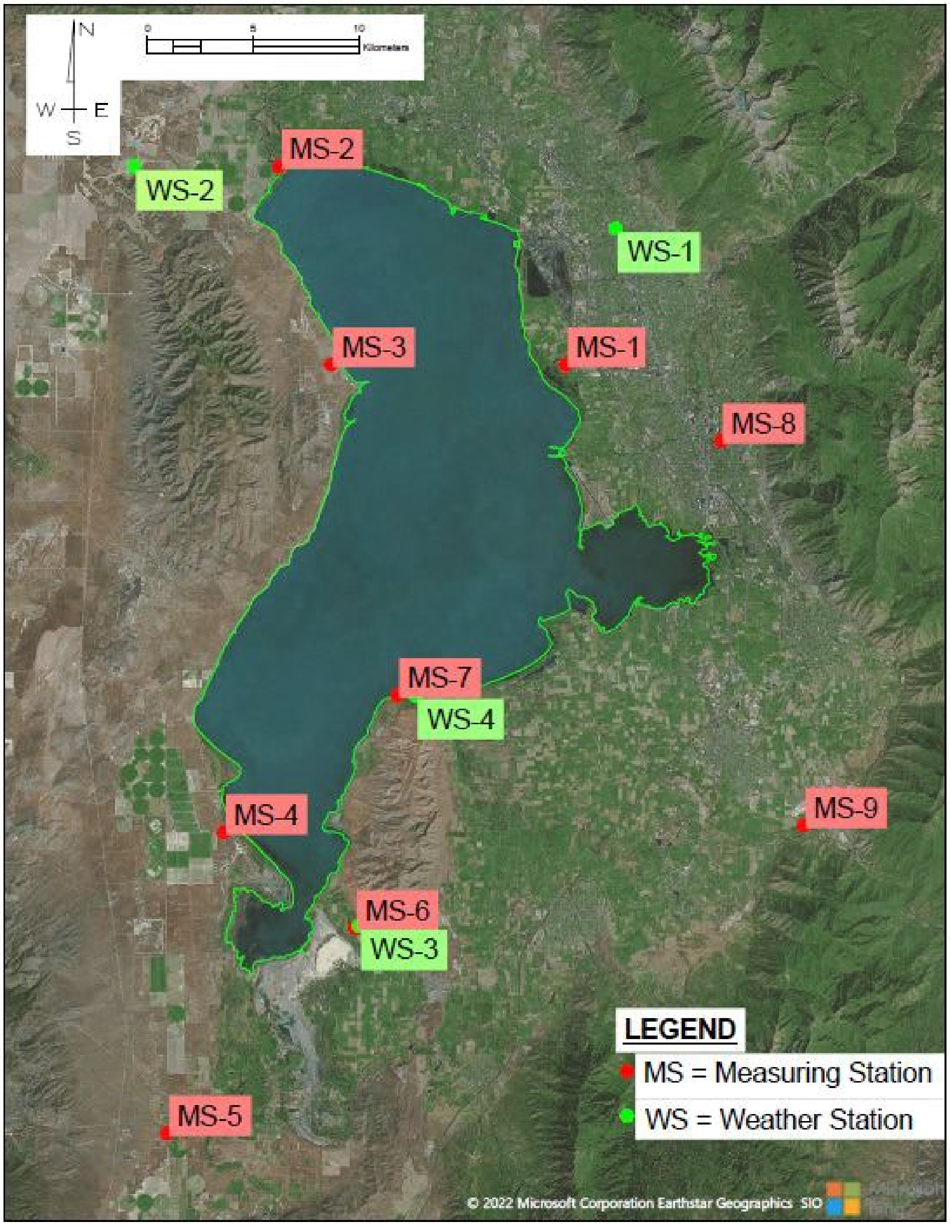


Figure 2.2 Bulk Atmospheric Deposition Measuring Station and Weather Station Locations. Abbreviations: MS-1 = Orem; MS-2 = Lehi Pump Station; MS-3 = Pelican Point; MS-4 = Mosida; MS-5 = Elberta; MS-6 = Genola; MS-7 = Lincoln Point; MS-8 = Brigham Young University (BYU); MS-9 = Spanish Fork; WS-1 = Lindon; WS-2 = EMCNolan; WS-3 = Genola; WS-4 = Lincoln Point

2.2. Sample Preperation and Analysis

Samples were collected from the measuring stations on the day following a storm to minimize any evaporation of collected precipitation. The water in each sample was visually inspected for contaminants such as bird feces and insects. All collected samples were found to be clear, never cloudy, or otherwise dirty (contaminated). Samples were transferred from the collection tube to a capped bottle for transportation. The collection tubes and funnels were cleaned every time a sample was collected.

The samples were analyzed by Chemtech-Ford Laboratories for concentrations, C_x, in milligrams per liter (mg/L) of total phosphorus (TP), total inorganic nitrogen (TIN), and ortho phosphorus (OP). The subscript x denotes the various measuring station locations. Chemtech-Ford

Laboratories is a TNI-accredited environmental testing laboratory. The Environmental Protection Agency (EPA) methods utilized for TP and TIN analysis were EPA 200.7 and EPA 353.2, respectively. The Standards Methods for the Examination of Water and Wastewater (SM) utilized for OP analysis were SM45000 P-E/F. All work (materials and labor) associated with the sample analysis was donated by Chemtech-Ford Laboratories. This research would not be possible without their support.

Analysis of TP and TIN concentrations was completed on all collected samples, while OP analysis began in January 2019. The TP and OP tests had a detection limit of 0.007 mg/L, and the TN test had a detection limit of 0.1 mg/L. Samples that resulted in concentrations below the detection limit were reported as below detection limit (BDL).

Table 2.1 provides a statistical summary of the mean, median, maximum and skew of C_x for each measuring station. The minimum value for each measuring station location is 0.00 mg/L and as such, is not shown in Table 1. The raw concentration data is attached in Appendix A.

Table 2.1 Statistical summary of concentration data for each measuring station

Total Phosphorus	**N**	**Mean**[1]	**Median**[1]	**Max**[1]	**Skew**
MS-1 (TP)	97.00	0.65	0.26	8.90	4.85
MS-2 (TP)	108.00	0.99	0.32	11.00	3.46
MS-3 (TP)	92.00	0.94	0.25	7.80	2.59
MS-4 (TP)	88.00	1.13	0.60	5.20	1.54
MS-5 (TP)	98.00	0.63	0.31	4.90	3.31
MS-6 (TP)	104.00	0.90	0.28	10.00	3.52
MS-7 (TP)	98.00	1.18	0.41	8.90	2.57
MS-8 (TP)	94.00	0.13	0.06	1.20	3.39
MS-9 (TP)	98.00	0.18	0.07	2.70	5.03
Total Inorganic Nitrogen					
MS-1 (TIN)	97.00	2.70	2.10	22.20	3.98
MS-2 (TIN)	107.00	2.23	1.80	11.70	1.99
MS-3 (TIN)	95.00	2.77	1.50	18.50	2.57
MS-4 (TIN)	88.00	2.68	1.90	10.30	1.45
MS-5 (TIN)	98.00	1.80	1.40	8.50	1.77
MS-6 (TIN)	103.00	1.58	1.00	11.80	2.72
MS-7 (TIN)	102.00	3.09	1.46	24.40	3.05
MS-8 (TIN)	88.00	1.77	1.30	9.59	2.15
MS-9 (TIN)	96.00	1.36	1.10	6.70	2.32
Ortho Phosphorus					
MS-1 (OP)	65.00	0.30	0.12	2.10	2.70
MS-2 (OP)	69.00	0.52	0.16	4.00	2.44
MS-3 (OP)	59.00	0.51	0.14	3.80	2.50
MS-4 (OP)	63.00	0.78	0.32	7.60	3.66
MS-5 (OP)	68.00	0.32	0.14	3.20	3.59
MS-6 (OP)	71.00	0.22	0.10	1.70	2.59
MS-7 (OP)	70.00	0.87	0.21	9.60	3.39
MS-8 (OP)	49.00	0.03	0.02	0.11	1.31
MS-9 (OP)	59.00	0.06	0.04	0.40	2.74

[1] mg/L

2.3. Other Data Collection and Definition

The Utah Climate Center, managed by Utah State University, was utilized to obtain daily precipitation data from four weather stations (WS) around the lake [13]. Figure 2.2 shows the locations of the four weather stations. The Lindon, Lincoln Point, and Genola stations are a part of the "fgnet" network and the EMCNolan station is a part of the "agwx" network. A python code was written to sum the total amount of precipitation, P_x, in inches (in), at each station between sample dates.

Table 2.2 provides a yearly summary of the total precipitation for each weather station location.

Table 2.2 Yearly summary of total precipitation for each weather station

	WS-1[1]	WS-2[1]	WS-3[1]	WS-4[1]
2017	12.05	12.05	11.16	12.32
2018	9.85	10.53	11.70	10.36
2019	15.42	13.55	14.91	12.73
2020	9.00	8.41	5.76	4.70
2021	15.35	9.39	10.85	10.65
2022	7.43	7.71	7.51	7.13

[1] inches

Central Utah Water Conservancy District (CUWCD) tracks and keeps record of the physical attributes of the reservoirs and streams within their jurisdiction, including Utah Lake. CUWCD provided Dr. A. Woodruff Miller with average monthly surface area data of the lake for the study period [14]. The average monthly surface area data, A_M (acres), were provided via a website that only stores data for the three most recent months. The data were collected and saved monthly to avoid loss.

Table 2.3 provides a summary of the average monthly surface area (acres) of Utah Lake during the study period.

Table 2.3 Average monthly surface area of Utah Lake

	2017[1]	**2018[1]**	**2019[1]**	**2020[1]**	**2021[1]**	**2022[1]**
Jan	77196	85462	82302	92199	87123	82655
Feb	79490	86390	83896	93110	87799	83230
Mar	81753	87315	85120	93474	88266	83769
Apr	84180	87617	86625	94011	88242	83832
May	86790	87593	89372	93277	87508	83300
Jun	87508	86437	92253	92500	86082	81947
Jul	86743	84368	92418	90827	83611	79622
Aug	84964	81656	90986	88639	81753	77537
Sep	83769	79755	89911	86920	80251	75989
Oct	82973	79323	89397	86113	79888	75360
Nov	84714	79987	90223	86236	80776	76023
Dec	84305	81005	91119	86601	81785	77127

[1] acres

2.4. Data Analysis

Three methods were used to compute and compare total loads and loading rates of phosphorus and nitrogen. All three methods computed a total load of each nutrient, in tons, to the surface of the lake between sample collection dates. Total monthly/yearly loads, in tons, and monthly/yearly loading rates, in tons/month and tons/year respectively, were extracted and reported in the results section.

Method 1 used the arithmetic mean of the nutrient concentrations to compute loading rates based on precipitation from each of the four weather stations. The average of the four loading rates was taken and reported as the lake loading rate. Method 2 used Thiessen polygons to area-weight the precipitation and nutrient concentrations. The percentage of lake surface area for each significant area was used to compute area-weighted averages of precipitation and nutrient concentrations, which were multiplied together to obtain the lake loading rate. Method 3 used Inverse distance weighting (IDW) interpolation to generate precipitation and nutrient concentration rasters for each sample date. Loading rates were computed by multiplying each nutrient raster by its respective precipitation raster and ratio of lake surface area.

2.4.1. Method 1

The arithmetic mean of the nutrient concentration, $\bar{C}$, for each sample date was computed, disregarding samples that were not collected/analyzed and using half of the respective nutrient detection limit for samples reported as BDL. The total load to the surface of the lake between sample dates, L_{M1}, in tons, was computed according to equation 2.1.

$$L_{M1} = \bar{C} * P_x * A_M * CF \qquad (2.1)$$

Where CF is a unit conversions factor to convert from units of $\frac{mg}{L} * in * ac$ to tons. CF is as defined in equation 2.2.

$$CF = \frac{43560\, ft^2}{1\, Ac} * \frac{1\, Kg}{1 * 10^6\, mg} * \frac{2.205\, lbs}{1\, Kg} * \frac{1\, Ton}{2000\, lbs} * \frac{3.785\, L}{1\, Gal} * \frac{7.48\, Gal}{1\, ft^3} * \frac{1\, ft}{12\, in} = 1.133 * 10^{-4} \qquad (2.2)$$

The total load to the surface of the lake between sample dates, L_{M1}, was computed four times for each of the three nutrients, changing the precipitation, P_x, to values from the different weather stations. The lake loading rate presented in the results section is the average of the results for the four different weather stations.

2.4.2. Method 2

The Utah Geospatial Resource Center (UGRC) maintains map data of Utah's Lakes, Rivers, Streams, & Springs which is derived from the National Hydrography Database [15]. We used the polygon of Utah Lake available for download from the UGRC website and the weather/measuring station locations to perform two Thiessen Polygon analyses. This analysis was performed in GIS software. We took the total significant area within the extents of Utah Lake for each weather/measuring station and divided by the total area of the Utah Lake polygon to determine the respective area ratio, AR, in percent.

Table 2.4 contains a numeric summary of the Thiessen Polygon results for the weather stations. Figure 2.3 shows a map of the results for the weather stations.

Table 2.4 Numeric summary of weather stations Thiessen polygon analysis results

Weather Station	Polygon Area[1]	Area Ratio[2]
WS-1	29227.86	32.06
WS-2	8261.95	9.06
WS-3	7568.70	8.31
WS-4	46106.86	50.57
Total	91165.37	100.00

[1] acres; [2] percentage (%)

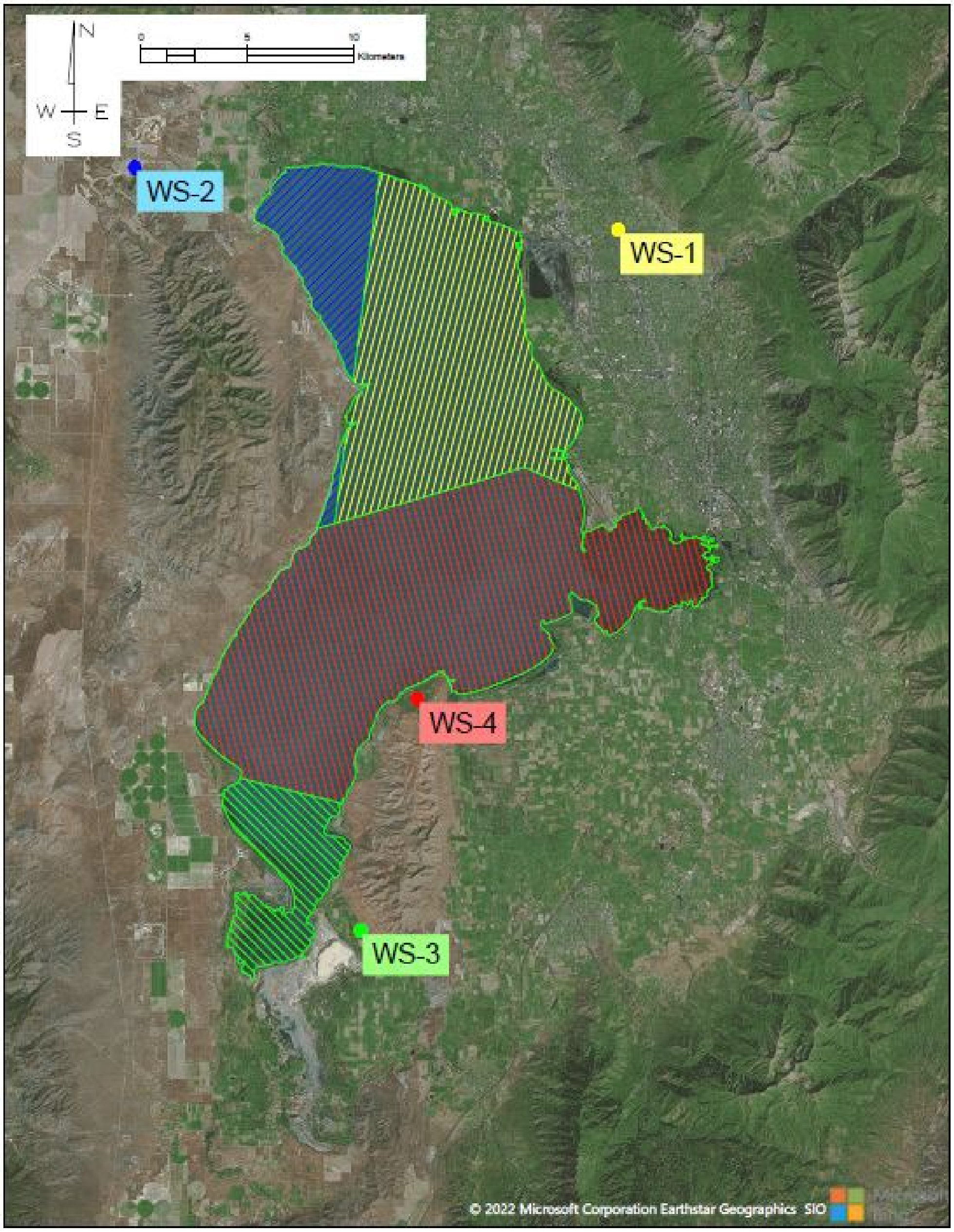


Figure 2.3 Map of weather stations Thiessen polygon analysis results. Abbreviations: WS-1 = Lindon; WS-2 = EMCNolan; WS-3 = Genola; WS-4 = Lincoln Point

Table 2.5 contains a numeric summary of the Thiessen Polygon results for the measuring stations. Figure 2.4 shows a map of the results for the measuring stations.

Table 2.5 Numeric summary of measuring stations Thiessen polygon analysis results

Weather Station	Polygon Area[1]	Area Ratio[2]
MS-1	19449.55	21.46
MS-2	10606.69	7.08
MS-3	0.00	21.33
MS-4	2877.21	11.63
MS-5	27050.90	0.00
MS-6	5164.41	3.16
MS-7	0.00	29.67
MS-8	91165.37	5.67
MS-9	0.00	0.00
Total	91165.37	100.00

[1] acres; [2] percentage (%)

The total load to the surface of the lake between sample dates, L_{M2}, in tons, was computed according to equation 2.3.

$$L_{M2} = \Sigma(C_{AW} * P_{AW} * A_M * CF) \tag{2.3}$$

The subscript AW denotes the area-weighted average for each sample date.

2.4.3. Method 3

The locations of the Weather and Measuring Stations, combined with their respective precipitation and nutrient concentration data, were used to perform Inverse Distance Weighting (IDW) interpolation across the surface of Utah Lake. The IDW analysis was coded in Python GIS software and used a distance exponent of 2. IDW interpolation was completed for the precipitation, P_R, and each nutrient (TP, TIN, and OP) concentration, N_R, on each sample date. Figures 2.5 and 2.6 show examples of the interpolated rasters for TP concentration and precipitation on various sample dates.

A mask function was used to filter each raster to the pixels inside of the Utah Lake polygon. Raster math (map algebra) was implemented to compute the total load to the surface of the lake between sample dates, L_{M3}, in tons, according to equation 2.4.

$$L_{M3} = \Sigma(\mathrm{N_R} * P_R * A_R * CF_R) * \frac{A_M}{A_{PG}} \tag{2.4}$$

The subscript R denotes specific values for each cell in the raster math calculations. The area of the Utah Lake polygon, A_{PG}, was constant in the calculations and had units of square meters. The conversion factor, CF_R, is a unit conversions factor to convert from units of $\frac{mg}{L} * in * m^2$ to tons. CF_R is as defined in equation 2.5.

$$CF_R = \frac{1\,Kg}{1 * 10^6\,mg} * \frac{2.205\,lbs}{1\,Kg} * \frac{1\,Ton}{2000\,lbs} * \frac{1\,m}{39.37\,in} * \frac{1000\,\mathrm{L}}{1\,m^3} = 2.800 * 10^{-8} \tag{2.5}$$

The results for L_{M3} were scaled by the ratio of the monthly average surface area of Utah Lake, A_M, to the Utah Lake polygon, A_{PG}.

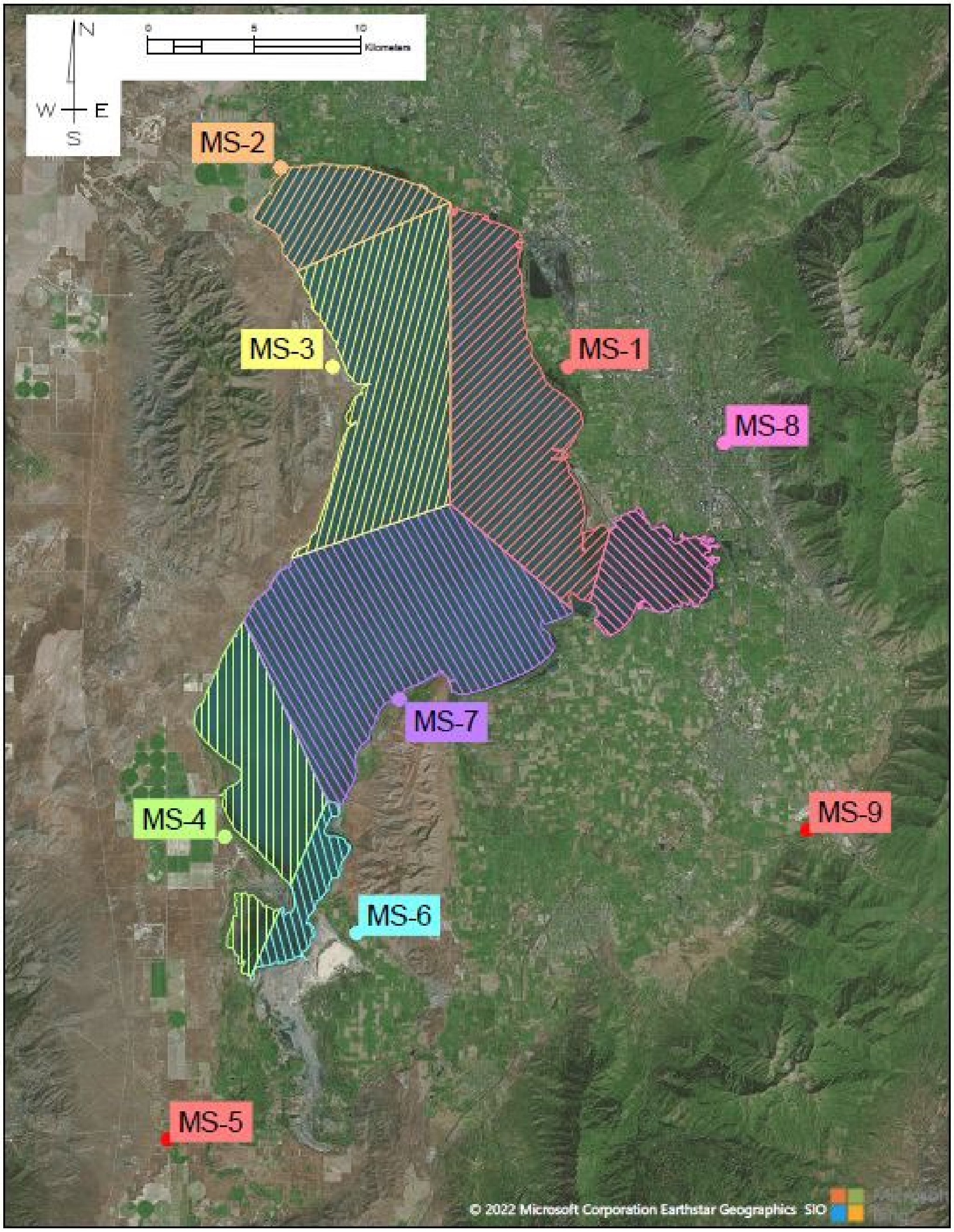
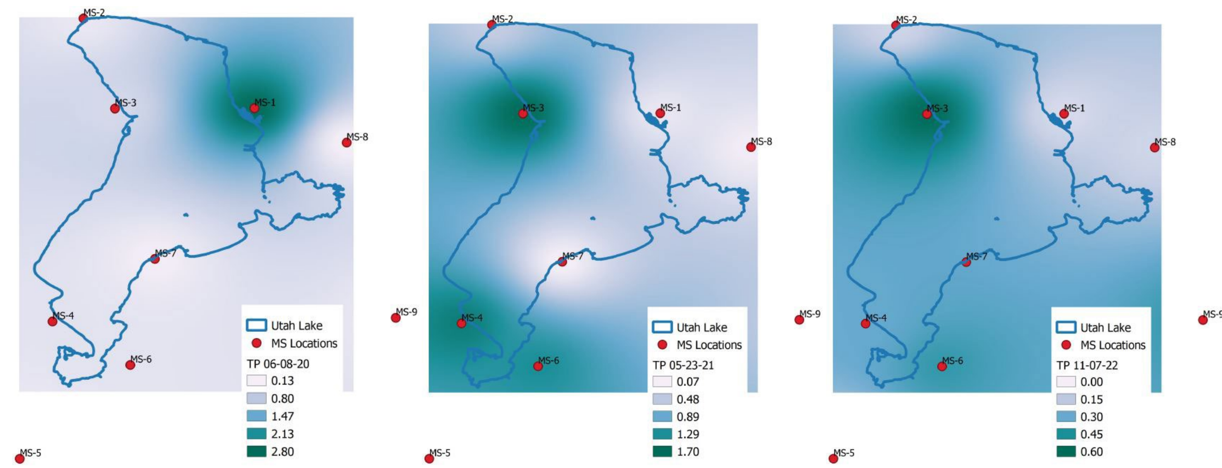
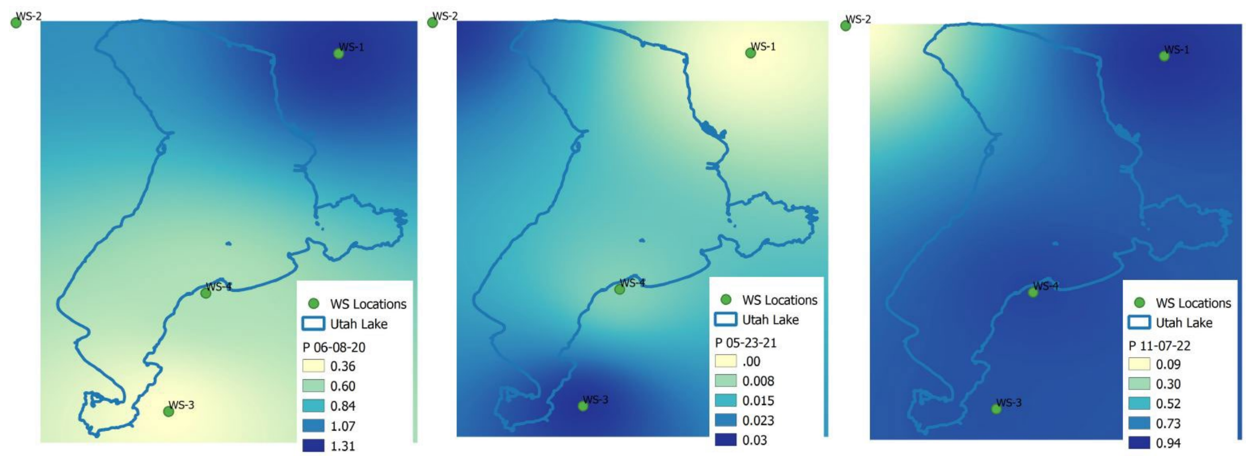


Figure 2.4 Map of measuring stations Thiessen polygon analysis results. Abbreviations: MS-1 = Orem; MS-2 = Lehi Pump Station; MS-3 = Pelican Point; MS-4 = Mosida; MS-5 = Elberta; MS-6 = Genola; MS-7 = Lincoln Point; MS-8 = Brigham Young University (BYU); MS-9 = Spanish Fork



(a) (b) (c)

Figure 2.5 Examples of TP concentration (mg/L) interpolated rasters from: (a) June 08, 2020; (b) May 23, 2021; and (c) November 07, 2022



(a) (b) (c)

Figure 2.6 Examples of precipitation (inches) interpolated rasters from: (a) June 08, 2020; (b) May 23, 2021; and (c) November 07, 2022

3. Results

Results from each analysis method for total load, calendar year loading rates, and winter/summer month loading rates are presented for TP, TIN, and OP. Results for water year loading rates are attached in Appendix B.

3.1. Total Nutrient Loads

Table 3.1 summarizes the total nutrient cumulative loads, in tons, for each of the three analysis methods. The total nutrient loads for TP and TIN represent the total mass deposited to the surface of the lake over the six-year study period. Similarly, the total nutrient load for OP represents the total mass deposited to the surface of the lake over the four-year study period.

Table 3.1 Summary of total nutrient loads

Nutrient	Method		
	M1[1]	M2[1]	M3[1]
TP	309	484	529
TIN	1,166	1,236	2,078
OP	106	160	201

[1] tons

Figures 3.1, 3.2 and 3.3 show the cumulative nutrient loading trends for analysis methods 1, 2 and 3, respectively.

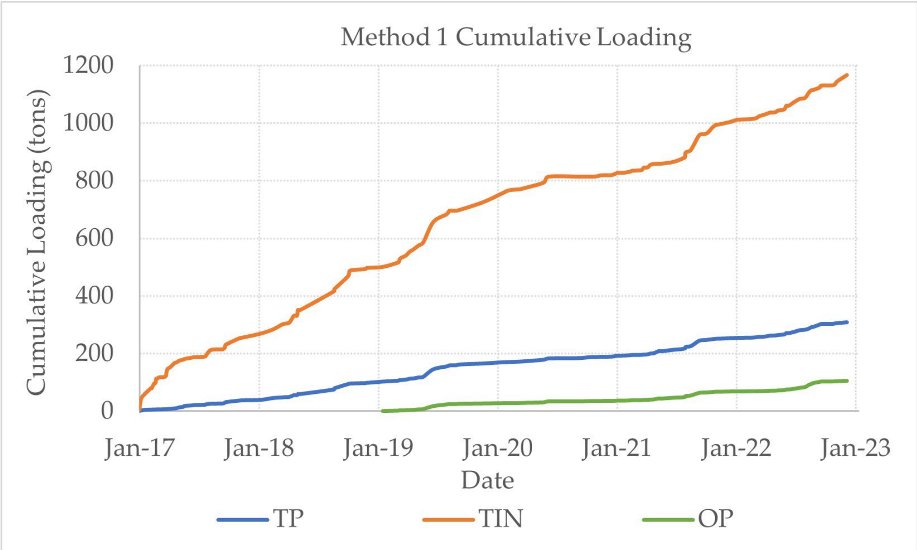


Figure 3.1 Method 1 cumulative loading results

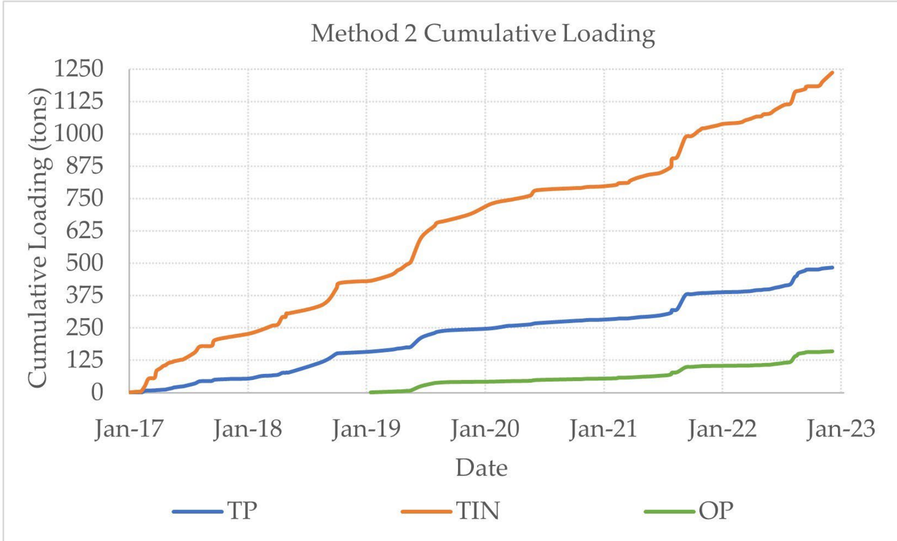


Figure 3.2 Method 2 cumulative loading results

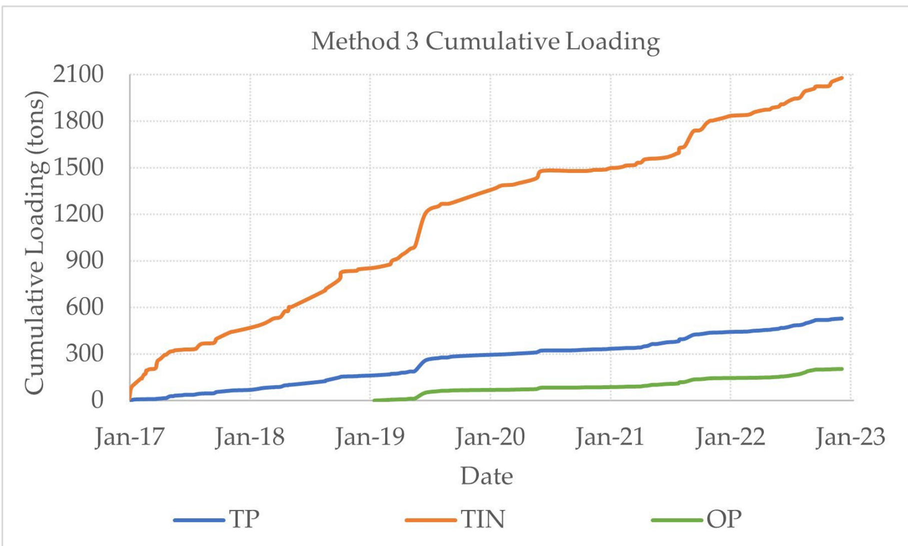


Figure 3.3 Method 3 cumulative loading results

3.2. Calendar Year Nutrient Loads

Table 3.2 summarizes the calendar year nutrient loads, in tons, and average loading rates, in tons/year, for each of the three analysis methods. The calendar year nutrient load represents the total mass of each nutrient deposited to the surface of the lake throughout the respective calendar year. The average loading rate for TP and TIN is the six-year average of mass deposited during the study period. Similarly, the average loading rate for OP is the 4-year average.

Figures 3.4, 3.5 and 3.6 show the calendar year nutrient loads and average loading rates for analysis methods 1, 2 and 3, respectively.

Table 3.2 Summary of calendar year loads and average loading rates

Nutrient	Method	Calendar Year						
		2017[1]	**2018[1]**	**2019[1]**	**2020[1]**	**2021[1]**	**2022[1]**	**Average[2]**
TP	**M1**	36.6	60.9	67.5	23.9	65.1	54.6	51.4
	M2	54.0	101.9	89.1	36.9	106.3	95.5	80.6
	M3	64.3	92.7	133.1	39.5	111.2	86.5	87.9
TIN	**M1**	252.0	240.9	227.9	93.9	189.7	157.1	193.6
	M2	217.3	212.3	260.7	105.3	240.5	199.7	206.0
	M3	436.8	400.6	479.7	162.2	345.0	246.2	345.1
OP	**M1**	N/A	N/A	26.8	9.0	33.2	37.1	26.5
	M2	N/A	N/A	41.4	12.4	49.8	56.3	40.0
	M3	N/A	N/A	67.0	18.2	58.4	57.7	50.3

[1] tons; [2] tons/year

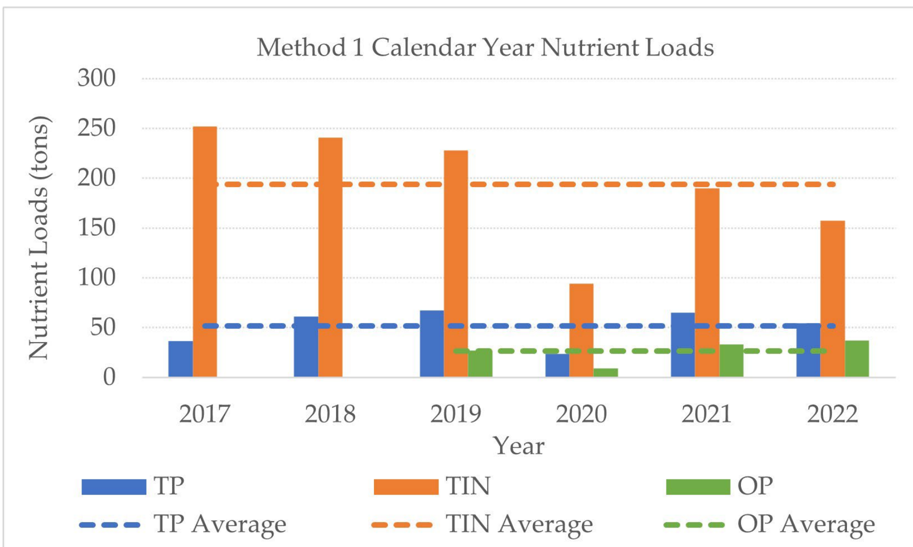


Figure 3.4 Method 1 calendar year loads and average loading rates results

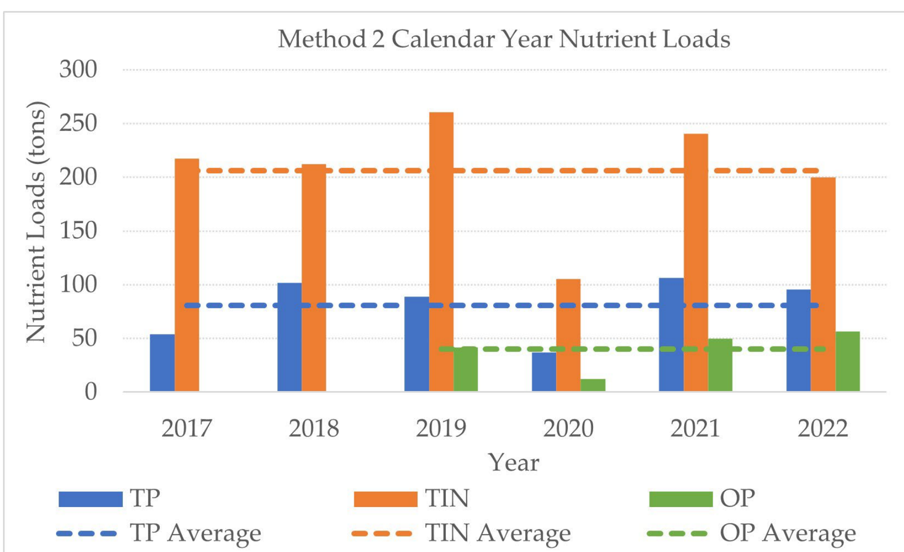


Figure 3.5 Method 2 calendar year loads and average loading rates results

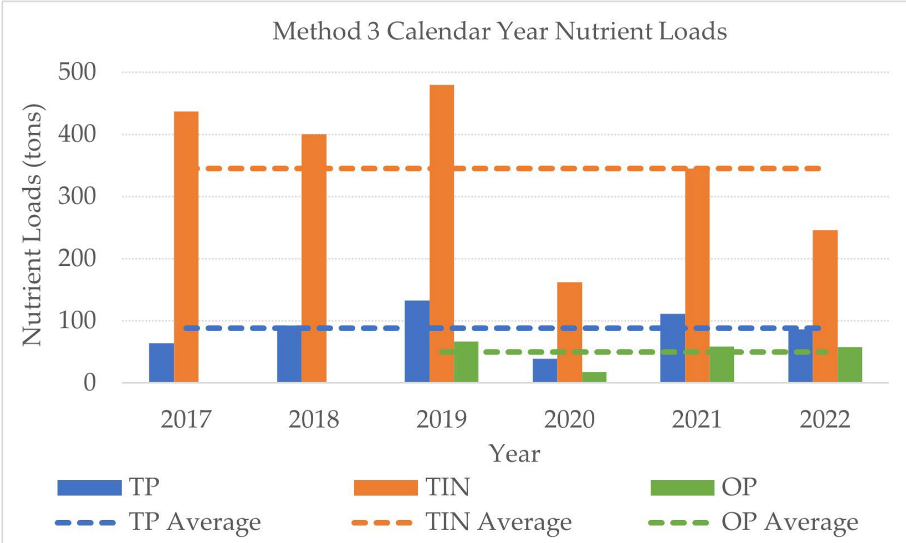


Figure 3.6 Method 3 calendar year loads and average loading rates results

3.3. Winter Month Nutrient Loads

Table 3.3 summarizes total winter month nutrient loads, in tons, and average winter month loading rates, in tons/month, for each of the three analysis methods. The total winter month loads for TP and TIN represent the total mass deposited to the surface of the lake during the respective month over the six-year study period. Similarly, the loads for OP represents the total mass deposited to the surface of the lake during the respective month over the four-year study period. The average winter month loading rate is the six-year, six-month average of TP/TIN, and four-year, six-month average of OP mass deposited throughout the winter months during the study period.

Table 3.3 Summary of winter month nutrient loads and average loading rates

Nutrient	Method	Winter Months						
		Oct[1]	Nov[1]	Dec[1]	Jan[1]	Feb[1]	Mar[1]	Average[2]
TP	M1	24.2	14.2	3.8	17.7	11.1	19.0	15.0
	M2	47.1	13.5	3.6	11.6	21.2	28.5	20.9
	M3	38.5	26.7	6.6	24.0	20.1	34.5	25.1
TIN	M1	91.8	71.1	20.1	119.1	82.8	125.2	85.0
	M2	115.6	57.0	16.5	63.3	50.9	144.7	74.7
	M3	163.4	135.0	37.9	198.7	141.6	212.6	148.2
OP	M1	3.4	1.9	1.1	2.5	1.6	6.0	2.7
	M2	5.9	3.4	1.1	2.6	3.6	6.7	3.9
	M3	7.2	3.9	1.9	2.9	3.2	11.8	5.1

[1] tons; [2] tons/month

Figures 3.7, 3.8 and 3.9 show the winter month nutrient loads and average winter month loading rates for analysis methods 1, 2 and 3, respectively.

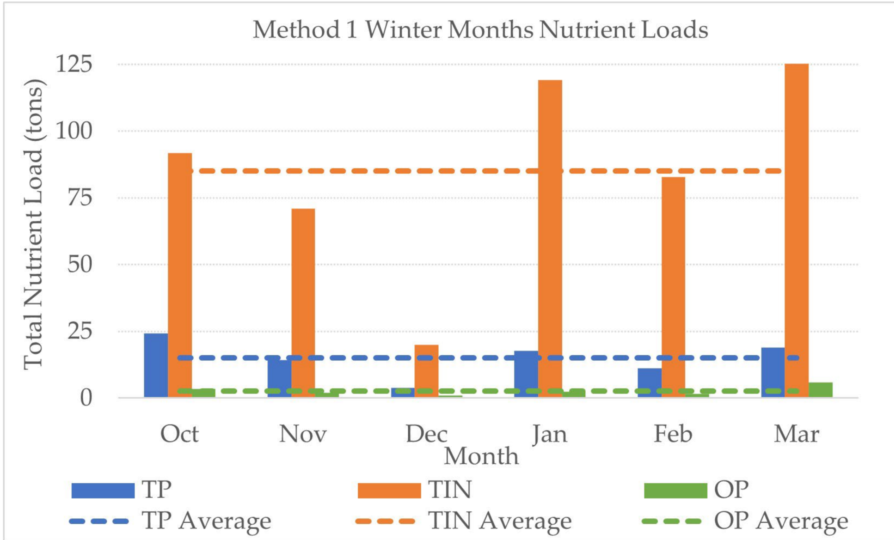


Figure 3.7 Method 1 winter month nutrient loads and average loading rates results

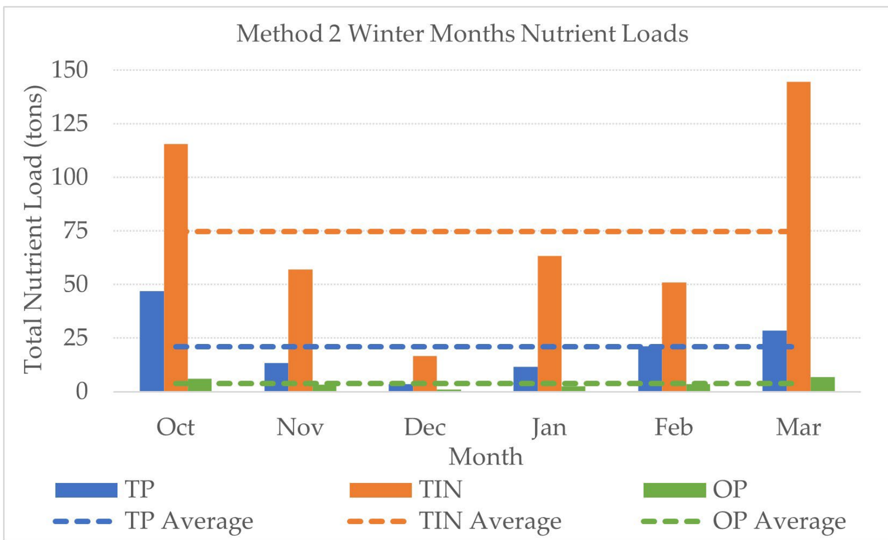


Figure 3.8 Method 2 winter month nutrient loads and average loading rates results

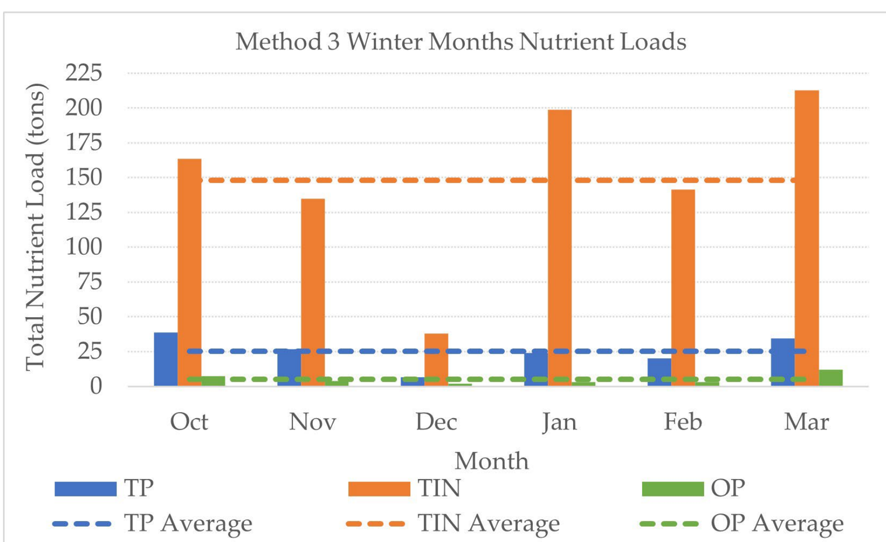


Figure 3.9 Method 3 winter month nutrient loads and average loading rates results

Table 3.4 summarizes the monthly average loading rate, in tons/month, for each winter month. The monthly averages for TP and TIN represent the average mass deposited to the surface of the lake during the respective month over the six-year study period. Similarly, the monthly averages for OP represents the average mass deposited to the surface of the lake during the respective month over the four-year study period.

Table 3.4 Summary of winter month average loading rates

Nutrient	Method	Winter Months					
		Oct[1]	Nov[1]	Dec[1]	Jan[1]	Feb[1]	Mar[1]
TP	M1	4.0	2.4	0.6	3.0	1.9	3.2
	M2	7.8	2.2	0.6	1.9	3.5	4.7
	M3	6.4	4.5	1.1	4.0	3.4	5.7
TIN	M1	15.3	11.9	3.3	19.9	13.8	20.9
	M2	19.3	9.5	2.8	10.6	8.5	24.1
	M3	27.2	22.5	6.3	33.1	23.6	35.4
OP	M1	0.8	0.5	0.3	0.6	0.4	1.5
	M2	1.5	0.8	0.3	0.6	0.9	1.7
	M3	1.8	1.0	0.5	0.7	0.8	2.9

[1] tons/month

3.4. Summer Month Nutrient Loads

Table 3.5 summarizes the total summer month nutrient loads, in tons, and average summer month loading rates, in tons/month, for each of the three analysis methods. The total summer month loads for TP and TIN represent the total mass deposited to the surface of the lake during the respective month over the six-year study period. Similarly, the loads for OP represents the total mass deposited to the surface of the lake during the respective month over the four-year study period. The average summer month loading rate is the six-year, six-month average of TP/TIN, and four-year, six-month average of OP mass deposited throughout the summer months during the study period.

Table 3.5 Summary of summer month nutrient loads and average loading rates

Nutrient	Method	Summer Months						
		Apr[1]	May[1]	Jun[1]	Jul[1]	Aug[1]	Sep[1]	Average[2]
TP	M1	22.4	34.3	47.6	12.8	55.2	41.6	35.6
	M2	24.1	26.5	56.6	27.4	133.4	82.7	58.4
	M3	37.1	57.5	106.7	21.2	81.6	64.6	61.5
TIN	M1	92.0	87.6	129.3	31.9	186.9	92.2	103.3
	M2	94.6	93.9	150.0	62.0	203.6	130.8	122.5
	M3	154.5	155.3	307.0	48.6	303.1	166.2	189.1
OP	M1	4.0	10.0	21.4	6.4	28.7	17.1	14.6
	M2	4.6	7.4	27.1	9.5	55.2	29.8	22.3
	M3	6.9	18.1	56.8	9.7	45.5	29.7	27.8

[1] tons; [2] tons/month

Figures 3.10, 3.11 and 3.12 show the summer month nutrient loads and average loading rates for analysis methods 1, 2 and 3, respectively.

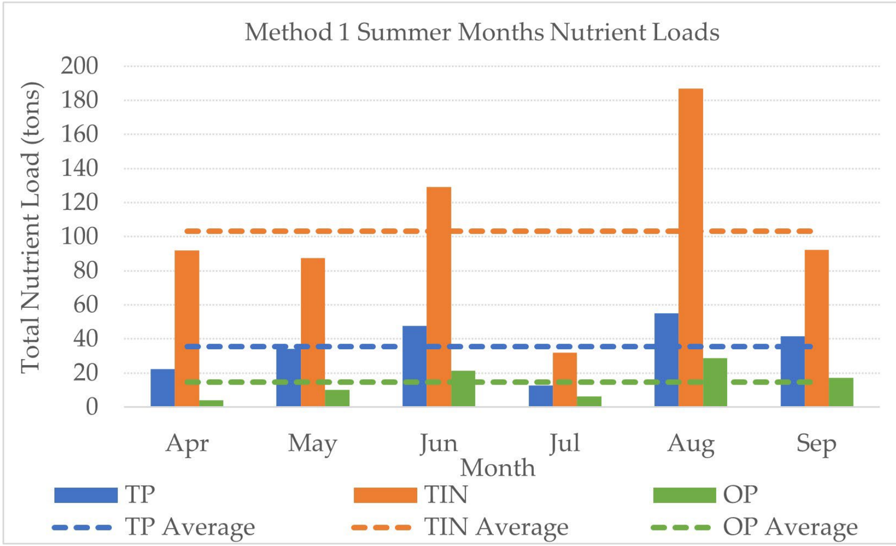


Figure 3.10 Method 1 summer month nutrient loads and average loading rates results

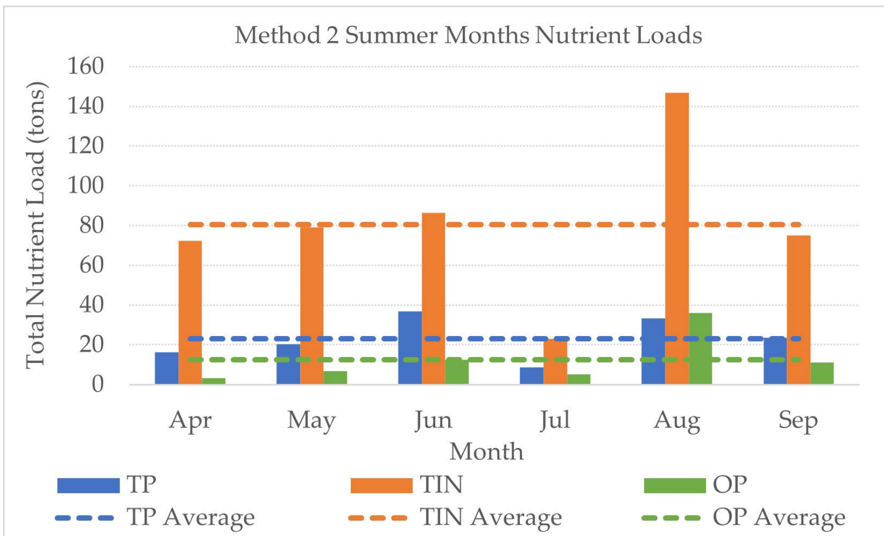


Figure 3.11 Method 2 summer month nutrient loads and average loading rates results

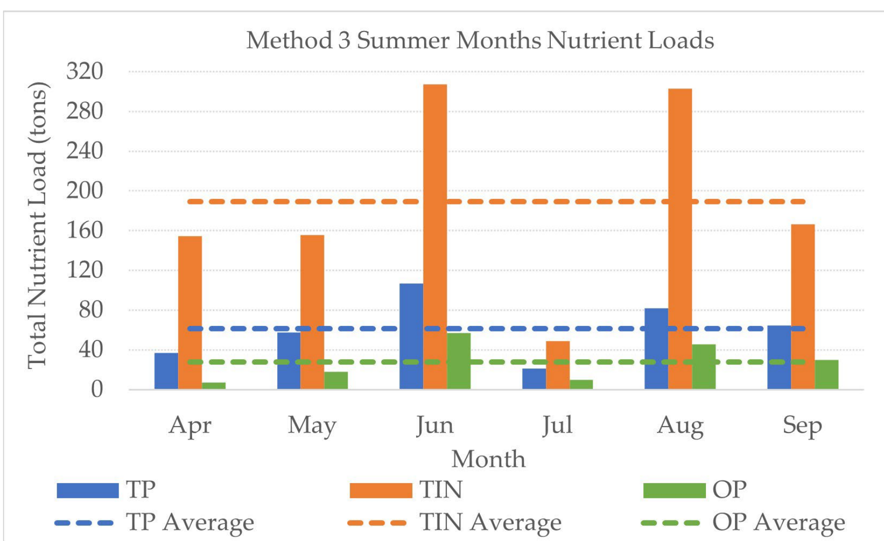


Figure 3.12 Method 3 summer month nutrient loads and average loading rates results

Table 3.6 summarizes the monthly average loading rate, in tons/month, for each summer month. The monthly averages for TP and TIN represent the average mass deposited to the surface of the lake during the respective month over the six-year study period. Similarly, the monthly averages for OP represents the average mass deposited to the surface of the lake during the respective month over the four-year study period.

Table 3.6 Summary of summer month average loading rates

Nutrient	Method	Summer Months					
		Apr[1]	May[1]	Jun[1]	Jul[1]	Aug[1]	Sep[1]
TP	M1	3.7	5.7	7.9	2.1	9.2	6.9
	M2	4.0	4.4	9.4	4.6	22.2	13.8
	M3	6.2	9.6	17.8	3.5	13.6	10.8
TIN	M1	15.3	14.6	21.5	5.3	31.2	15.4
	M2	15.8	15.7	25.0	10.3	33.9	21.8
	M3	25.7	25.9	51.2	8.1	50.5	27.7
OP	M1	1.0	2.5	5.3	1.6	7.2	4.3
	M2	1.2	1.9	6.8	2.4	13.8	7.5
	M3	1.7	4.5	14.2	2.4	11.4	7.4

[1] tons/month

3.5. Comparison

The results for total load, calendar year load, and average seasonal (winter/summer month) nutrient loading rates from each of the three methods were statistically compared to each other to discern the variation in the calculated loads. The mean of the three analysis methods is presented. The percent difference (% Diff), calculated as the difference between method 3 and the other methods, divided by method 3, is also presented.

Method 3 predominantly predicted the largest loads for each nutrient and period (i.e., total, calendar year, winter/summer months). On the other hand, method 1 predominantly predicted the smallest loads for each nutrient and period. Method 2 rarely resulted in a smaller or larger loads than the other two methods.

3.5.1. Total Nutrient Load Comparison

Table 3.7 compares the total nutrient load, in tons, for each of the three analysis methods. As seen in the table, method 3 consistently predicted larger total loads than the two other methods.

Table 3.7 Summary of total nutrient load comparison

Total Nutrient Loads Comparison						
Nutrient	M1[1]	M2[1]	M3[1]	Mean[1]	% Diff (M3-M1)	% Diff (M3-M2)
TP	309	484	529	441	41%	9%
TIN	1166	1236	2078	1494	44%	41%
OP	106	160	201	156	47%	21%

[1] tons

3.5.2. Calendar Year Nutrient Load Comparison

Table 3.8 compares the results for the calendar year nutrient loads, in tons, and average loading rates, in tons/year. The results for 2018 and 2022 TP are the only periods in which method 2 predicted a larger load than method 3.

Table 3.8 Summary of calendar year nutrient load comparison

Calendar Year Nutrient Loads Comparison							
Year	**Nutrient**	**M1**	**M2**	**M3**	**Mean**	**% Diff (M3-M1)**	**% Diff (M3-M2)**
2017[1]	**TP**	36.6	54.0	64.3	51.6	43%	16%
	TIN	252.0	217.3	436.8	302.0	42%	50%
	OP	N/A	N/A	N/A	N/A	N/A	N/A
2018[1]	**TP**	60.9	101.9	92.7	85.2	34%	-10%
	TIN	240.9	212.3	400.6	284.6	40%	47%
	OP	N/A	N/A	N/A	N/A	N/A	N/A
2019[1]	**TP**	67.5	89.1	133.1	96.6	49%	33%
	TIN	227.9	260.7	479.7	322.8	52%	46%
	OP	26.8	41.4	67.0	45.1	60%	38%
2020[1]	**TP**	23.9	36.9	39.5	33.4	40%	7%
	TIN	93.9	105.3	162.2	120.5	42%	35%
	OP	9.0	12.4	18.2	13.2	50%	32%
2021[1]	**TP**	65.1	106.3	111.2	94.2	41%	4%
	TIN	189.7	240.5	345.0	258.4	45%	30%
	OP	33.2	49.8	58.4	47.1	43%	15%
2022[1]	**TP**	54.6	95.5	86.5	78.9	37%	-10%
	TIN	157.1	199.7	246.2	201.0	36%	19%
	OP	37.1	56.3	57.7	50.4	36%	2%
Average[2]	**TP**	51.4	80.6	87.9	73.3	41%	8%
	TIN	193.6	206.0	345.1	248.2	44%	40%
	OP	26.5	40.0	50.3	38.9	47%	21%

[1] tons; [2] tons/year

3.5.3. Seasonal Nutrient Load Comparison

Table 3.9 compares the results for the average seasonal (winter/summer month) loading rates, in tons/month. Like the total nutrient load comparison, method 3 consistently predicted larger loading rates than the two other methods.

Table 3.9 Summary of seasonal average nutrient load comparison

Seasonal Average Nutrient Loads Comparison							
Season	**Nutrient**	**M1[1]**	**M2[1]**	**M3[1]**	**Mean[1]**	**% Diff (M3-M1)**	**% Diff (M3-M2)**
Winter	**TP**	15.0	20.9	25.1	20.3	40%	17%
	TIN	85.0	74.7	148.2	102.6	43%	50%
	OP	2.7	3.9	5.1	3.9	47%	25%
Summer	**TP**	35.6	58.4	61.5	51.8	42%	5%
	TIN	103.3	122.5	189.1	138.3	45%	35%
	OP	14.6	22.3	27.8	21.6	47%	20%

[1] tons/month

4. Discussion

This research shows strong evidence that bulk atmospheric deposition is a significant pathway in which nutrients are transported to Utah Lake. The nutrient concentrations detected in more than 850 samples over the six-year study period were analyzed using three numerical/spatial methods. The analysis methods predict total nutrients loads to the surface of Utah Lake of 309 to 529 tons of TP, 1,166 to 2,078 tons of TIN, and 106 to 201 tons of OP. These total loads were extracted to average calendar year loading rates of 51.4 to 87.9 tons/year of TP, 193.6 to 345.1 tons/year of TIN, and 26.5 to 50.3 tons/year of OP. Furthermore, average winter month loading rates were determined to be between 15.0 to 25.1 tons/month of TP, 85.0 to 148.2 tons/month of TIN, and 2.7 to 5.1 tons/month of OP. Likewise, average summer month loading rates were determined to be between 35.6 to 61.5 tons/month of TP, 103.3 to 189.1 tons/month TIN, and 14.6 to 27.8 tons/month of OP.

Table 3.10 contains general yearly and winter/summer month nutrient loading rates, in tons/month, for each analysis method. The yearly loading rates are 72-month averages for TP/TIN, and 48-month averages for OP. Similarly, the winter/summer month loading rates are 36-month averages for TP/TIN, and 24-month averages for OP.

Table 3.10 Summary of general nutrient loading rates

Nutrient	Tons / Month	Method		
		M1	M2	M3
TP	Yearly	4.3	6.7	7.3
	Winter	2.5	3.5	4.2
	Summer	5.9	9.7	10.2
TIN	Yearly	16.1	17.2	28.8
	Winter	14.2	12.4	24.7
	Summer	17.2	20.4	31.5
OP	Yearly	2.2	3.3	4.2
	Winter	0.7	1.0	1.3
	Summer	3.6	5.6	6.9

The nutrient loading rates vary throughout the year, with the summer months being larger than the winter months. This research indicates that bulk atmospheric deposition contributes significantly to the overall nutrient budget of Utah Lake.

Funding: The field work was funded by the Wasatch Front Water Quality Council. The sample analysis was donated by Chemtech-Ford Laboratories.

Acknowledgments: We would like to acknowledge Brigham Young University, Wasatch Front Water Quality Council, Chemtech-Ford Laboratories and Dr. Theron G. Miller for supporting this work.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Merritt, L.B. and A.W. Miller, *Interim Report on Nutrient Loadings to Utah Lake*. 2016.
2. Olsen, J.M., et al., *Measuring and Calculating Current Atmospheric Phosphorous and Nitrogen Loadings to Utah Lake Using Field Samples and Geostatistical Analysis.* Hydrology, 2018. **5**(3): p. 45.
3. Randall, M.C., et al., *Sediment potentially controls in-lake phosphorus cycling and harmful cyanobacteria in shallow, eutrophic Utah Lake.* PLoS One, 2019. **14**(2).
4. PSOMAS and SWCA, *Utah Lake TMDL: Pollutant Loading Assessment & Designated Beneficial Use Impairment Assessment*, S.o.U.D.o.W. Quality, Editor. 2007. p. 1-88.
5. Abu-Hmeidan, H.Y., G.P. Williams, and A.W. Miller, *Characterizing Total Phosphorus in Current and Geologic Utah Lake Sediments: Implications for Water Quality Management Issues.* Hydrology, 2018. **5**(1): p. 8.
6. Zheng, T., et al., *Characteristics of Atmospheric Deposition during the Period of Algal Bloom Formation in Urban Water Bodies.* Sustainability, 2019. **11**(6).
7. Anderson, K.A. and J.A. Downing, *Dry and Wet Atmospheric Deposition of Nitrogen, Phosphorus and Silicon in an Agricultural Region.* Water, Air, and Soil Pollution, 2006. **176**(1): p. 351-374.
8. Barrus, S.M., et al., *Nutrient Atmospheric Deposition on Utah Lake: A Comparison of Sampling and Analytical Methods.* Hydrology, 2021. **8**(3): p. 123.
9. Reidhead, J.G., *Significance of the Rates of Atmospheric Deposition Around Utah Lake and Phosphorus-Fractionation of Local Soils*. 2019: Brigham Young University.
10. Barrus, S.M., *Improvements of Atmospheric Deposition Sampling Procedures and Further Analysis of its Impact on Utah Lake*. 2021, Brigham Young University.
11. Kuprov, R., et al., *Composition and secondary formation of fine particulate matter in the Salt Lake Valley: Winter 2009.* Journal of the Air & Waste Management Association, 2014. **64**(8): p. 957-969.
12. Hinds, W.C. and Y. Zhu, *Aerosol technology: properties, behavior, and measurement of airborne particles*. 2022: John Wiley & Sons.
13. Utah Climate Center. Available from: https://climate.usu.edu/mchd/index.php.
14. Central Utah Water Conservancy District. *Utah Lake Data*. Available from: https://api2.cuwcd.com/Internal/Historical/ReportDataSets/ulweather.
15. Utah Geospatial Resource Center. *Water Data Services Overview*. Available from: https://gis.utah.gov/data/water/.

Appendix A

Table A.1 Raw Total Phosphorus concentration data

Date	MS-8[1]	MS-9[1]	MS-7[1]	MS-6[1]	MS-5[1]	MS-4[1]	MS-3[1]	MS-2[1]	MS-1[1]
31-Oct-16	0.03								
21-Nov-16	0.04								
29-Nov-16	0.02								
1-Dec-16	0.21								
10-Dec-16	0.15								
12-Dec-16	0.06								
16-Dec-16	0.13								
24-Dec-16									
2-Jan-17									
3-Jan-17	BDL								
8-Jan-17	0.28								
19-Jan-17	0.21								
21-Jan-17	BDL							0.02	
7-Feb-17	0.07								
10-Feb-17	0.01		0.08		0.09	0.1	0.09	0.07	
11-Feb-17		0.01						0.02	
17-Feb-17		BDL							
18-Feb-17	0.09								
19-Feb-17	0.05								
21-Feb-17								0.05	
22-Feb-17	0.01	BDL	1.96		0.12	0.07	0.18		
23-Feb-17	0.01	BDL						0.02	
24-Feb-17		0.01							
27-Feb-17	0.02	0.01	0.17		0.15	0.09	0.05		
5-Mar-17	0.14	0.08	0.2	BDL		0.13	0.21		
23-Mar-17	0.06	0.34	0.37	0.28	0.48	0.21	0.11	0.05	0.07
27-Mar-17	BDL	0.01	0.08	0.02	0.06	0.15	0.16	0.01	0.02
30-Mar-17	0.04	0.08	0.06	0.04	0.26	0.16	0.06	0.01	0.16
8-Apr-17	0.14	0.02	0.07	0.28		1.66	0.14	0.18	0.24
19-Apr-17	0.23	0.09	0.07	0.09	0.32	0.2	0.06	0.46	0.14
21-Apr-17			0.06	0.03	0.07	0.1	0.14	0.06	0.18

25-Apr-17	0.01	0.07	0.06	10		0.9	0.05	0.1	0.15
6-May-17			0.37	2.1	0.64	4	0.1		0.37
17-May-17		0.08	8.9	2.6	0.52	0.42	0.04	0.06	0.5
21-May-17		BDL	1.4	9.8	0.18	2.6	0.21	0.76	0.46
13-Jun-17	0.34	2.7			1.2				
20-Jun-17							1	11	1.1
17-Jul-17				7.8	0.79				
20-Jul-17		0.22							
23-Jul-17								6.7	
25-Jul-17		0.24	8.8	5.3	0.56	4.6		0.71	2
10-Aug-17	0.15	0.11		0.64	0.66			1.5	0.46
15-Sep-17	0.13	0.05	0.69	0.07	0.12	0.55	0.14	1.3	0.16
22-Sep-17								0.47	
24-Sep-17			0.18	0.07	0.11	0.75	0.06	0.4	1.3
5-Nov-17	0.29		1.1	0.62	0.99		0.82		1.1
17-Nov-17	0.1	0.02	0.18	0.34	1.8	0.86	0.12	2.3	0.29
9-Jan-18	0.11	0.24	0.1	0.06	0.14	1.5	0.03	0.43	0.16
15-Feb-18	0.14	0.06	0.03	0.16	0.27		6.7	0.14	0.01
16-Mar-18	0.01	0.02	0.01	0.04	1.3	0.16	0.67	0.07	BDL
20-Mar-18								0.34	
23-Mar-18		BDL	0.03	0.02	0.05		2.5	1.6	
7-Apr-18	0.18	0.02	1.6	0.09	0.14	0.21	0.55	0.1	0.3
20-Apr-18		0.53	0.55	0.55			1.8	0.14	0.23
30-Apr-18	0.03	0.05	0.49	0.91		0.45	0.3	1.3	0.12
3-May-18		0.31	0.23	2.7	0.8	0.1	0.02	0.07	0.04
11-May-18	0.05		0.18	1.8	0.38	0.04	1.4	0.16	0.07
21-Aug-18		0.13						2.1	
22-Aug-18	0.21	0.69	6.3	6	0.08	4.9	1.3	0.42	0.18
3-Oct-18	0.11	0.4	5.3	0.73	0.95			1.1	0.52
10-Oct-18	0.02	0.06	0.09	0.07	0.06	0.58	0.04	0.04	0.06
24-Nov-18		0.23							
30-Nov-18	0.01		0.4	0.1	0.17		0.19	0.02	0.16
18-Jan-19	0.02	0.02	0.04	0.46	0.66		0.01	0.03	0.44
6-Mar-19	0.02	0.01	0.11	0.24	0.13	0.38			0.15
8-Mar-19								0.29	
13-Mar-19								0.13	
29-Mar-19	BDL	0.07	0.04	0.05	0.23	0.04	0.4	BDL	1.2
10-Apr-19		0.01	0.57	0.26	0.3	1.8	0.19	0.03	
21-Apr-19	0.01	BDL	0.6	0.06	0.09			0.03	0.18
7-May-19		0.46	0.23	0.05	0.26	0.77	0.53	0.09	0.06
21-May-19	0.05	0.01	0.39	0.1	0.58	0.05	0.08	0.24	0.08
21-Jun-19			2.2	0.39	0.63	3.1			0.61
1-Aug-19		0.08	3.7	0.44	0.26	2			1.8

9-Aug-19	0.1	0.22	1.4	1.4	0.12	2.5		0.1	8.9
28-Aug-19		2.3							
11-Sep-19	0.05		1.7	0.02	0.14	1.3	7.8	0.76	0.27
20-Nov-19	0.04	0.06	0.12	0.1	0.25		0.62	0.9	0.18
16-Jan-20		0.02	0.42						0.05
23-Jan-20	0.01	0.01	0.04	0.47		0.13	0.43	0.11	0.05
8-Feb-20			0.04	0.04		0.05		0.08	
13-Mar-20	0.01	BDL	0.11	0.1	0.15		2.1	0.7	0.12
25-Mar-20	0.02	0.04	0.06	0.06	0.84	0.4	0.1	0.06	0.04
23-May-20		0.06	0.94	0.28	1.2		0.25	0.62	0.58
8-Jun-20	0.13	0.17	0.35	0.08	0.36	0.52	0.27	2.8	0.26
8-Sep-20	0.51	0.18							
11-Oct-20	1.2	1.1		4		5.2	3.9	4.5	2.5
13-Oct-20			2.3	0.23	0.76	2.1	0.24	0.36	BDL
25-Oct-20		0.16	4.9	0.3	3			4.1	1.2
8-Nov-20		0.26				1.6	0.37	1.3	
13-Nov-20	0.08								
17-Dec-20	0.17	0.38	1.5	0.07	0.97	1.9	0.41		0.1
4-Jan-21		0.07	1.7	0.92	0.63				0.71
23-Jan-21	0.47		0.68	0.08		1.1	0.25	0.41	0.14
12-Feb-21		0.09	0.68	0.17	0.45	0.43	BDL	0.2	0.08
18-Feb-21	BDL	BDL	0.15	0.13	0.08	0.08	BDL	0.13	
13-Mar-21	0.08	0.03	0.25	0.18	0.45	0.33	0.09	0.39	0.22
20-Mar-21	0.06	0.06	0.1	0.03	0.25	0.1	0.04	0.36	0.13
26-Mar-21	0.14	0.03	0.16	0.18	0.26	0.14	0.08	0.19	0.17
6-Apr-21							1.7	0.07	
15-Apr-21			0.66	0.32	0.53	0.22	0.16	2.5	0.32
26-Apr-21		0.06	0.46	0.19	1.3	0.13	1.1	1.3	0.22
10-May-21				2.2	4.9			2.1	
23-May-21	0.1	0.07	1.3	1	1.5	1.7	0.43	0.16	0.46
24-Jun-21			3.7	0.8		0.48	0.82	9.2	1
18-Jul-21		0.4		1.5	1.8				2.9
22-Jul-21	0.4	0.7	2.7	0.5	0.7	1.8		7.4	0.2
30-Jul-21		0.05	7.9	1.1	0.1	4		0.5	2.5
1-Aug-21		0.05	0.9	0.1	0.1	2.8	6.3	0.3	0.4
17-Aug-21	0.06	0.04	1.1	0.09	0.07	0.7	3.9	0.02	0.09
11-Sep-21	0.03	0.1		3.2	0.7			1.8	0.8
28-Sep-21	0.06	0.1	3.2	0.5	0.3	2.2	3.2	2.1	0.9
8-Oct-21		0.3	0.7	0.2	0.2	0.6	0.3	0.6	0.3
19-Oct-21	BDL	0.05	0.09	0.08	0.2	0.5	0.3	0.04	0.1
26-Oct-21	0.02	0.6	0.05	0.05	0.08	0.1	0.04	0.04	0.04
2-Nov-21	0.2		0.2	0.1	1.2	0.7	0.2	0.3	0.1
9-Nov-21	BDL	0.1	0.08	0.09	0.1	0.5	0.07	0.02	0.04

10-Dec-21	0.02	0.02	0.6	0.6	0.2	0.2	0.07	0.07	0.07
15-Dec-21	0.4	0.2	0.1	0.06	0.2	0.8	0.1	0.1	0.1
30-Dec-21	0.03	0.09	0.05	0.02	0.04	0.3	0.1	0.7	0.08
5-Jan-22	0.1	BDL	0.5	0.4	0.4	0.3	0.04	0.04	
21-Feb-22	0.6	0.02	0.4	0.3	1	3.6	1.4	0.02	0.9
5-Mar-22	BDL	0.04	BDL	0.7	1.1	2.6	0.2	0.1	0.2
15-Mar-22	0.04	0.06	0.05	0.6	0.6	0.9	0.2	0.2	0.2
29-Mar-22	1	0.3	0.5	0.5	0.2	0.4	0.4	0.4	0.4
15-Apr-22	0.4	0.06	3.4	4.4	0.3	0.6	0.5	2.3	2.4
22-Apr-22	0.4	0.2	1.3	0.6	4.8	0.8	0.9	1.8	1.5
3-May-22	0.1	0.1	0.4	1.3	0.5	2.2	2	0.6	0.5
10-May-22	0.04	0.1	0.2	0.6	0.9	1.2	0.8	0.8	0.6
29-May-22	0.09	0.06	0.6	0.2	1.2	1	0.6	3.8	0.2
5-Jun-22	0.05								2.4
13-Jun-22			2.7	0.3	0.7	0.7	0.7	0.7	0.7
29-Jun-22			2.5	2.3	1.8	1.8	1.8	2.5	2.5
15-Jul-22		0.2	0.8	1	1	3.9	5.4	0.6	
1-Aug-22	0.04	0.08		1	2.8			1.3	3
13-Aug-22		0.05		0.6	0.1	0.6	2.8	0.3	1.4
20-Aug-22	0.1	BDL	3.9	0.1	0.2	2.1	3.8	0.8	0.6
25-Aug-22	BDL	0.05		0.3	0.2		0.2	1.2	0.9
15-Sep-22	0.01			0.8	0.2	2.2	3.5	4.1	1.4
17-Sep-22	BDL	0.2	2.4	0.09	0.3	2.6	2.1	0.3	0.7
23-Sep-22	BDL	0.06	4	0.3	1.3	0.8	2.1	0.3	
22-Oct-22	0.04	0.2	1	0.4	0.4	0.6	0.2	1.3	0.3
31-Oct-22	0.2	0.1	0.8	0.1	0.1	0.4	0.09	0.08	0.2
7-Nov-22	0.1		0.4	0.05	0.3	0.6	0.1	0.08	0.4
7-Dec-22	0.1	0.09	0.4	0.2	0.4	0.2	0.4	0.4	0.6

[1] mg/L

Table A.2 Raw Total Inorganic Nitrogen concentration data

Date	MS-8[1]	MS-9[1]	MS-7[1]	MS-6[1]	MS-5[1]	MS-4[1]	MS-3[1]	MS-2[1]	MS-1[1]
31-Oct-16									
21-Nov-16									
29-Nov-16									
1-Dec-16									
10-Dec-16									
12-Dec-16	0.82								
16-Dec-16	0.43								
24-Dec-16	0.34								
2-Jan-17	0.82								
3-Jan-17	0.72								
8-Jan-17	9.59								

19-Jan-17	1.51								
21-Jan-17	1.24							0.33	
7-Feb-17	1.91								
10-Feb-17	BDL		1.42		0.5	1.38	BDL	2.94	
11-Feb-17		2.04						1.07	
17-Feb-17		1.8							
18-Feb-17	BDL								
19-Feb-17	1.65								
21-Feb-17								2.94	
22-Feb-17	1.02	1.23	24.4		0.95	1.24	1.04		
23-Feb-17	1.04	1.17						2.33	
24-Feb-17		1.36							
27-Feb-17	0.88	0.7	5.31		6.26	2.28	3.33		
5-Mar-17	1.87	1.18	4.83	2.19		2.63	3.33		
23-Mar-17	3.06	1.36	3.06	1.89	3.33	1.61	1.36	2.31	1.38
27-Mar-17	1.25	1.3	1.35	1.19	1.12	2.23	2.04	1.4	1.13
30-Mar-17	2.27	2.28	2.46	1.43	1.79	2.14	2.2	5.33	3.1
8-Apr-17	2.81	1.35	2.11	2.37		7.24	4.07	8.05	2.9
19-Apr-17	3.22	1.14	0.95	1.24	1.21	1.75	0.84	3.91	1.91
21-Apr-17			5.03	1.31	1.3	1.81	2.76	2.13	2.67
25-Apr-17	0.8	0.7	1	1.6		1.5	1.3	4.3	4.4
6-May-17			1.5	2.3	2.1	4.8	1.1		3.3
17-May-17		2.7	6.9	7.3	1.7	1.9	1.1	3.2	1.6
21-May-17		0.7	1.7	0.9	1.8	2.7	0.7	2.1	1.4
13-Jun-17	2.03	3.34	14		BDL		BDL		
20-Jun-17							9.91	BDL	4.25
17-Jul-17				11.8	BDL				
20-Jul-17		0.78							1.53
23-Jul-17								BDL	
25-Jul-17		3.31	23.6	3.55	2.81	BDL		3.47	11.4
10-Aug-17	2.88	1.41	21.4	BDL	BDL			7.11	BDL
15-Sep-17	0.91	0.9	1	0.51	0.94	1.2	0.7	2.33	1.16
22-Sep-17								1.21	
24-Sep-17			1.05	1.1	1.25	2.6	0.66	2.7	4.7
5-Nov-17	6.3		BDL	1.8	4.3		3.6		4.4
17-Nov-17	1.8	0.6	0.9	1.5	6.9	3.8	1.7	1.5	2.4
9-Jan-18	5.6	2	1.2	1	1.8	7.2	0.8	2	2.5
15-Feb-18	3.1	1.7	2.4	2.2	2		1.6	3	0.6
16-Mar-18	1.3	0.5	0.5	0.4	8.5	1.7	3.6	1.2	1
20-Mar-18								1	
23-Mar-18		0.5	0.5	0.4	1.2		6.3	0.6	
7-Apr-18	2.7	0.7	1.2	0.8	1.2	1	0.7	3	2.5
20-Apr-18		1.7	0.4	1.6			7.8	0.9	2.4

30-Apr-18	0.6	0.7	1.3	1.1		1.4	0.7	5	0.8
3-May-18		1.8	1.7	8.9	2.7	1.9	0.9	2.5	1.4
11-May-18	2.1		2.7	1	1.4	0.9	2.4	3.7	1.6
21-Aug-18		3.5						5.7	
22-Aug-18	5.8	5.2		4.4	1.3		5.7	2.4	2.5
3-Oct-18	1.8	1.1	12.4	1.3	2.2		10.2	0.4	2.1
10-Oct-18	0.6	0.6	0.7	0.5	0.7	5	0.4	1.2	0.7
24-Nov-18		0.8							
30-Nov-18	0.5		0.3	BDL	0.6		0.4	1.6	0.8
18-Jan-19	BDL	0.2	BDL	BDL	BDL		0.2	0.8	BDL
6-Mar-19	0.8	0.8	BDL	1.1	1.5	BDL			0.6
8-Mar-19								1	
13-Mar-19								1.9	
29-Mar-19	1.4	0.2	BDL	1	1.1	0.8	3.1	1.8	1.5
10-Apr-19		0.8	2.6	1.5	1.7	2.8	1.8	2.5	
21-Apr-19	1.9	1.1	1.2	1.1	BDL			2.6	0.5
7-May-19		1.3	1.3	0.8	0.5	2.9	1.3	0.9	1.3
21-May-19	1.4	0.5	1	0.4	BDL	0.7	0.5	1.2	1
21-Jun-19			3.6	1	3	10.3			0.9
1-Aug-19		0.9	9.6	0.9	0.3	6.4			4.1
9-Aug-19	2	1.8	4.8	4.1	4.1	10.1		0.4	22.2
28-Aug-19		6.7							
11-Sep-19	1.6		3.7	BDL	0.3	3.7		BDL	2.1
20-Nov-19	5.1	2.3	BDL	0.6	0.9		4.1	2.7	1.6
16-Jan-20		0.7	1.8						1.1
23-Jan-20	1.2	1.1	1.2	1.1		1.3	1.1	1.7	2.7
8-Feb-20			BDL	0.9		0.8		1.4	
13-Mar-20	2.2	0.7	1.1	0.5	1.8		BDL	BDL	1.2
25-Mar-20	0.4	0.5	0.3	0.2	2	0.2	0.3	1.7	0.4
23-May-20		1.9	BDL	2.4	BDL		2.6	3.9	2.9
8-Jun-20	1.3	2	1.8	0.5	1.6	3.2	1.3	8.5	1.8
8-Sep-20									
11-Oct-20									
13-Oct-20			1.8	BDL	1.9	4.2	0.7	BDL	1.5
25-Oct-20		1.2	6.1	0.6	4.9	1.4		BDL	5.1
8-Nov-20		1.2				3.6	3.4	1.6	
13-Nov-20	1.3								
17-Dec-20	BDL	BDL	1.3	BDL	1	0.6	4.5		0.8
4-Jan-21		1.3	2.9	BDL	0.5				5
23-Jan-21	BDL		0.5	0.2		1.1	1.1	0.7	1
12-Feb-21		0.9	0.7	BDL	0.7	0.2	0.2	2.1	0.7
18-Feb-21	0.2	0.2	0.2	0.2	0.6	0.2	BDL	1.2	
13-Mar-21	1.1	1.1	1.4	0.4	3.2	1.7	0.7	2.5	2.1

20-Mar-21	0.7	0.7	BDL	BDL	0.5	BDL	0.2	BDL	1
26-Mar-21	2.2	1.1	1.1	0.9	1.6	BDL	0.8	2.3	2
6-Apr-21							BDL	1.6	
15-Apr-21			2	1.8	2.6	1.3	0.9	4.5	2.1
26-Apr-21		0.5	1.2	0.7	4.1	1	1.5	BDL	2.1
10-May-21				BDL	BDL			0.9	
23-May-21	4.1	0.7	5.1	2.6	4.5	6.4	3.5	BDL	2.6
24-Jun-21			2.3	3.4		2.7	3.7	2.5	4.3
18-Jul-21		3.8		5.5	BDL		18.5		8.2
22-Jul-21		3.6	6.5	3.1	5.2	3.8	11.7	11.7	2.3
30-Jul-21		1.3	18.9	3	1.6	5.1		1.8	2.4
1-Aug-21		1.4	4.6	0.8	1.2	4.3	17.4	2.2	2.1
17-Aug-21	2.7	1.3	3.2	1.3	1.4	2.6	4.5	1.8	1.8
11-Sep-21	4.2	1.9		4.4	1			5.4	1.1
28-Sep-21	3.7	2.3	3.6	1.3	2.2	5.3	3.3	BDL	1.1
8-Oct-21		1.3	2.2	1.2	1.9	3.5	0.9	1.4	2.2
19-Oct-21	1.5	1.4	0.2	0.8	1.7	2.1	1.6	1.5	0.6
26-Oct-21	0.9	1.3	0.2	0.5	1.1	0.2	0.7	1.2	1.2
2-Nov-21	3.5		BDL	0.4	1.6	1.1	4.5	4.3	5.2
9-Nov-21	0.8	0.8	0.2	0.6	1	2.6	0.6	2.3	0.8
10-Dec-21	0.5	0.5	0.3	0.2	1.5	1.5	2	2	1
15-Dec-21	0.9	0.7	BDL	BDL	0.4	1.8	0.3	0.7	0.5
30-Dec-21	1	1	0.3	0.8	1.3	1.6	1.4	2	2.2
5-Jan-22	2	0.6	1.9	1.7	1.5	0.9	1.5	1.2	
21-Feb-22	2.6	1.1	4	1	2.4	6.9	1.1	1.6	5.1
5-Mar-22	2.4	1	1.3	0.9	1.5	1.9	1.5	1.2	1.2
15-Mar-22	0.6	1.9	0.9	0.9	1.9	1.8	1.1	1.1	3.1
29-Mar-22	5.7	2.3	3	3.5	2.4	3.1	3.1	2.9	2.8
15-Apr-22	1.5	0.7	7.8	7.7	1.4	1.4	3.1	2.8	4.2
22-Apr-22	1.5	0.7	2.3	1.4	2.9	1.4	1.4	3.9	5.2
3-May-22	1	2.1	1	3.9	0.9	4.3	4	2.4	3
10-May-22	0.9	1	1.9	3.4	0.5	4	2.5	3.2	2.8
29-May-22	0.8	0.4	1.4	BDL	3.6	0.4	1.5	5.6	0.4
5-Jun-22	0.7								5.9
13-Jun-22			5.1	1	1.5	2	3.1	3.3	2.7
29-Jun-22			7.2	6.8	6.3	6.2	6.3	6.8	7.1
15-Jul-22		1.6	3.2	2.6	3	5.3	7.5	0.9	
1-Aug-22	0.2	0.6	2.9	BDL	4.1		9	1.4	4.6
13-Aug-22		4.2		2.3	1	2.3	10.2	2.4	4.1
20-Aug-22	3.8	0.2	2.3	1	1.1	3.7	1.9	2.9	2.3
25-Aug-22	0.6	0.9	BDL	BDL	0.4	BDL	0.5	0.3	0.2
15-Sep-22	1.3		BDL	BDL	1	5.5	0.2	BDL	6.6
17-Sep-22	1.4	0.9	6.1	0.7	1.8	10	4	1.8	2.4

23-Sep-22	0.9	1.7	8.3	0.5	4.3	1.3	6.1	0.4	
22-Oct-22	0.7	0.9	BDL	0.7	0.5	0.8	0.9	2.1	1.5
31-Oct-22	0.6	0.2	0.7	0.2	0.2	0.8	0.8	0.9	1.9
7-Nov-22	1.5		1.7	0.9	1.3	5	0.6	1	1.8
7-Dec-22	1.2	0.5	1.5	0.7	1	1.2	3.3	1.6	11

[1] mg/L

Table A.3 Raw Ortho Phosphorus concentration data

Date	MS-8	MS-9	MS-7	MS-6	MS-5	MS-4	MS-3	MS-2	MS-1
18-Jan-19	BDL	BDL	0.01	0.01	BDL		0.02	BDL	0.06
6-Mar-19	BDL	0.02	0.02	0.07	0.04	0.32			0.02
8-Mar-19								0.11	
13-Mar-19								0.01	
29-Mar-19			0.04	0.02	0.18	0.03	0.12		0.36
10-Apr-19		0.01	0.29	0.02	0.16	BDL	0.08	0.02	
21-Apr-19			0.1	0.02	0.01			0.01	0.01
7-May-19		0.34	0.08	0.02	0.13	0.52	0.23	0.02	0.05
21-May-19			0.27	0.09	BDL	0.02	0.02	0.05	0.05
21-Jun-19			0.51	0.08	0.28	1.9			0.03
1-Aug-19		0.04	2.2	0.04	BDL	1.5			1.1
9-Aug-19	0.1	0.1	1	1.1	0.03	2.2		0.04	
28-Aug-19									
11-Sep-19	BDL		1.4	BDL	0.08	1.1		0.52	0.22
20-Nov-19	BDL	0.01	BDL	0.04	0.2		0.17	0.22	0.06
16-Jan-20		BDL	0.11						0.01
23-Jan-20	BDL	BDL	0.03	0.05		0.02	0.07	0.02	0.03
8-Feb-20			BDL			BDL			
13-Mar-20	BDL	BDL	0.02	BDL	0.06		0.21	0.44	0.05
25-Mar-20	BDL	BDL	0.02	BDL	0.81	0.2	0.02	0.07	0.06
23-May-20		0.02	BDL				0.08	0.48	0.4
8-Jun-20	0.02	0.09	0.23	0.02	0.27	0.41	0.15	2.3	0.16
8-Sep-20									
11-Oct-20		0.1	0.21	0.24	1.4			2.5	
13-Oct-20			1.2	BDL	0.59	1.7	0.25	0.02	0.1
25-Oct-20		0.1	0.21	0.24	1.4			2.5	
8-Nov-20		0.15				0.53	0.18	BDL	
13-Nov-20	0.01								
17-Dec-20	0.11	0.02	0.78	0.02	0.51	0.76	0.18		0.07
4-Jan-21		BDL	0.76	0.2	BDL				0.17
23-Jan-21	BDL		0.34	BDL		0.38	0.11	0.19	0.06
12-Feb-21		0.02	0.15	0.12	0.39	0.19	0.06	0.1	0.06
18-Feb-21	0.02	0.02	0.11	0.02	0.07	0.11	0.03	0.05	
13-Mar-21	0.04	0.04	0.2	0.06	0.35	0.18	0.05	0.22	0.16

20-Mar-21	0.09	0.09	0.1	0.05	0.16	0.1	0.06	0.09	0.08
26-Mar-21	0.04	0.04	0.12	0.13	0.12	0.03	0.05	0.09	0.1
6-Apr-21							0.26	0.05	
15-Apr-21			0.24	0.16	0.28	0.07	0.05	1.3	0.08
26-Apr-21		0.02	0.25	0.12	0.28	0.1	1	0.45	0.13
10-May-21				0.69	3.2			0.36	
23-May-21	0.04	0.07	0.88	0.15	1.2	1.6	0.24	0.03	0.24
24-Jun-21			2.6	0.57		0.29	0.54	4	0.51
18-Jul-21		0.23		0.95	0.06				2
22-Jul-21	0.08	0.4	1.9	0.2	0.44	1.3		3.5	0.11
30-Jul-21		0.05	6.9	0.64	BDL	2		0.33	2.1
1-Aug-21		0.04	0.71	0.1	0.1	1.6	3.8	0.19	0.26
17-Aug-21	0.02	0.08	0.58	0.1	0.04	0.56	2.4	0.03	0.1
11-Sep-21	0.08	0.05		1.4	0.26			1.2	0.28
28-Sep-21	0.01	0.04	2.1	0.22	0.13	1.2	1.9	0.96	0.04
8-Oct-21		0.08	0.48	0.1	0.1	0.31	0.08	0.29	0.09
19-Oct-21	BDL	0.06	0.03	0.06	0.14	0.36	0.14	0.04	0.04
26-Oct-21	0.02	0.24	0.02	0.04	0.07	0.21	0.06	0.01	0.07
2-Nov-21	0.04		0.23	0.1	0.07	0.59	0.41	0.35	0.24
9-Nov-21	0.02	0.05	0.01	0.06	0.11	0.22	0.02	0.01	0.02
10-Dec-21	0.04	0.03	0.1	0.12	0.12	0.12	0.04	0.05	0.09
15-Dec-21	0.1	0.1	0.06	0.02	0.05	0.05	0.06	0.07	0.09
30-Dec-21	0.03	0.01	BDL	0.03	0.02	0.04	0.03	BDL	BDL
5-Jan-22	BDL	0.05	0.07	BDL	0.05	0.01	0.02	0.06	
21-Feb-22	0.05	BDL	0.08	0.04	0.72	2.2	0.59	0.04	0.31
5-Mar-22	BDL	0.01	0.02	0.11	0.08	0.24	BDL	0.05	0.26
15-Mar-22	0.01	BDL	BDL	0.47	0.28	0.14	BDL	BDL	0.05
29-Mar-22	0.01	0.02	0.17	0.27	0.12	0.12	0.14	0.13	0.12
15-Apr-22	0.05	0.02	1.6	1.7	0.11	0.17	0.23	0.25	0.32
22-Apr-22	0.06	BDL	0.24	0.18	0.53	0.27	0.17	0.57	0.56
3-May-22	0.02	0.07	0.13	0.7	0.17	1.3	1.3	0.31	0.31
10-May-22	0.06	0.02	0.12	0.47	0.63	0.52	0.44	0.4	0.36
29-May-22	0.02	0.03	0.01	0.02	0.66	0.05	0.19	2.6	0.03
5-Jun-22	0.04								1.2
13-Jun-22			1.4	0.17	0.31	0.5	0.42	0.42	0.33
29-Jun-22			1.4	1.3	1.2	1.2	1.2	1.3	1.3
15-Jul-22		0.13	0.41	0.38	0.38	2.3	3.8	0.16	
1-Aug-22	0.04	0.09	5.3	0.39	1.3	7.6		0.6	1.4
13-Aug-22		0.03	9.6	0.04	0.06	0.25	1.7	0.14	0.81
20-Aug-22	0.03	0.04	2.3	0.06	0.14	1.4	2.4	0.46	0.26
25-Aug-22	0.02	0.06	6.4	0.11	0.08	3.8	0.07	0.68	0.34
15-Sep-22	0.01			0.17	0.09	1.2	1.8	2.7	0.55
17-Sep-22	0.02	0.06	1.5	0.05	0.17	1.8	1.1	0.18	0.1

23-Sep-22	0.01	0.06	1.8	0.09	0.41	0.25	0.99	0.07	
22-Oct-22	0.03	0.06	0.13	0.21	0.22	0.38	0.06	0.89	0.16
31-Oct-22	0.02	0.08	0.1	0.32	0.08	0.08	0.03	BDL	0.06
7-Nov-22	0.02		0.15	0.05	0.09	0.32	0.04	0.04	0.13
7-Dec-22	0.03	0.01	0.23	0.05	0.04	0.06	0.05	0.25	0.34

[1] mg/L

Appendix B

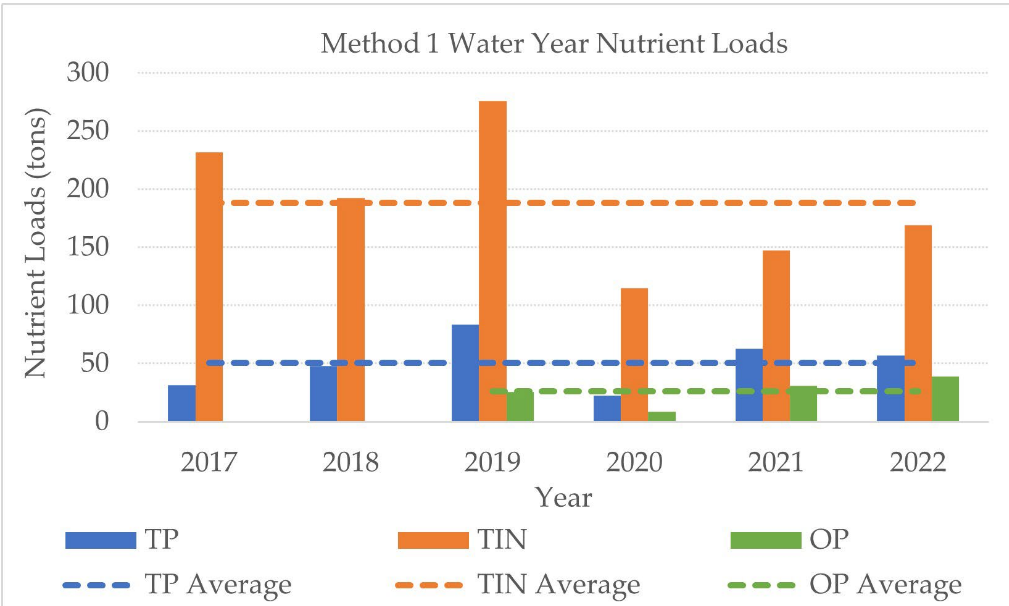


Figure B.1 Method 1 water years loads and average loading rates results

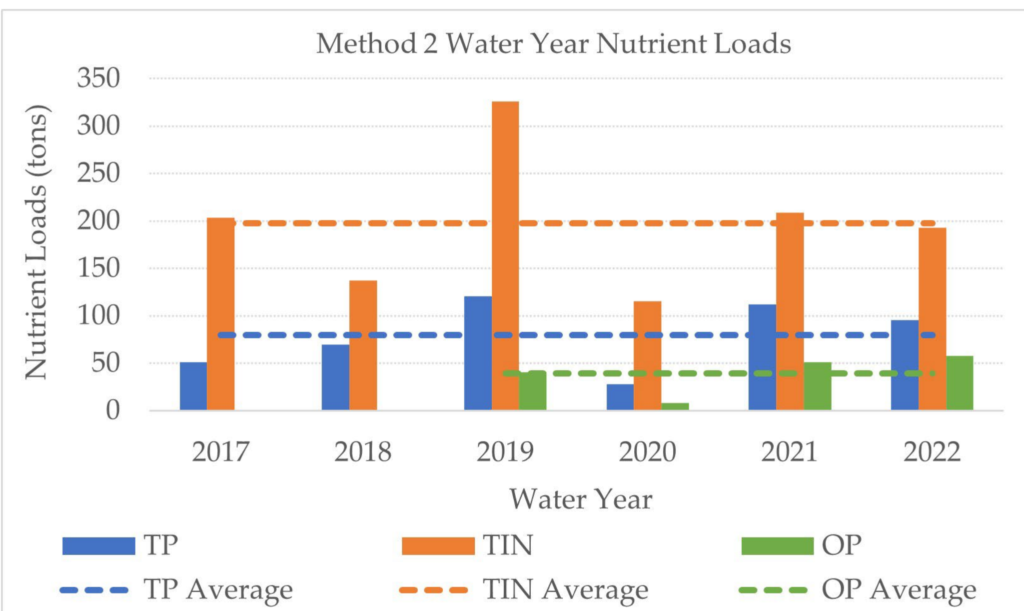


Figure B.2 Method 2 water years loads and average loading rates results

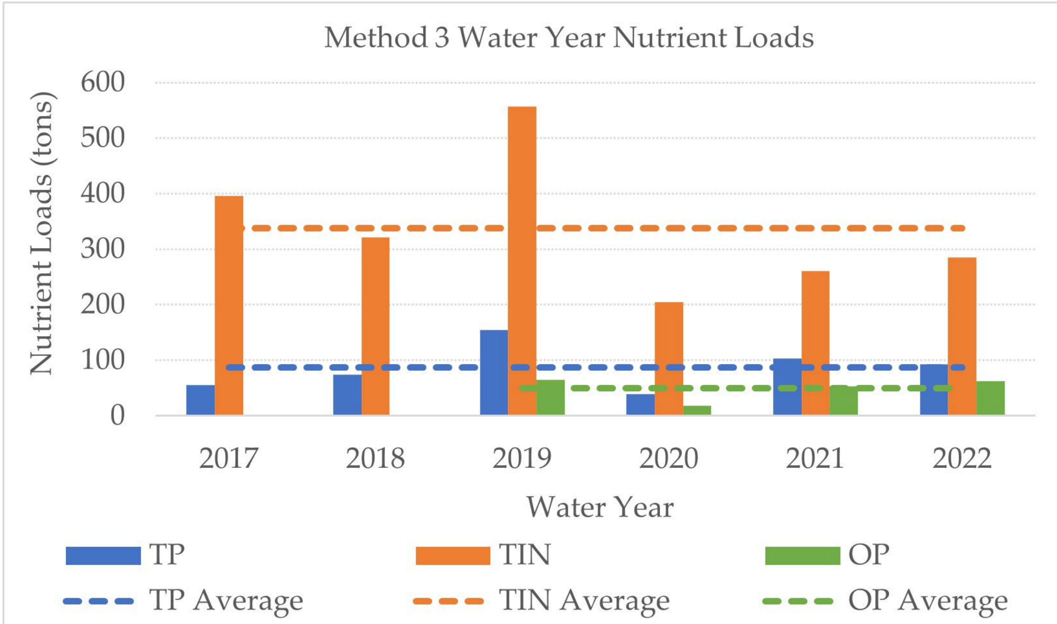


Figure B.3 Method 3 water years loads and average loading rates results