Great Salt Lake and Utah Lake Statistical Analysis: Vol II Utah Lake

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Executive Summary

This study analyzes the data available from the official Utah Department of Water Quality (DWQ) sources available for Utah Lake. It provides a description of those data sources and describes the data both qualitatively and statistically.

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Statistical Analysis of Utah Lake Data

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1. Introduction

1.1 Utah Lake Description

This study analyzes the data for Utah Lake available from the official Utah Department of Water Quality (DWQ) sources. It provides a description of those data sources and describes the data both qualitatively and statistically. In addition, this report discusses data collected by University researchers that supplement the official data. Analysis of these non-official data are not as in-depth as these data are discussed in separate reports.

Utah Lake is a major physical feature in the Utah Valley and a valuable natural resource. Utah Lake is a shallow, turbid, slightly saline, eutrophic lake in a semi-arid area. It has good pollution degradation and stabilization capacity because of its shallow, well-oxygenated, high pH waters. It supports and harbors abundant wildlife as part of a productive ecosystem. The lake provides and supports a wide range of beneficial uses: ecological habitats, water storage, and recreation (e.g., boating, sailing, fishing, and hunting). Abundant wildlife and ecological richness are some of its more significant assets [1].

Beginning some 150 years ago, local water users used much of summertime Utah Lake outflow, the Jordan River, for irrigation in southern areas of the Salt Lake Valley. However, with ongoing urbanization, particularly following World War II, irrigated acreage has been steadily declining, and is now less than about 25% of the area that was irrigated by the Jordan River 100 years ago. Compared to pre-colonization conditions, the lake size and flows have not likely changed dramatically; natural inflows and outflows have decreased due to upstream water diversions, but these reductions have been significantly offset by importing water from the Weber River Basin and Uintah Basin drainages. Utah Valley groundwater outflow is relatively small [1].

1.2 Water Quality and Nutrients

Utah Lake is rather unique in that the majority of nutrient inflows remain in the Lake; current estimates are that over 95% of nutrient inflows remain in the Lake. Total nutrient inflows to Utah Lake, including sources such as streams, overland flow, sediment sources, biological sources (i.e., carp), dust, and geochemical processes, provide nutrient loadings that are tens-of-times larger than those that would designate the Lake as eutrophic. There is a current debate over whether available nutrient concentrations in the water column are governed by nutrient inflows or are governed by in-lake processes. If the former, then controls on nutrient inflows can affect water quality, if the later, then nutrient inflow controls will have little impact on Utah Lake water quality.

This report describes and analyzes water quality data collected in Utah Lake. The remainder of Section 1 describes the data available from official State of Utah sources. It provides an overview of the data, including the different types, locations, and times of the measurements.

Table 1.1 Locations and number of samples available at each location used in this study. The locations (sites) are ordered by the number of samples available at the site. The shaded entries represent sites with over 2,500 samples. The yellow entries represent sites where duplicate sampling was performed at the same point. Even though these represent sites with duplicate samples, only a limited number of samples were duplicated.

Location	Station ID	Num. of Meas.	Location	Station ID	Num. of Meas.
Jordan R at Utah L outlet U121 Xing	4994790	11936	UL 5mi N-NW of Lincoln Beach-1 mi offshore	4917330	366
UL 1 mi W of Provo boat harbor	4917390	7312	UL 1 mi NE of pelican point #10	4917410	366
UL 3 mi W-NW of Lincoln Beach	4917500	7187	UL 1.5 mi NW of Provo boat harbor #16	4917400	366
UL 0.5 mi W of Geneva discharge #15-A	4917310	6994	UL near shore NE of Spanish Fk R inlet	4917702	255
UL 1 mi E of pelican point	4917370	6824	UL at Lindon Marina Beach NE of launch ramps	4917335	228
UL 2 mi E of Saratoga Springs #12	4917520	6229	UL @ Lindon Beach	4917333	184
UL outside entrance to Provo Bay	4917770	5771	UL at Lincoln Beach north of Lincoln Marina	4917706	184
UL 0.5 mi W of Geneva discharge #15-A Replicate of 4917310	4917320	4312	UL 300 FT offshore from Geneva Steel	4917300	167
UL 1 mi NE of Lincoln Point #03	4917710	3609	UL 0.7 mi E of pelican point	4917530	157
UL 1 mile SE of Bird Island	4917715	3510	UL at American Fork Marina near boat ramp	4917305	126
UL 2 miles W of Vineyard	4917365	3369	UL S of Lincoln Marina	4917709	96
UL at middle of Provo Bay	4917450	2716	UL at Lincoln Marina (Beach)	4917708	96
UL Goshen Bay SW end	4917600	2573	UL American Fork Beach	4917385	90
Spanish Fork River at UL inlet	4995578	880	UL Saratoga Springs Marina Picnic Area	4917418	84
UL Goshen Bay midway off main point on E shore	4917620	727	UL Saratoga Springs Marina Boat Ramp	4917414	76
UL SP @ Marina	4917433	535	UL State Park Marina, W side (outside) of marina W dike near south jetty	4917431	60
UL W of Provo boat harbor-6 mi N of Lincoln Beach #08	4917340	522	UL at mixing zone-WLA	4917470	55
UL 2.5 mi NE of Lincoln Point #02	4917700	451	UL @ Day Use Area	4917435	27
UL 0.5 mi S of American Fork boat harbor #14	4917380	401	Provo River Delta Restoration	4917343	24
UL 4 mi E of Saratoga Springs #11	4917510	374	UL south of Lindon Marina south dike	4917323	12
UL 1 mi SE of pelican point #09	4917420	374	UL 1.5 miles W of UL State Park HQ building	4917388	6

1.3 Data Sources

1.3.1 Water Quality Data – Utah Lake

We downloaded the water quality data analyzed in this report from the Utah Ambient Water Quality Monitoring System (AWQMS) managed by the Utah Department of Water Quality (DWQ). Data were downloaded in August of 2020. To select the data I drew a polygon around Utah Lake and selected all the stations inside the polygon. To download the data, we used these selected stations, all of the available water quality parameters, a start date of January 1st, 1901, and a stop date of August 1st, 2020. However, only data through 2019 were available on the web site. This query resulted in data downloaded from 89 locations; we retained data only from stations inside Utah Lake, and excluded data from the surrounding area. We did include data from the outfall, and the major inlets. This resulted in data from 42 sampling locations retained.

Table 1.1 lists the locations in the AWQMS data base that contained data used in this report along with the number of samples of any type that are available at that station. The number of samples range from nearly 12,000 measurements at the Jordan River outlet to only 12 measurements at the South Dike in the Lindon Marina.

Figure 1.1 shows the locations of these sampling sites. In addition to the in-lake sample locations, we included the Jordan River outfall and the Spanish Fork River and Provo River inlets. The Provo River inlet sampling location is located inside the Utah Lake boundary, while both the Jordan River outlet and the Spanish Fork River inlet are located outside the lake boundaries.

This report presents a statistical analysis of these data, and describes the efforts to develop a clean historic time-series data sets for selected water quality parameters and make these data available through a web interface.

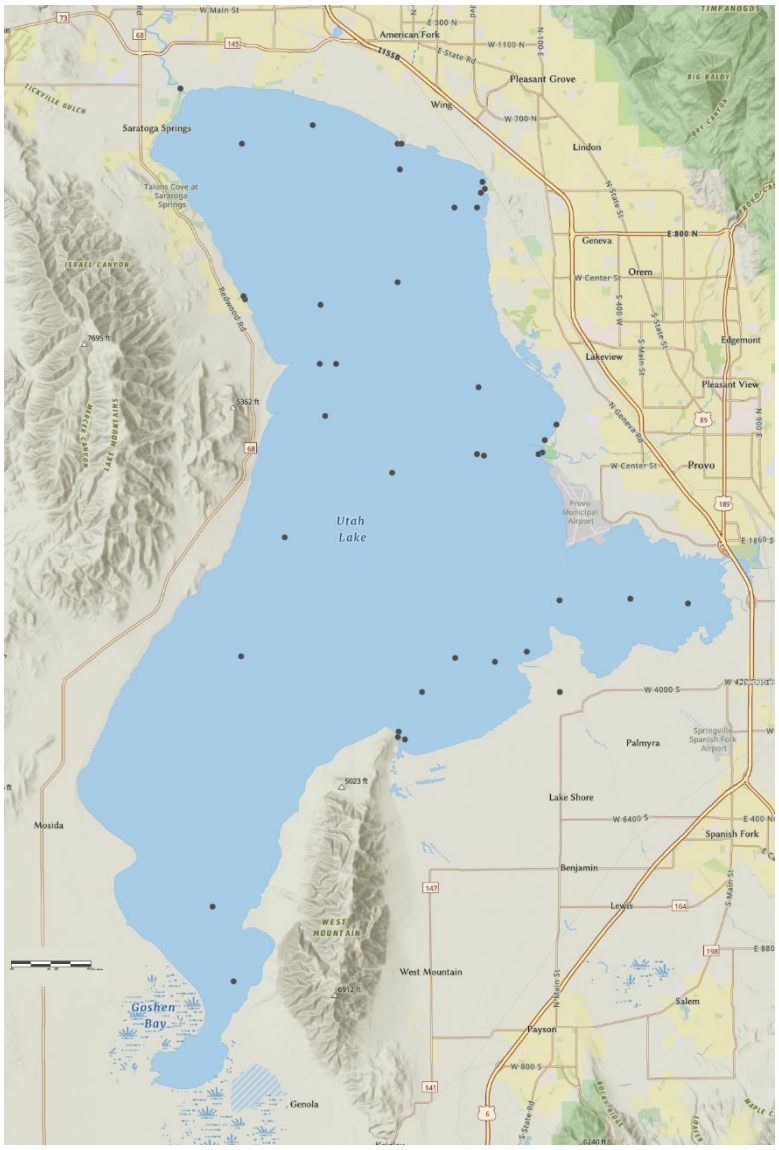

Figure 1.1 Utah Lake sample locations for this report from the DWQ AQWMS database. These stations include the Jordan River outlet, the Spanish Fork River inlet, and the Provo River inlet. The Provo River inlet sampling location is located inside the Utah Lake boundary.

Analysis requires us to clean and evaluate the data to make sure the data are reasonable. For data series with missing values, we will evaluate and use various data imputation methods to estimate missing values to support the statistical analysis of time series issues, for standard statistical analysis we will not use any imputed data. We will identify when and how we imputed data for time series analysis, including a description of the methods used.

This report will evaluate data using different groupings or sub-catagories; the first analysis will treat the entire data set as a single set of measurements and look at the different analytes and their changes over time. The second analysis will look at the different sample locations to determine if there are statistical differences among the

various sample sites and describe these differences, if they exist. When we compare individual sites, the sites with only a few data points will not be considered.

Site	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1997	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Jordan R at Utah L outlet U121 Xing	8	72	225	209	170	51	162	184	206	276	348	245	224	283	227	194	419	369	293	400	421	246		111	271	129	113	185	166	150	177	182	309	370	721	452	259		10			43	179	132
Utah Lake 1 mi W of Provo boat harbor					37											69	152	226		13			41	42		90	97	77	113	191	186	136	126	386	150	161	180	275	140	313	233	1085	930	1165
Utah Lake 3 mi W-NW of Lincoln Beach					38											69	211	198					43	42		89	101	69	67	202	184	133	119	377	123	152	161	359	194	229	183	1070	927	1148
Utah Lake 0.5 mi W of Geneva discharge #15-A																	162	444		35	29	74	80	78		110	111	98	75	234	212	203	131	278	134	143	131	323	154	235	149	937	802	892
Utah Lake 1 mi E of pelican point					36											73	100	455					44	41		68	84	69	66	184	179	123	113	309	97	109	168	341	191	199	156	1046	860	955
Utah Lake 2 mi E of Saratoga Springs #12																	99	192		13			44	40		73	92	69	66	241	159	127	105	308	121	110	134	330	184	188	144	1041	803	1022
Utah Lake outside entrance to Provo Bay					36											35	200	498		13		45		37					19	110	171	129	40	279	94	146	109	222	183	189	121	758	698	1010
Utah Lake 0.5 mi W of Geneva discharge #15-A Replicate of 4917310																	156	416				24	54	27		18	18			25	21	13		116	51	72	52	128	118	86	66	933	604	764
Utah Lake 1 mi NE of Lincoln Point #03																	123	226																								1021	816	1113
Utah Lake 1 mile SE of Bird Island																																									1063	939	1241
Utah Lake 2 miles W of Vineyard																																									1093	941	1063
Utah Lake at middle of Provo Bay																																	100	250	102	101	154	148	64	76	547	357	560
Utah Lake Goshen Bay SW end																																	98	248	87	102	110	142	97	72	503	324	462
Spanish Fork River at Utah Lake inlet																																								3	1	242	316	206
Utah Lake Goshen Bay midway off main point on E shore																35	98	387		12			38																					
Utah Lake W of Provo boat harbor-6 mi N of Lincoln Beach #08																	129	229			24	43														41								
Utah Lake SP @ Marina																																			6					14	280	78	18	30
Utah Lake 2.5 mi NE of Lincoln Point #02																	154	233														6												
Utah Lake 0.5 mi S of American Fork boat harbor #14																	130	229																										
Utah Lake 4 mi E of Saratoga Springs #11					34												100	204																										
Utah Lake 1 mi SE of pelican point #09																	100	225																7										
Utah Lake 5mi N-NW of Lincoln Beach-1 mi offshore																	99	230																										
Utah Lake 1 mi NE of pelican point #10																	100	227																										
Utah Lake 1.5 mi NW of Provo boat harbor #16																	101	225																										
Utah Lake near shore NE of Spanish Fk R inlet																																									3	49	34	48
Utah Lake at Lindon Marina Beach NE of launch ramps																																									34	44	19	28
Utah Lake 300 FT offshore from Geneva Steel					40											35	23			7	1	16																						
Utah Lake at Lincoln Beach north of Lincoln Marina																																									3	27	19	60
Utah Lake 0.7 mi E of pelican point					35											68																												
Utah Lake @ Lindon Beach																																							6		24	29	18	24
Utah Lake at American Fork Marina near boat ramp																																									6	16	18	29
Utah Lake S of Lincoln Marina																																									15	17	24
Utah Lake Saratoga Springs Marina Picnic Area																																										18	36
Utah Lake American Fork Beach																																										9	18	27
Utah Lake at Lincoln Marina (Beach)																																										2	18	29
Utah Lake Saratoga Springs Marina Boat Ramp																																											20	28
Utah Lake at mixing zone-WLA																																					44							
Utah Lake State Park Marina, W side (outside) of marina W dike near south jetty																																											9	27
Provo River Delta Restoration																																										24			
Utah Lake @ Day Use Area																																			21								1	
Utah Lake south of Lindon Marina south dike																																									3	3		
Utah Lake 1.5 miles W of Utah Lake State Park HQ building																																										3		

Figure 1.2 Utah Lake sample locations showing the total number of analyte measurements in each year. The green highlighted boxes show years in which measurements were made at a location. This figure shows that the majority of the sites have limited long-term data with large gaps when measurements were not taken.

1.3.2 Monitoring Locations

Figure 1.2 shows the locations with samples highlighted by the number of measurements with results at each location in a year. This figure does not include results with zero or non-detections values in the count. These locations are listed in the same order as those in Table 1.1, though the numbers are slightly different from those in the Table 1.1, as Table 1.1 counts the total number of samples, while Figure 1.2 counts only samples that have results, e.g., values that are not zero or a non-detect. This figure considers all the different analytes, and is counting the number of results in each year for any analyte.

The data have two apparent groupings, sites with more than 2,000 samples and sites with less than 2,000 samples (see Table 1.1). For the former, the lowest number of samples is 2,573 and for the later, the highest number of samples is 880, a very large difference or gap. There are 13 sites with more than 2,500 samples, but Station 4917320 represents duplicate samples for Station 4917310, so there are only 12 independent sites with over 2,500 samples. There are 29 locations with less than 900 samples and of these 11 locations have less than 100 measurements of any analyte.

Figure 1.2 shows that the earliest measurements are from 1974 at the Jordan River outlet. The Jordan River outlet is the only location that has measurements before 1978, starting at that time; seven (7) other locations have measurements in 1978. After 1978, there is a large gap, where only the Jordan River outlet has measurements until 1989, a large number of locations have measurements in 1989, 1990, and 1991. Only the Jordan River location has measurements in 1992 and 2000. From 2001 until 2019, six (6) other locations have intermittent samples. These locations are at the Utah Highway 121 crossing, 1 mile west of Provo boat harbor, 3 mile west-northwest of Lincoln Beach, 0.5 mile west of the Geneva discharge, 1 mile east of Pelican Point, 2 mile east of Saratoga Springs and outside the entrance to Provo Bay. Starting in 2008, 2 other locations, one

at middle of Provo Bay and the other in southwest end Goshen Bay the have samples until 2019, with the exception of 2016 when these locations do not have samples.

Figure 1.2 figures shows that the majority of the sampling sites within Utah Lake do not have long-term data records, making trend analysis difficult. The first eight sites in the figure have the longest records. Several sites, starting in about 2016 have detailed data measurements with a number of analytes.

1.3.3 Analytes in Database

Tables A.1 and A.2, both in Appendix A, list the different analytes noted in the AQWMS database. Table A.1 and Table A.2 list analytes in the database that had detections, or only non-detections, respectively. The analytes listed in Table A.2 were not detected above detection limits.

There were 83 analytes with detections, the number of detections for different analytes ranges from only 1 to 6,614 for radium and specific conductance, respectively. Table A.1 lists the analytes and the total number of measurements that were processed, and the number of detections. In addition, this table list samples with "non-detects" (ND) "Present Above Quantification Limits" (GT lim), "Present Below Quantification Limits" (LT Lim), "detections" (detect), and the total number of samples analyzed.

Table A.1 shows that there were 18 analytes that had more than 1,000 detections, however not all of these are useful. For example, this group includes both dissolved oxygen (DO) concentration and DO saturation values, while these measure slightly different processes, saturation is dependent on both concentration and temperature, they are essentially the same and not completely independent. This group of analytes with over 1,000 detections includes "Depth, data logger" as a measurement, which is not useful unless we know what other parameters were measured by the probe at that depth; this data base does not include this information, so these depth data are not useful. If we eliminate these two data sets, we have 16 analytes with more than 1,000 measurements for study.

Table A.2 lists 164 analytes that were tested and reported to the database but resulted in non-detects. The number of tests range from 50 samples analyzed for beryllium to 18 different analytes that were only analyzed once. The majority of these analytes, 95 different chemicals, had between 6 and 17 samples analyzed, only 1 analyte (beryllium) had more than 17 samples analyzed and was not detected.

1.3.4 Preliminary Data Analysis

To support analysis, we set the value for all samples that had detections above the detection limit to the upper detection limit, and all the samples with detections below the detection limit to the lower detection limit.

Data with detections below the lower detection limit included Escherichia coli (E. coli) data that had 116 detections below the detection limit (Table A.1) and total coliform that had 5 detections below the detection limit (Table A.1). These values were set to 1 MPN/100ml, where MPN is the "most probable number" for both E. coli and total coliform.

Data with detections above the detection limit included total coliform, secci depth, E. coli, and total fixed solids, which had 850, 12, 8, and 7 samples above the detection limit, respectively. For secci depth, this is actually a small value – e.g., the secci depth was very small. For analysis, these samples were set to 2,419.6 MPN/100ml for total coliform and E. coli. The data were set to values of 0.1 m 0.05 mg/l for secci depth and total fixed solids, respectively.

Table A.3 presents summary statistics for all the analytes that had detections. The table reports the number of detections (N), the sample mean, median, maximum, minimum standard deviation (Std. Dev), skewness, and kurtosis. Skewness and kurtosis are statistical parameters to determine if data are not normally distributed (Gaussian) and if they are not, help characterize the distribution. Skewness is a measure of how symmetric the distribution is about its mean. A skew of zero (0) indicates a symmetric distribution, often Gaussian; a positive skew indicates a distribution with a tail on the right, while a negative skew has the tail on the left. Kurtosis measures the curve of a distribution; it indicates how far or how many outliers are present in the distribution. A Gaussian distribution has a kurtosis value of 3 and by definition has no outliers. For example, a Laplace distribution is symmetrical (no skew), but has tails that approach zero slower than a Gaussian distribution (kurtosis not equal to 3), so has "outliers" if the distribution were assumed to be Gaussian.

2. Trend Analysis

3. Location Analysis

4. Discussion

References

[1] L. B. Merritt and A. W. Miller, "Interim Report on Nutrient Loadings to Utah Lake: 2016," Jordan River, Farmington Bay & Utah Lake Water Quality Council, Provo, Ut, October, 2016 2016.

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Appendix A – Utah DWQ AWQMS Data

A.1 Sample Types

Table A.1 lists the analytes that are included in the Utah Lake samples from the DWQ AWQMS database that have detections. In this table GT Lim is for detections greater than the quantification limit, and LT Lim is for detections less than the quantification limit. The total column is the total number of samples including non-detections. Table A.2 lists the analytes that were sampled but had only non-detections.

Table A-1 Measurement and detection types in data base listed by the total number of detections.

	Number of Measurements				
Measurement Type	**ND**	**GT Lim**	**LT Lim**	**Detects**	**Total**
Specific conductance				6614	6614
pH				6524	6524
Temperature, water				6047	6047
Dissolved oxygen (DO)				5952	5952
Dissolved oxygen saturation				5442	5442
Depth, data-logger (ported)				4720	4720
Depth, Secchi disk depth	7	12		3083	3102
Phosphate-phosphorus	269			2659	2928
Total suspended solids	24			1281	1305
Sulfate	1			1164	1165
Nitrogen	3			1161	1164
Inorganic nitrogen (nitrate and nitrite)	657			1157	1814
Chloride				1137	1137
Total dissolved solids				1061	1061
Calcium				1058	1058
Magnesium				1058	1058
Potassium				1054	1054
Escherichia coli		8	116	1050	1174
Sodium				1050	1050
Organic carbon	1			847	848
Carbon dioxide	2			831	833
Chlorophyll a, uncorrected for pheophytin	51			821	872
Bicarbonate				816	816
Total volatile solids	155			716	871
Hardness, Ca, Mg				715	715
Carbonate	10			690	700
Turbidity				683	683
Ammonia-nitrogen	1250			681	1931
Arsenic	6			633	639
Alkalinity, total				597	597
Calcium carbonate				576	576
Barium	79			549	628
Hydroxide	58			508	566
Chlorophyll a, corrected for pheophytin	120			433	553
Boron				431	431
Kjeldahl nitrogen	2			427	429
Iron	296			399	695
Lead	272			353	625
Total Coliform	9	850	5	333	1197
Copper	296			332	628
Manganese	283			319	602
Salinity				264	264
Light, photosynthetic active radiation at depth (PAR)				250	250
Selenium	387			242	629
Chlorophyll a, free of pheophytin				237	237
Pheophytin a	415			231	646
Sum of anions				215	215
Sum of cations				215	215
Flow	6			208	214
Nitrate	33			172	205
Total fixed solids	106	7		150	263
Zinc	493			141	634
Chromium	490			134	624
Aluminum	257			132	389
Chemical oxygen demand	31			106	137
Orthophosphate	10			92	102
Chlorophyll a	1			80	81
Fecal Coliform	9	1		76	86

Measurement Type	Number of Measurements ND	GT Lim	LT Lim	Detects	Total
Depth				71	71
Biochemical oxygen demand, standard conditions	15			63	78
Carbonaceous biochemical oxygen demand, standard conditions	63	3		39	105
Fecal Streptococcus Group Bacteria				31	31
Fluoride				29	29
Organic Nitrogen				28	28
Silica				27	27
Temperature, air				25	25
Mercury	431			22	453
Cadmium	603			21	624
Nickel	368			21	389
Nitrite	159			21	180
Settleable solids	13			9	22
Chlorine				8	8
Escherichia				8	8
Silver	518			6	524
Chromium(VI)	8			6	14
Beta particle				6	6
Alpha particle	1			3	4
Oil and Grease				2	2
.alpha.-Endosulfan	11			1	12
Di(2-ethylhexyl) phthalate	5			1	6
Dibutyl phthalate	5			1	6
Radium-226				1	1
Tritium				1	1

A.2 Analytes without a detection

Table A-2 lists the analytes in the AWQMS database that do not have any detections in Utah Lake. The table lists both the analyte name and the number of samples or measurements that were made of that analyte. Table A-2 is ordered by the number of samples for each analyte.

Table A-2 Measurement types with only non-detects in the data base

Measurement Type	Number of Measurements	Measurement Type	Number of Measurements
Beryllium	50	N-Nitrosodi-n-propylamine	6
Aroclor 1016	17	N-Nitrosodiphenylamine	6
Aroclor 1221	17	o-Chlorophenol	6
Aroclor 1232	17	o-Cresol	6
Aroclor 1242	17	o-Nitroaniline	6
Aroclor 1248	17	o-Nitrophenol	6
Aroclor 1254	17	p-Bromophenyl phenyl ether (retired) use BDE-003	6
Aroclor 1260	17	p-Chloroaniline	6
Heptachlor epoxide	14	p-Chloro-m-cresol	6
Aldrin	13	p-Chlorophenyl phenyl ether	6
Chlordane	13	p-Cresol	6
Dieldrin	13	Phenol	6
Endrin	13	p-Nitroaniline	6
Heptachlor	13	p-Nitrophenol	6
Lindane	13	Pyrene	6
Methoxychlor	13	Dicamba	4
Toxaphene	13	3-Hydroxycarbofuran	3
alpha.-Hexachlorocyclohexane	12	Aldicarb	3
beta.-Endosulfan	12	Aldicarb sulfone	3
beta.-Hexachlorocyclohexane	12	Aldicarb sulfoxide	3
delta.-Hexachlorocyclohexane	12	Carbaryl	3
2,4-D	12	Carbofuran	3
Endosulfan sulfate	12	cis-1,3-Dichloropropene	3
Endrin aldehyde	12	Dalapon	3
p,p'-DDD	12	Dinoseb	3
p,p'-DDE	12	Methomyl	3
p,p'-DDT	12	Oxamyl	3
Silvex	12	Picloram	3
Pentachlorophenol	10	1,1,1-Trichloroethane	2
2,4,5-T	8	1,1,2,2-Tetrachloroethane	2
m-Dichlorobenzene	8	1,1,2-Trichloroethane	2
o-Dichlorobenzene	8	1,1-Dichloroethane	2
p-Dichlorobenzene	8	1,1-Dichloroethylene	2
Benzo[a]pyrene	7	1,2-Dichloroethane	2
Chlorthal-dimethyl	7	1,2-Dichloropropane	2
Endrin ketone	7	2-Chloroethyl vinyl ether	2
Hexachlorobenzene	7	2-Hexanone	2
Hexachlorocyclopentadiene	7	Acetone	2
1,2,4-Trichlorobenzene	6	Acrolein	2
2,4,6-Trichlorophenol	6	Acrylonitrile	2
2,4-Dichlorophenol	6	Benzene	2
2,4-Dimethylphenol	6	Carbon disulfide	2
2,4-Dinitrophenol	6	Carbon tetrachloride	2
2,4-Dinitrotoluene	6	Chlorobenzene	2
2,6-Dinitrotoluene	6	Chlorodibromomethane	2
2-Chloronaphthalene	6	Chloroethane	2
2-Methylnaphthalene	6	Chloroform	2
3,3'-Dichlorobenzidine	6	Chloromethane	2
4,6-Dinitro-o-cresol	6	Cyclohexane	2
Acenaphthene	6	Dichlorobromomethane	2
Acenaphthylene	6	Ethylbenzene	2
Aniline	6	Methyl bromide	2
Anthracene	6	Methyl ethyl ketone	2
Benz[a]anthracene	6	Methyl isobutyl ketone	2
Benzidine	6	Methylene chloride	2
Benzo(b)fluoranthene	6	Styrene	2
Benzo[ghi]perylene	6	Tetrachloroethylene	2
Benzo[k]fluoranthene	6	Toluene	2
Benzoic acid	6	trans-1,2-Dichloroethylene	2
Benzyl alcohol	6	trans-1,3-Dichloropropene	2

Measurement Type	Number of Measurements	Measurement Type	Number of Measurements
Bis(2-chloro-1-methylethyl) ether	6	Tribromomethane	2
Bis(2-chloroethoxy)methane	6	Trichloroethylene	2
Bis(2-chloroethyl) ether	6	Vinyl acetate	2
Butyl benzyl phthalate	6	Vinyl chloride	2
C1-C3 Fluorenes	6	Xylene	2
C1-C4 Chrysenes	6	Alachlor	1
C1-C4 Fluoranthenes	6	Atrazine	1
C1-C4 Phenanthrenes	6	Butachlor	1
Dibenz[a,h]anthracene	6	CFC-11	1
Dibenzofuran	6	Cyanide	1
Diethyl phthalate	6	Cyanides amenable to chlorination (HCN & CN)	1
Dimethyl phthalate	6	Di(2-ethylhexyl) adipate	1
Di-n-octyl phthalate	6	Diazinon	1
Hexachlorobutadiene	6	Dichlorprop	1
Hexachloroethane	6	Malathion	1
Indeno[1,2,3-cd]pyrene	6	Methiocarb	1
Isophorone	6	Methyl parathion	1
m-Cresol	6	Metolachlor	1
m-Nitroaniline	6	Metribuzin	1
Naphthalene	6	Propachlor	1
Nitrobenzene	6	Propoxur	1
N-Nitrosodimethylamine	6	Radium-228	1
		Simazine	1

A.3 Summary Statistics for Analytes with Detections

A.3.1 Summary Statistics

Table A-2 presents Summary statistics for all the analytes in the AQWS database that had detections. The table includes the number of detections (N), the sample mean, median, maximum, minimum standard deviation (Std. Dev), skewness, and kurtosis. While most are familiar with the standard statistics, skewness and kurtosis provide indices that allow you to determine if your data are not normally distributed (Gaussian) and if they are not, something about the distribution. Skewness is a measure of how symmetric the distribution is about its mean. A skew of zero (0) indicates a symmetric distribution, often Gaussian, with a positive skew has a tail on the right, while a negative skew has the tail on the left. Kurtosis measures the curve of a distribution, you can think of it as determining how far or how many outliers are present. A kurtosis of 3 indicates a Gaussian distribution with by definition no outliers. For example, a Laplace distribution is symmetrical, but has tails that approach zero slower than a Gaussian distribution, so produces "outliers" in standard statistics.

Data that are approximately Gaussian are highlighted light green.

Table A-2 Measurement types with only non-detects in the data base. Data that are approximately Gaussian are highlighted light green.

Characteristic Name	N	Mean	Median	Max.	Min.	Std. Dev	Skew	Kurt.
Specific conductance	6614	1758.35	1772.15	20980.0	0.00	501.40	14.41	539.50
pH	6524	8.41	8.40	14.08	3.20	0.29	-0.49	41.02
Temperature, water	6047	18.78	20.07	29.23	-0.34	5.81	-0.91	0.24
Dissolved oxygen (DO)	5952	8.25	7.77	103.30	0.00	3.85	14.31	295.88
Dissolved oxygen saturation	5442	101.08	95.42	371.19	0.00	27.60	2.55	14.82
Depth, data-logger (ported)	4720	1.23	1.00	6.12	-0.30	0.97	1.10	1.88
Depth, Secchi disk depth	3083	0.27	0.25	7.00	0.00	0.21	15.29	402.48
Phosphate-phosphorus	2659	0.07	0.05	4.19	0.00	0.12	17.07	501.97
Total suspended solids	1281	63.26	45.00	900.00	1.00	75.46	5.20	38.85
Sulfate	1164	265.61	266.00	905.00	26.00	87.49	0.60	3.25
Nitrogen	1161	0.69	0.61	5.32	0.18	0.43	6.22	50.52
Inorganic nitrogen (nitrate and nitrite)	1157	0.23	0.12	5.24	0.01	0.48	6.04	44.01
Chloride	1137	284.33	287.90	751.00	12.80	95.66	-0.19	0.83
Total dissolved solids	1061	1016.94	1000.00	2340.00	106.00	281.45	0.26	0.78
Calcium	1058	62.59	59.00	213.00	24.50	21.93	3.35	13.98
Magnesium	1058	63.73	64.10	134.00	13.00	13.98	-0.06	1.63
Potassium	1054	18.88	19.00	45.40	2.00	4.89	-0.21	1.58
Escherichia coli	1050	113.81	15.80	2419.60	0.00	287.78	4.46	23.45
Sodium	1050	213.95	220.00	706.00	2.00	64.78	0.30	3.78
Organic carbon	847	6.84	6.10	96.40	1.60	4.24	12.96	249.36
Carbon dioxide	831	4.76	2.00	307.00	0.00	15.64	12.32	195.18
Chlorophyll a, uncorrected for pheophytin	821	40.51	21.30	597.50	0.20	58.84	3.92	21.76
Bicarbonate	816	241.52	239.00	530.00	131.00	39.14	1.38	5.80
Total volatile solids	716	12.30	9.00	110.00	2.00	11.09	3.40	18.40
Hardness, Ca, Mg	715	413.27	406.40	898.50	137.20	94.67	1.70	5.04
Carbonate	690	2.89	0.00	123.00	0.00	6.26	10.70	195.91
Turbidity	683	62.30	41.60	790.00	0.10	89.12	5.31	33.68
Ammonia-nitrogen	681	0.16	0.07	3.92	0.01	0.31	6.72	64.14
Arsenic	633	12.34	11.00	135.00	1.00	7.49	7.74	115.13
Alkalinity, total	597	198.85	199.00	333.00	127.00	24.66	1.22	5.42
Calcium carbonate	576	204.84	202.00	434.00	111.00	33.06	1.51	5.69
Barium	549	63.74	81.80	309.00	0.05	50.21	0.14	0.10
Hydroxide	508	0.00	0.00	0.00	0.00	0.00	0.00	-3.02
Chlorophyll a, corrected for pheophytin	433	39.11	19.36	379.30	1.62	53.40	2.95	10.48
Boron	431	336.34	345.00	793.00	42.40	89.27	0.01	2.63
Kjeldahl nitrogen	427	1.08	0.90	16.50	0.00	1.00	9.28	132.11
Iron	399	114.92	1.20	1700.00	0.05	250.52	2.81	8.90
Lead	353	1.68	0.21	25.00	0.05	3.39	3.50	14.79
Total Coliform	333	678.88	307.59	13100.00	0.00	1019.00	6.00	65.97
Copper	332	2.19	1.46	47.00	0.51	3.28	9.05	109.77

Characteristic Name	N	Mean	Median	Max.	Min.	Std. Dev	Skew	Kurt.
Manganese	319	41.80	26.60	322.00	2.60	45.65	2.87	10.84
Salinity	264	0.84	0.83	1.52	0.00	0.18	-0.28	3.31
Light, photosynthetic active radiation (PAR)	250	366.64	85.00	1950.00	0.10	531.70	1.57	1.22
Selenium	242	1.25	1.06	8.00	0.36	0.77	3.45	24.61
Chlorophyll a, free of pheophytin	237	31.42	11.40	284.70	0.74	42.30	2.60	8.61
Pheophytin a	231	5.25	1.00	74.67	0.16	10.20	3.65	15.93
Sum of anions	215	546.84	677.00	1190.00	0.00	366.93	-0.55	-1.16
Sum of cations	215	279.79	352.00	596.00	0.00	183.11	-0.62	-1.13
Flow	205	421.12	250.00	2980.00	0.00	534.72	1.85	4.00
Nitrate	172	0.30	0.07	4.01	0.01	0.49	3.89	22.41
Total fixed solids	150	52.75	42.00	283.00	0.05	48.57	1.99	5.83
Zinc	141	21.43	15.40	105.00	5.00	17.22	2.06	5.16
Chromium	134	2.27	1.55	15.00	0.50	2.37	3.05	10.06
Aluminum	132	345.46	317.00	1430.00	5.43	324.45	1.11	1.03
Chemical oxygen demand	106	27.76	23.50	106.00	10.00	16.62	2.65	9.54
Orthophosphate	92	0.08	0.04	1.42	0.01	0.15	7.39	62.85
Chlorophyll a	80	32.24	15.15	318.50	3.60	47.80	3.60	16.67
Fecal Coliform	76	187.29	23.50	2400.00	0.00	467.28	3.66	13.65
Depth	71	1.87	1.80	3.60	0.00	0.93	0.19	-0.98
Biochemical oxygen demand, stnd. conditions	63	6.44	4.00	50.00	1.00	7.12	4.30	23.37
Carbonaceous biochemical oxygen demand, standard conditions	39	6.51	5.00	23.00	2.00	4.94	1.87	3.17
Fecal Streptococcus Group Bacteria	31	126.16	60.00	480.00	0.00	150.59	1.26	0.28
Fluoride	29	0.73	0.70	1.10	0.40	0.15	0.37	0.63
Organic Nitrogen	28	0.72	0.62	2.11	0.35	0.32	3.12	12.78
Silica	27	23.26	23.00	40.00	5.00	5.65	-0.34	5.91
Temperature, air	25	14.23	12.20	35.00	1.50	11.29	0.47	-1.25
Mercury	22	0.80	0.31	4.10	0.10	1.03	2.21	4.66
Cadmium	21	1.24	1.00	5.00	0.06	1.35	1.55	2.19
Nickel	21	6.66	2.93	25.00	2.53	6.90	2.01	3.40
Nitrite	21	0.08	0.04	0.55	0.01	0.12	3.43	13.14
Settleable solids	9	0.10	0.05	0.40	0.05	0.11	2.81	8.08
Chlorine	8	0.00	0.00	0.03	0.00	0.01	2.83	8.00
Escherichia	8	18.89	13.30	45.00	1.00	15.93	0.70	-0.97
Beta particle	6	21.33	19.50	39.00	4.00	12.37	0.14	-0.32
Chromium(VI)	6	3.83	4.00	5.00	2.00	1.17	-0.67	-0.45
Silver	6	3.50	4.00	5.00	1.00	1.76	-0.49	-1.93
Alpha particle	3	11.67	14.00	19.00	2.00	8.74	-1.12	
Oil and Grease	2	7.00	7.00	7.80	6.20	1.13		
.alpha.-Endosulfan	1	0.03	0.03	0.03	0.03			
Di(2-ethylhexyl) phthalate	1	174.00	174.00	174.00	174.00			
Dibutyl phthalate	1	14.00	14.00	14.00	14.00			
Radium-226	1	1.00	1.00	1.00	1.00			
Tritium	1	450.00	450.00	450.00	450.00			

A.3.2 Histogram Plots

This section presents histogram plots for samples with enough detections to generate a histogram. Included with the histogram plots are box plots showing the median (line in the middle), mean (diamond), 25th and 75th percentiles (ends of the box), the line ends which represents the inter-quartile range (IQR) which is defined as the 3rd quartile minus the 1st quartile. Outliers are presented as dots. The "red" region defines the densest region of the data or "shortest half" of the data.

Figure A.3.1a Histogram and box plots of the data with detections.

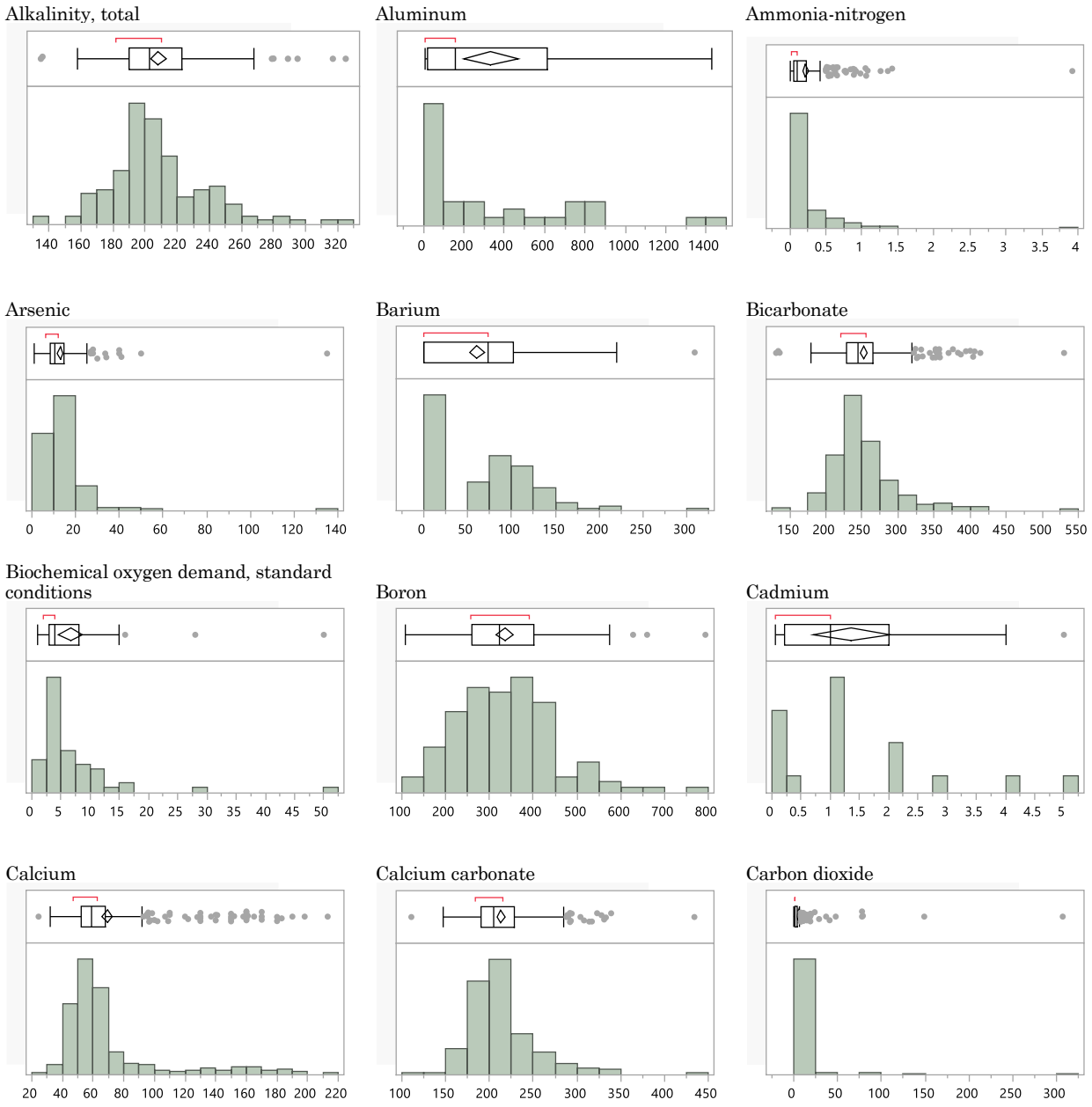
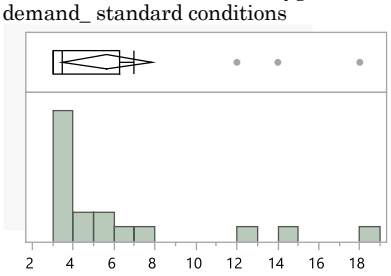
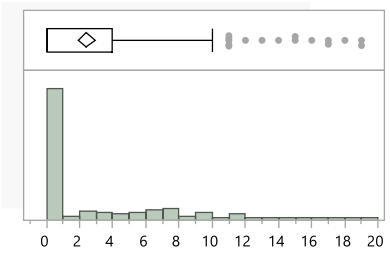


Figure A.3.1b Histogram and box plots of the data with detections (continued).

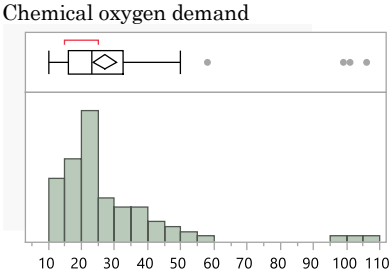
Carbonaceous biochemical oxygen demand_ standard conditions



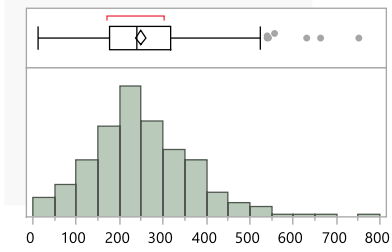
Carbonate



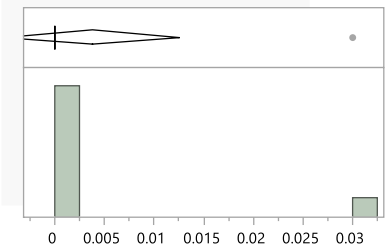
Chemical oxygen demand



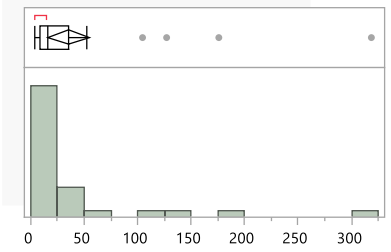
Chloride



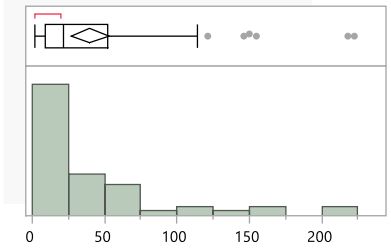
Chlorine



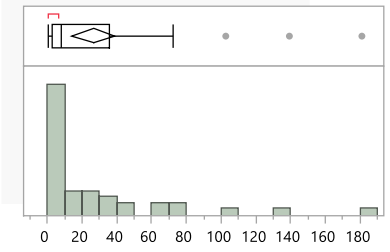
Chlorophyll a



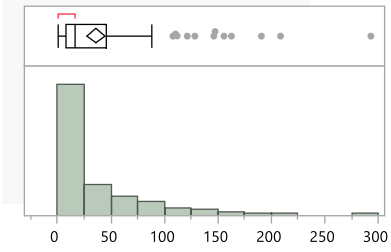
Chlorophyll a_ corrected for pheophytin



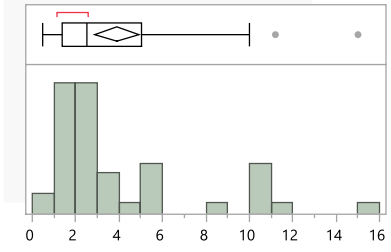
Chlorophyll a_ free of pheophytin



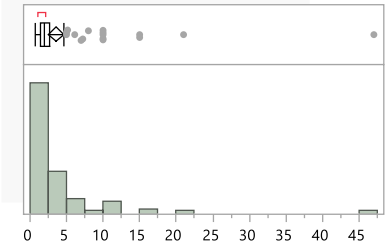
Chlorophyll a_ uncorrected for pheophytin



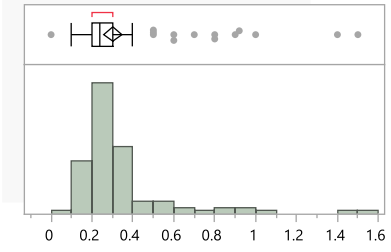
Chromium



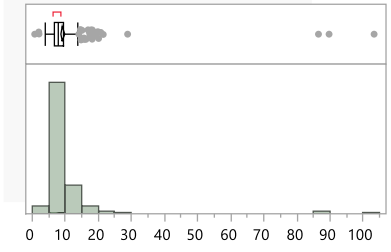
Copper



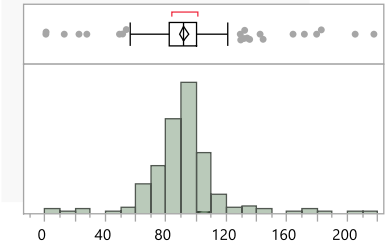
Depth_ Secchi disk depth



Dissolved oxygen (DO)



Dissolved oxygen saturation



Escherichia coli

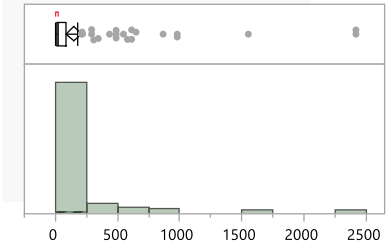
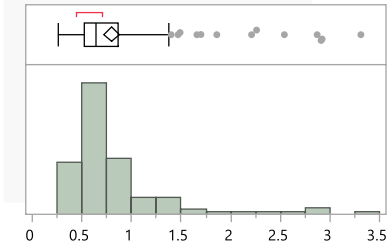


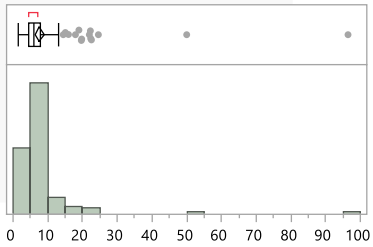
Figure A.3.1b Histogram and box plots of the data with detections (continued).

Figure A.3.1b Histogram and box plots of the data with detections (continued).

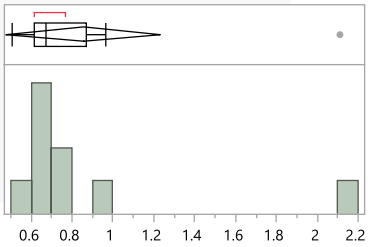
Nitrogen



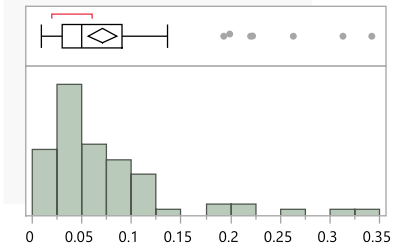
Organic carbon



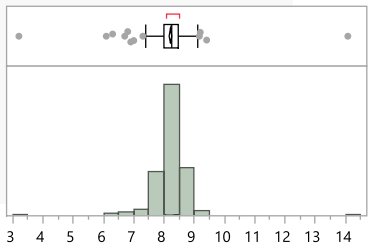
Organic Nitrogen



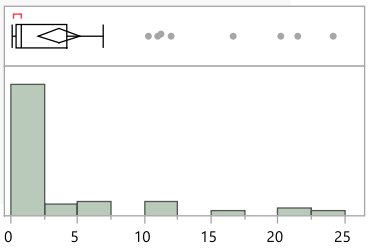
Orthophosphate



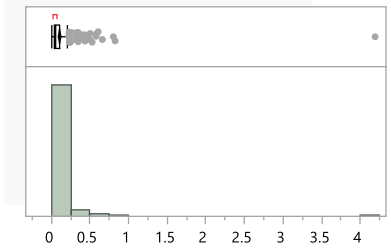
pH



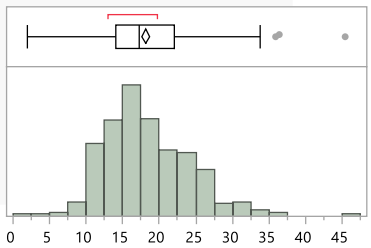
Pheophytin a



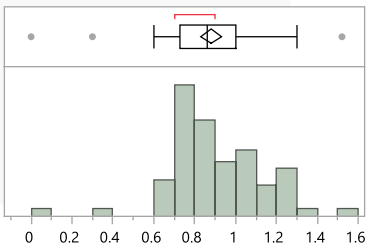
Phosphate-phosphorus



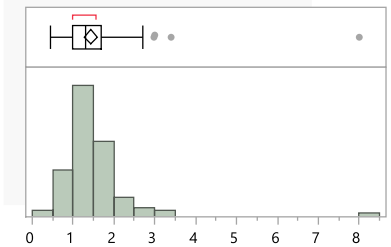
Potassium



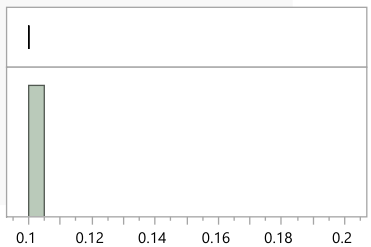
Salinity



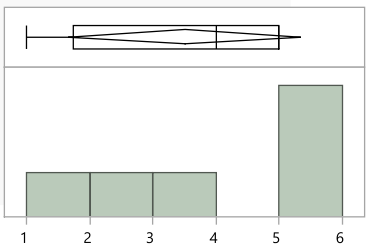
Selenium



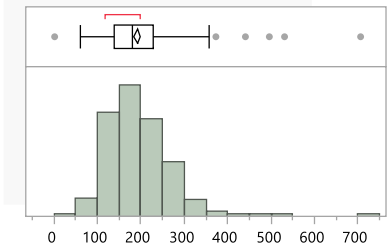
Settleable solids



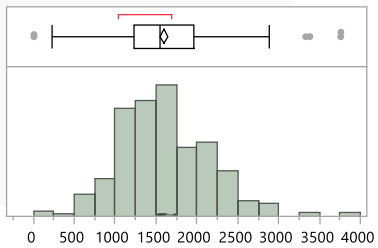
Silver



Sodium



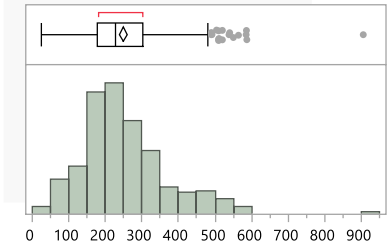
Specific conductance



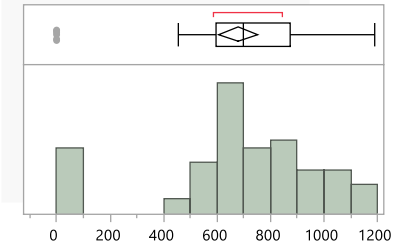
Styrene

Figure A.3.1b Histogram and box plots of the data with detections (continued).

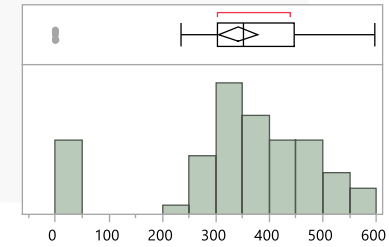
Sulfate



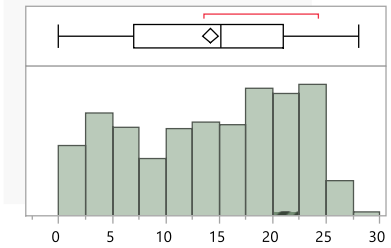
Sum of anions



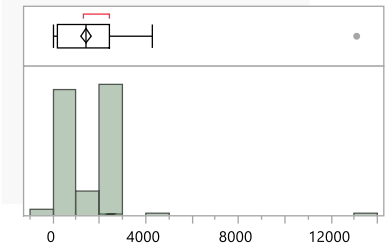
Sum of cations



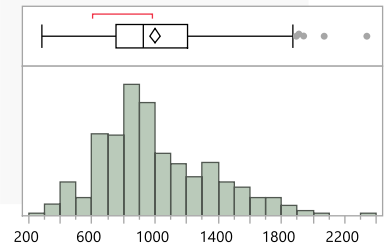
Temperature_ water



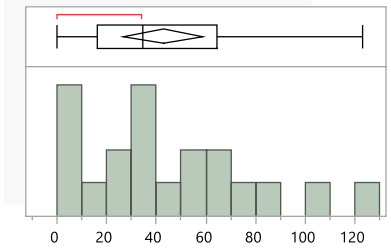
Total Coliform



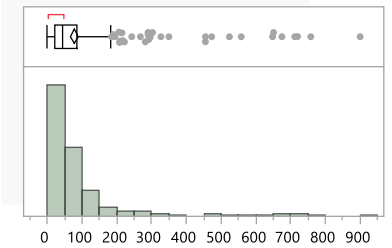
Total dissolved solids



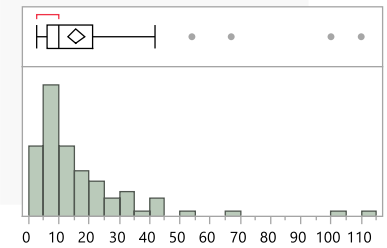
Total fixed solids



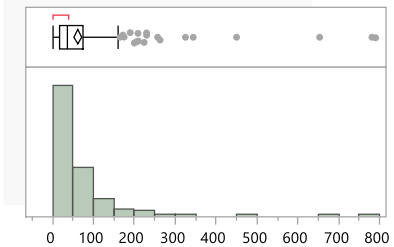
Total suspended solids



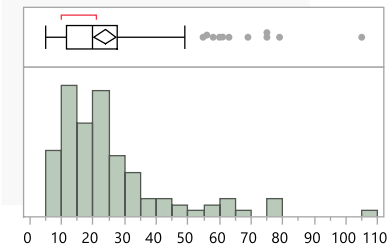
Total volatile solids



Turbidity



Zinc



Appendix C – Journal and Conference Papers

The appendix contains a list of the major journal papers and thesis that are the basis of this report. Where possible, a complete copy of the article is included, for some documents, such as the Theses, the entire document is not included because of length or copyright restrictions, for these documents the published abstract is included. References for all the documents are provided.

C.1 Deer Creek Studies

C.1.1 Included Documents

Casbeer et al. 2018

Casbeer, W.; Williams, G.; Borup, M. Phosphorus Distribution in Delta Sediments: A Unique Data Set from Deer Creek Reservoir. *Hydrology* **2018**, *5*, 58.
[Document included]

C.2 Utah Lake Sediment and Soils

C.2.1 Included Documents

Abu-Hmeidan et al., 2018

Abu-Hmeidan, H.; Williams, G.; Miller, A. Characterizing total phosphorus in current and geologic Utah lake sediments: Implications for water quality management issues. *Hydrology* **2018**, *5*, 8.

Randall et al., 2019

Randall, M.C.; Carling, G.T.; Dastrup, D.B.; Miller, T.; Nelson, S.T.; Rey, K.A.; Hansen, N.C.; Bickmore, B.R.; Aanderud, Z.T. Sediment potentially controls in-lake phosphorus cycling and harmful cyanobacteria in shallow, eutrophic Utah Lake. *PloS one* **2019**, *14*, e0212238.

C.2.2 Documents Not Included

Abu-Hmeidan, Y.H. 2017

Abu-Hmeidan, Y., Hani. Characterizing Current and Geologic Phosphorus in Utah Lake Sediment Using Field Samples, Laboratory Methods, and Statistical Analysis: Implications for Water Quality Issues. Brigham Young University, Masters Thesis, 2017.

Abstract

Phosphorus is an essential nutrient for aquatic life forms and plays a major role in the algae blooms that occur in lakes and reservoirs. It is considered a primary limiting nutrient of phytoplankton growth in streams, lakes, and reservoirs. Excess amounts of phosphorous may cause excess growth and biomass of algae. If phosphorus is available in excess, often from sewage and industrial discharges, the high levels in a lake or reservoir can lead to eutrophication.

Utah Lake is a shallow, basin-bottom lake in a semi-arid climate with sediments that are thousands of feet thick. Starting 165 years ago, humans have been discharging wastewater into Utah Lake, which in our day has raised serious questions on how the state can mitigate the negative effects of the external nutrient loading. Even though Utah Lake receives a significant amount of anthropogenic phosphorous, there are high levels of phosphorous in geologic deposits in the area, providing a long-term natural source. This study intends to provide data on the current distribution of phosphorous in lake sediments, potential for that

phosphorous to be released into the water column affecting phytoplankton growth, and how historic lake sediment phosphorous levels compare to the levels in current sediments.

Sediments play an important role in the overall metabolism of shallow lakes. They supply the water column with phosphorus and must be considered as they serve as a sink and source. More than 50 branches of surface flow discharge into Utah Lake, 15 of which are major. Based on previous data, a positive retention of phosphorus from these branches occurs in the lake, of which the sediment plays a role. Phosphorus release from sediment occurs under very complicated processes under many different conditions. Some main influential factors include the iron and calcium content, redox potential, microbial processes, turbidity, sediment resuspension, temperature, and pH.

In this study, I analyzed 85 sediment samples sampled across Utah Lake for total phosphorus. I created Geospatial maps to show the phosphorous distribution. The data showed an average phosphorus level of 666 ppm and varied in distribution throughout the lake, though the majority of the lake had levels in the 600 to 800 ppm range. There were a few samples, which had lower total phosphorus levels, in the 200 to 300 ppm range. Based on the map, I found that these lower values were in locations representing potential springs. I hypothesize that this underground water source leached some of the phosphorous from the sediments in these areas. I found that total phosphorus concentrations in current lake sediment are quite similar to phosphorus levels in historic lake sediments levels. I also performed laboratory experiments to characterize sediment-water interactions and estimate the amount of phosphorus that could be released to the water column.

Randall, M.C. 2017

Randall, M.C. Characterizing the Fate and Mobility of Phosphorus in Utah Lake Sediments. Brigham Young University, Masters Thesis, 2017.

Abstract

An increasing number of lakes worldwide are impacted by eutrophication and harmful algal blooms due to nutrient inputs. Utah Lake is a unique eutrophic freshwater lake that is naturally shallow, turbid, and alkaline with high dissolved oxygen levels. Recently, the Utah Division of Water Quality has proposed a new limitation of phosphorus (P) loading to Utah Lake from wastewater treatment plants in an effort to mitigate eutrophication. However, reducing external P loads may not lead to immediate improvements in water quality due to the legacy pool of nutrients in lake sediments. The purpose of this study was to characterize the fate and mobility of P in Utah Lake sediments to better understand P cycling in this unique system. We analyzed P speciation, mineralogy, and binding capacity in lake sediment samples collected from 15 locations across Utah Lake. P concentrations in sediment ranged from 306 to 1894 ppm, with highest concentrations in Provo Bay near the major metropolitan area. Sequential leach tests indicate that ~25-50% of P is associated with Ca ($CaCO_3$/ $Ca_{10}(PO_4)_6(OH,F,Cl)_2$ ≈ P) and 40- 60% is associated with Fe (Fe(OOH) ≈ P). Ca-associated P was confirmed by SEM images, which showed the highest P concentrations correlating with Ca (carbonate minerals/apatite). The Ca-associated P fraction is likely immobile, but the Fe-bound P is potentially bioavailable under changing redox conditions. Batch sorption results indicate that lake sediments have a high capacity to absorb and remove P from the water column, with an average uptake of 70-96% removal over the range of 1-10 mg/L P. Mineral precipitation and sorption to bottom sediments is an efficient removal mechanism of P in Utah

Lake, but a significant portion of P may be temporarily available for resuspension and cycling in surface waters. Mitigating lake eutrophication is a complex problem that goes beyond decreasing external nutrient loads to the water body and requires a better understanding in-lake P cycling.

C.3 Atmospheric Deposition

C.3.1 Included Documents

Olsen et al., 2018

Olsen, J.; Williams, G.; Miller, A.; Merritt, L. Measuring and calculating current atmospheric phosphorous and nitrogen loadings to Utah Lake using field samples and geostatistical analysis. *Hydrology* 2018, ***5***, 45.

Goodman, M.M. *et al.*, 2019

Goodman, M.M. et al., "Trace element chemistry of atmospheric deposition along the Wasatch Front (Utah, USA) reflects regional playa dust and local urban aerosols," *Chemical Geology*, vol. **530**, p. 119317, 2019.

C.3.2 Documents Not Included

Olsen, J.M. 2018

Olsen, J.M. 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. Brigham Young University, Masters Thesis, 2018.

Abstract

Atmospheric nutrient loading and transport though 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.

Reidhead, J.G. 2019

Reidhead, J.G. Significance of the Rates of Atmospheric Deposition around Utah Lake and Phosphorus-Fractionation of Local Soils. Brigham Young University, Masters Thesis, 2019.

Abstract

Eutrophic Utah Lake receives a large nutrient load from a variety of sources, including treated wastewater discharges, runoff and tributaries, recycling from bottom sediments and Atmospheric Deposition (AD). AD was the focus of this study and was comprised of two complementary parts. First was a study of nitrogen and phosphorus depositions from the atmosphere, and second was a study of phosphorous as contained in soils near Utah Lake via fractionation methods. The soil samples were found to contain approximately 1,000 mg-P/kg soil for total phosphorus (TP). A separate phosphorus (P) fractionation gave slightly higher values, excluding the residual P, we are 95% confident that one gram of sample soil contains between 2.2 and 4.3percent water soluble P, 0.6 to 1.1 percent loosely-bound P, 2.5 to 4.4 percent aluminum andiron-bound P, and 90.7 to 94.2 percent calcium-bound P.AD results indicate that during the period from April 1 to Nov 17, 2018, Utah Lake received approximately 58 tons of soluble reactive P, 153 tons of TP, 118 tons of nitrogen (N)from nitrate, and 387 tons of N from ammonium via AD. Nutrient quantities from AD are very large compared to the 17 ton/yr of P needed for a eutrophic loading to the lake. Because of the very large overall nutrient loading to Utah Lake, itis likely that some other limiting growth factors are controlling algal growth.

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