ASSESSMENT OF BEAR LAKE WATER QUALITY

A Report for PacifiCorp

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Cover photo: Bear Lake from the International Space Station on September 6, 2016. NASA Earth Observatory (https://earthobservatory.nasa.gov)

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Executive Summary

The assessment presented herein examined the historical and existing water quality conditions of Bear Lake, the Bear River upstream of Bear Lake and tributaries to the river and other influences within the watershed.

Bear Lake has a unique blue color that is dependent on the ongoing precipitation of various mineral forms of calcium carbonate. The continuous precipitation of minerals, such as aragonite and calcite, are predicated upon the alkaline state of the lake, which has pH values generally higher than approximately 8.4 to 8.5, and the alkaline nature of its tributaries and the Bear River inflows. The ongoing mineral precipitation within the lake not only produces its unique blue color but also limits light penetration and appears to sequester nutrients and algae within the precipitate itself, contributing to the oligotrophic state of Bear Lake.

Principal water quality concerns relate to maintaining the:

- Carbonate chemistry conditions within Bear Lake. Specifically, retaining an environment wherein pH is sufficient that chemical precipitation continues to be a dominant process. Mineral precipitation plays multiple roles, including:
    - Sequestering nutrients in persistent mineral form (i.e., removing nutrients from the water column).
    - Sequestering and settling algae from the water column, keeping primary production low (mineral precipitation probably also plays a similar role for organic matter in the lake).
    - Promoting light limitation to further limit primary production.
    - Creating the unique blue color of Bear Lake.
- Maintaining the oligotrophic state of the lake for the long term with regards to nutrient inputs. Chemical precipitation is an important process in maintaining the trophic state of Bear Lake. However, other factors play a role, including the relatively modest nutrient inputs to the lake. The upper Bear River diversions introduce nitrogen and phosphorus, as well as organic matter. The unique chemistry of the lake appears to moderate eutrophication pressure of these nutrient inputs.

Bear Lake is unique in the ability to maintain an oligotrophic status, largely through the geologically derived alkaline source waters. The buffering capacity of the lake was addressed with a basic data analysis and equilibrium chemistry model. A more comprehensive exploration would require additional data and a more complex model. Additional monitoring would likewise be necessary to improve the groundwater-surface water relationship at Bear Lake, as well as support model development and application.

The products of this study include an extensive literature compilation, development of a database of available water quality data, and MINTEQ model and model files.

Assessment of Bear Lake Water Quality

1. Introduction

The Bear River Basin, located in Utah, Idaho and Wyoming, includes the Bear River and its tributaries, as well as Bear Lake, and terminates at the Great Salt Lake (Figure 1). Bear Lake, a water body spanning Utah and Idaho, has a unique limnology that results in the lake's notable blue color.

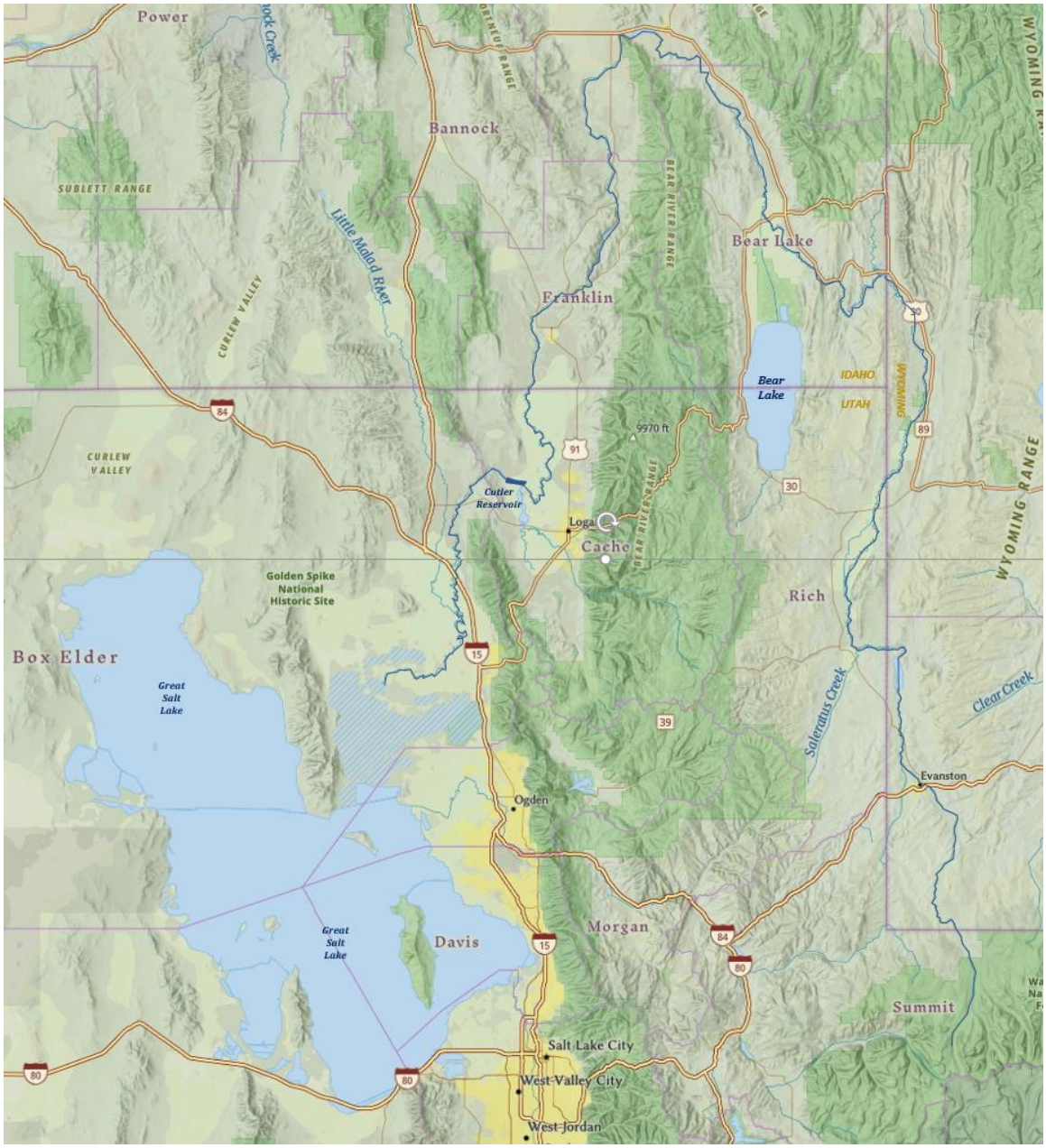


Figure 1. Bear River System, including the Bear River (approximate path, dark blue), Bear Lake, and the Great Salt Lake.

2. Purpose

The purpose of this report is to evaluate the unique water quality conditions within Bear Lake, which are responsible for both the blue color and the oligotrophic state of the lake. The studies included herein examine the historical and existing water quality conditions of Bear Lake, Bear River upstream of Bear Lake, Bear Lake tributaries and other influences within the watershed to provide a preliminary assessment of Bear Lake water quality.

3. Bear River System

The Bear River originates in the Uinta Mountains of northeastern Utah at the confluence of the Hayden Fork and Stillwater Fork. From there, the river travels in a generally northern direction, passing through Wyoming and Utah, before turning west into Idaho. The river continues to travel through Idaho before turning south and re-entering Utah, ultimately terminating at the Great Salt Lake. The river course is approximately 350 miles long, one of the longest rivers in the United States that does not terminate at the ocean (Jibson, 1991).

This report focuses on the Bear River system in the immediate area of Bear Lake (Dingle Marsh and Mud Lake) and Bear Lake. Major tributaries downstream of Bear Lake include Logan River, Cub River, Mink Creek, Soda Creek, and Malad River (Bear River Commission, 1997). There are several other on-river facilities downstream of Bear Lake (e.g., Alexander Reservoir, Oneida Narrows Reservoir, etc.), but those are not discussed herein.

3.1. Dingle Marsh (Bear Lake National Wildlife Refuge) and Mud Lake

Dingle Marsh (also referred to as the Bear Lake National Wildlife Refuge or Dingle Swamp), is located south of the Stewart Diversion Dam on the Bear River and north of Bear Lake. Historically (within the past 12,000 years), Bear River did not connect directly or at least permanently to Bear Lake. However, beginning in the early 1900s, canals and dams were constructed that connected Bear River with Bear Lake.

Waters diverted from Bear River at Stewart Dam feed into the Rainbow Inlet Canal and, from there, through Dingle Marsh and, by extension, Mud Lake (located in the southern portion of the marsh) (Figure 2). Dingle Marsh contains areas of open water and flooded meadow, with no clearly defined canals for water distribution (USFWS, 2019). Under pre-development conditions, Mud Lake did not typically flow into Bear Lake due to a naturally occurring sandbar separating the two water bodies. Since the early 1900's diversion structures and conveyance facilities have been constructed allowing for water from the Bear River to be diverted into Bear Lake and then released back to Bear River. Dingle Marsh and Mud Lake are still used as part of the conveyance system, along with a series of canals, dams, and pump stations.

The water conveyance system between Bear River and Bear Lake includes several canals, regulating dams and one pumping station (Figure 2). Currently, almost all water flowing

in the Bear River upstream of Bear Lake is diverted at Stewart Dam, unless the flows exceed 5,000 cfs (flows over 5,000 cfs have only been recorded once during the operating history of the dam). The original river channel downstream of Stewart Dam has a typical flow of 5 to 7 cfs due to dam leakage. The current channel capacity is estimated at approximately 200 cfs, with higher releases from the dam resulting in downstream flooding. From Stewart Dam, diverted Bear River water flows into the Rainbow Inlet Canal via Rainbow Dam. From there, water flows south towards Dingle Marsh and Mud Lake. Along the way, the Dingle Canal flows into the Rainbow Inlet Canal.

There is no single flow path through Dingle Marsh and Mud Lake, but water entering into the marsh typically flows into Bear Lake (via Mud Lake) or back towards the Bear River (via the Bear Lake Outlet Canal). From Mud Lake, Bear River water can be diverted to and stored in Bear Lake, entering Bear Lake through the Causeway Water Regulating Dam via gravity flow or through two sluiceways in the Lifton Pump Station. Bear River water can also bypass storage in Bear Lake, by traveling from Stewart Dam through the Rainbow Inlet Canal directly into the Bear Lake Outlet Canal, without reaching Mud Lake.

Releases from Bear Lake to the Bear River are implemented via gravity or pumping. If the water surface elevation of Bear Lake exceeds the water surface elevation of Mud Lake, releases are made via gravity through the Lifton Pump Station sluiceways. If Bear Lake is lower than Mud Lake, pumps at Lifton Pump Station are used. Bear Lake water is released into Mud Lake and then enters the Bear Lake Outlet Canal, passes through the Outlet Water Regulating Dam (Paris Dike), and finally into the Bear River channel. Normally, spring runoff water from Bear River is stored in Bear Lake unless the lake is full, in which case the spring runoff bypasses the lake and is conveyed from Rainbow Inlet Canal to the Bear Lake Outlet Canal and back to the river.

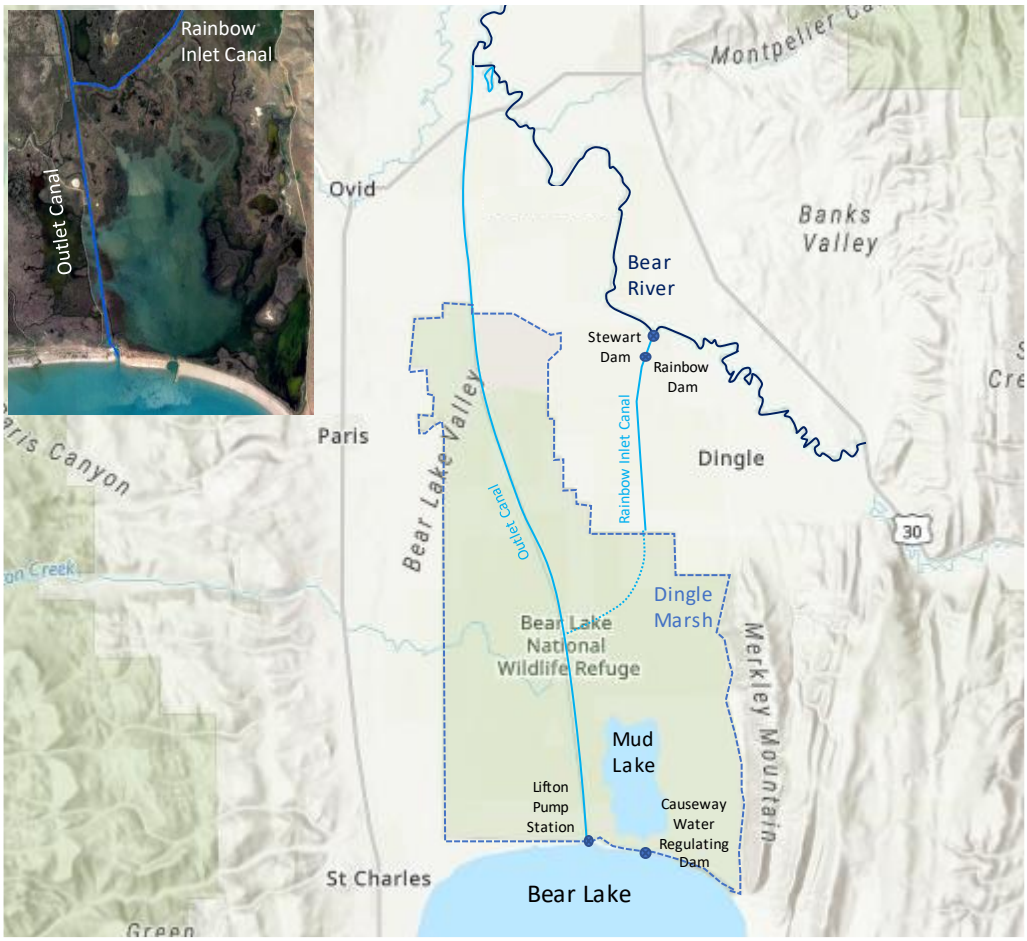


Figure 2. Bear River and Bear Lake water conveyance system. The map has clear delineation of Mud Lake, but in practice, Mud Lake's boundaries are not well defined. The inset (upper left corner, Source: Google Earth) is a satellite map of Mud Lake, highlighting the amorphous nature of the water body.

3.2. Bear Lake

Bear Lake occupies the southeastern corner of Idaho and the northeastern corner of Utah (Figure 1) and has a volume of 6.5 million acre-feet (maf), with approximately 1.4 maf being actively managed. The lake is approximately 19 miles long in the north-south direction and 7.5 miles wide, with its deepest point of 210 ft near the middle of the eastern shore (Figure 4). The mean depth at full capacity is approximately 90 ft. At maximum capacity, Bear Lake water surface elevation is 5,923.65 ft above mean sea level (msl). Water surface elevation varied approximately 20 ft between 1970 and 2025, but intra-annual variations were typically less than 5.0 ft (Figure 3). The Bear Lake natural watershed is 519 mi^2, creating a relatively small watershed area to lake area ratio of 4.8:1. However, with the diversion of the Bear River water into Bear Lake, the watershed area increased to 3,185 mi^2, and the watershed to lake area ratio increased to 29.5:1 (Dean *et al.*, 2009).

Mean annual inflow and outflow is on the order of 400 thousand acre-feet (taf) per year, approximately six percent of the lake volume. Hydrological inflows into Bear Lake include the Bear River diversion, tributaries, groundwater, and precipitation.

Hydrological outflows from Bear Lake include canal flow, groundwater, and evaporation. Residence time in Bear Lake ranges from approximately 16 to 37 years (Dean *et al.*, 2007; 2009). All flow volumes and flux calculations are approximate.

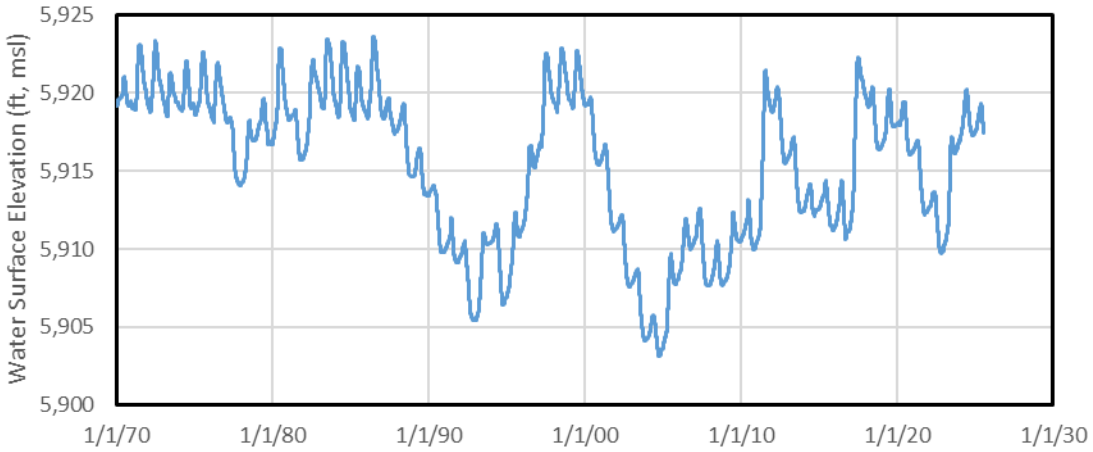


Figure 3. Water surface elevation (ft, msl) in Bear Lake from January 1970 through July 2025 (PacifiCorp, 2025).

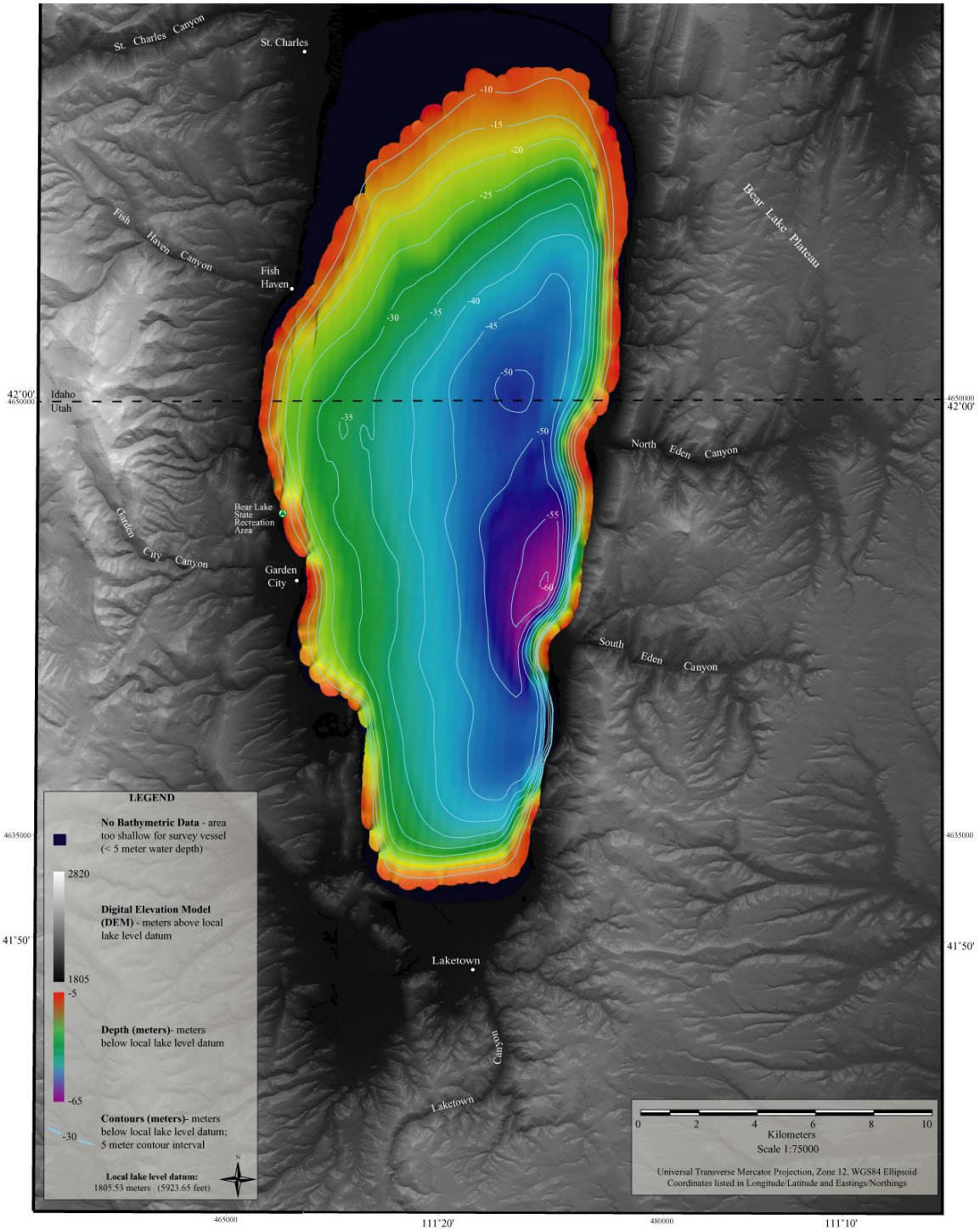


Figure 4. Bear Lake bathymetric map measured by USGS in 2002 (Source: Geophysical Surveys of Bear Lake, Utah-Idaho, September, OFR 03-150).

Table 1. Bear Lake, watershed, primary inflows, outflow, and water conveyance system hydrologic features.

Bear Lake and Watershed Characteristics	Value	Units	Value	Units
Bear Lake Volume[1]	6.5	maf	8.0	km^3
Bear Lake, Active Storage Volume[5]	1.4	maf	1.7	km^3
Bear Lake Surface Area[1]	110	mi^2	284	km^2
Bear Lake Shoreline[2]	48	mi	77	km
Bear Lake Full Capacity Elevation[1]	5,922	ft	1,805	m
Bear Lake Maximum Depth[1]	207	ft	63	m
Bear Lake Mean depth (full)[1]	92	ft	28	m
Watershed Area[3]	3,185	mi^2	8,250	km^2
Watershed Area: Bear Lake Surface Area[1]	29.5: 1	-	29.5: 1	-
Primary Inflows and Outflow	**Value**	**Units**	**Value**	**Units**
Bear River Mean Annual Inflow[3]	242.3	cfs	6.86	cms
Total Tributary Mean Annual Inflow[3]	194.3	cfs	5.5	cms
Average Annual Precipitation (Bear Lake State Park, Utah, 1989 – 2005[4])	1.2	ft/yr	0.4	m/yr
Mean Annual Surface Hydrological Flux to Bear Lake (calculated, including precipitation)	391,534	af/yr	0.483	km^3/yr
Bear Lake Outlet Canal mean annual flow[3]	101.0	cfs	2.9	cms
Bear Lake Annual Average Evaporation[2]	4.6	ft/yr	1.4	m/yr
Mean Annual Surface Hydrological Flux from Bear Lake (calculated, including evaporation)	393,386	af/yr	0.485	km^3/yr
Water Conveyance System Characteristics[5]	**Value**	**Units**	**Value**	**Units**
Bear River original channel capacity	200 cfs	cfs	5.7	cms
Stewart Dam flow capacity	5,000	cfs	141.6	cms
Rainbow Inlet Canal flow capacity	4,700	cfs	133.1	cms
Causeway Water Regulating Dam flow capacity	5,500	cfs	155.7	cms
Lifton Pump Station flow capacity (total)	2,100	cfs	59.5	cms
Outlet Water Regulating Dam (Paris Dike) flow capacity	5,000	cfs	141.6	cms
Bear Lake Outlet Canal flow capacity (Historical Maximum Flow)	3,080	cfs	87.2	cms

[1] Dean *et al*. (2009)
[2] Palacios *et al*. (2007)
[3] Lamarra *et al*. (1986)
[4] WRCC (2019)
[5] PacifiCorp (2016)

4. Available Bear River Basin Data

To support the assessment of Bear Lake water quality, available data were acquired and reviewed. Data included physical parameters, nutrient concentrations, primary production indicators, and major ion concentrations for Bear Lake and select tributaries and the primary inflow and outflow locations of Bear Lake. Meteorological data was also assessed. These data allow for the analysis of current conditions. Specifically, analysis of the current water quality conditions of Bear Lake and Bear Lake inflows (tributaries and precipitation) and outflows (Outlet Canal) which includes an assessment of physical measurements, such as water temperature, dissolved oxygen, and pH, either at the surface or as vertical profiles; and water quality parameters, such as nutrient concentrations, primary production indicators and major ion concentrations.

Overall, water quality, meteorology, and stage and flow data were obtained from fifty-nine sites in the Bear River Basin: twenty-eight Ambient Water Quality Monitoring System (AWQMS) monitoring sites (twenty-two on the lake and six in the basin), eighteen United States Geological Survey (USGS) sites (six on the lake and twelve in the basin), nine sites monitored by Ecosystems Research Institute (ERI) for PacifiCorp (two on the lake and seven in the basin), one site managed by the Utah Bureau of Land Management (Utah BLM), and three sites monitored by Watercourse Engineering, Inc. (WCE) for PacifiCorp in 2019 (two on the lake and one in the basin) (Table 2). Thirty-two of the fifty-nine sites were on or around Bear Lake, twenty-six were in the surrounding tributaries or rivers, and one was a meteorological station to the south of Bear Lake. Site numbers 29 through 31 in Table 2 are notable as they represent hourly continuous water quality data at fixed platforms on Bear Lake. This United States Geological Survey effort was financially supported by a partnership of Bear Lake Watch, the Idaho Department of Environmental Quality, PacifiCorp, and the Utah Division of Water Quality. In this report, some data was examined for single-year sites 29 and 30 while the analysis below focused on site 31 which was in the same location for all 7 years at the deepest point of Bear Lake.

Table 2. AWQMS, USGS, Utah BLM, PacifiCorp, and WCE monitoring sites.

Site #	Agency	Site ID	Site Name	Latitude (NAD83)	Longitude (NAD83)	Approx. Lake Depth, ft
1	AWQMS	4907050	Bear Lake south of Gus Rich Point, at State Route 30 Mile Point 114.17	41.89627	-111.36478	65
2	AWQMS	4907072	Bear Lake State Park at Bluewater Beach	41.90895	-111.37861	<30
3	AWQMS	4907082	Bear Lake State Park at Camp Hunt BSA	41.98141	-111.40504	<30
4	AWQMS	4907085	Bear Lake State Park at Rendezvous Beach	41.848	-111.352	<30
5	AWQMS	4907092	Bear Lake State Park at Cisco Beach	41.9464	-111.27869	<30
6	AWQMS	4907180	Bear Lake 1 mile offshore from North Eden Canyon	41.983822	-111.304653	165

Site #	Agency	Site ID	Site Name	Latitude (NAD83)	Longitude (NAD83)	Approx. Lake Depth, ft
7	AWQMS	4907170	Bear Lake east-southeast of Lakota Resort	41.973825	-111.358533	115
8	AWQMS	4907160	Bear Lake near Pickleville	41.916883	-111.36715	100
9	AWQMS	4906980	Bear Lake off North Beach	42.10049	-111.29243	50
10	AWQMS	4907000	Bear Lake off State Marina	41.96577	-111.38188	100
11	AWQMS	4907150	Bear Lake South End (06) 1 Mile offshore	41.85633	-111.32965	65
12	AWQMS	4906960	Bear Lake southeast of St. Charles	42.06938	-111.33716	65
13	AWQMS	4906620	Bear Lake at Lifton (Summer), Near St. Charles, Idaho	42.12105	-111.3152	<30
14	AWQMS	4917190	Bear Lake USGS Platform 1.6 miles east of Gus Rich Point	41.90308	-111.33781	130
15	AWQMS	4906945	Bear Lake 1 mile east of shoreline halfway (1.2 miles north) from Idaho state line to Fish Haven	42.01842	-111.38245	100
16	AWQMS	4907088	Bear Lake near east shore 1.3 miles northwest of South Eden Canyon	41.94511	-111.29076	200
17	AWQMS	4907005	Bear Lake 2.8 miles east of Bear Lake State Park boat ramp	41.96991	-111.34407	115
18	AWQMS	4906964	Bear Lake 3.0 miles south of Lifton (Bear Lake) outlet	42.07844	-111.30939	80
19	AWQMS	4906962	Bear Lake southeast of St. Charles Replicate of 4906960	42.06938	-111.33716	80
20	AWQMS	4907010	Bear Lake 3.0 miles east-southeast of State Park Marina	41.95536	-111.33448	140
21	AWQMS	4906965	Bear Lake 3.0 miles south of Lifton (Bear Lake) outlet Replicate of 4906964	42.07844	-111.30939	65
22	AWQMS	4906950	Bear Lake 3.0 miles east of Fish Haven	42.03482	-111.32891	115
23	AWQMS	4907100	Big Creek above Bear Lake	41.8391	-111.32964	na
24	AWQMS	4907550	Inflow to Dingle Marsh from Bear River (Rainbow Canal)	42.18493	-111.29604	na
25	AWQMS	4907120	North Eden Canyon Creek at Cisco Road Crossing	41.98577	-111.25631	na
26	AWQMS	4907140	South Eden Canyon Creek at Bridge, 0.3 miles northwest of Nebeker Ranch	41.92688	-111.28242	na
27	AWQMS	4907200	Swan Creek above Bear Lake	41.98549	-111.41187	na
28	AWQMS	4907230	Sweetwater Stream above confluence with Bear Lake at Lodge	41.90827	-111.37854	na
29	USGS	415411111201601	Bear Lake 1.6 miles east of Gus Rich Point	41.9030833	-111.3378	130

Site #	Agency	Site ID	Site Name	Latitude (NAD83)	Longitude (NAD83)	Approx. Lake Depth, ft
30	USGS	420407111201201	Bear Lake 3.6 miles northeast of Fish Haven, Idaho	42.0687222	-111.3365833	80
31	USGS	415941111175401	Bear Lake near east shore 0.4 miles south of Utah-Idaho border	41.99471667	-111.2984667	200
32	USGS	415231111174701	Bear Lake near Laketown, Utah	41.87536111	-111.2964722	<30
33	USGS	10055500	Bear Lake at Lifton near St. Charles, ID	42.12111	-111.31444	<30
34	USGS	10055000	Bear Lake at State Park Marina near Garden City, Utah	41.96591667	-111.3981778	<30
35	USGS	421457111162201	Bear River near Dingle, Idaho	42.24916667	-111.2727778	na
36	USGS	420722111185501	Lifton Pump Station at Lifton, Idaho	42.12280556	-111.3153333	na
37	USGS	421819111213301	Mud Lake Outlet Canal near Montpelier, Idaho	42.30527778	-111.3591667	na
38	USGS	421943111220601	Ovid Creek near Ovid, Idaho	42.32861111	-111.3683333	na
39	USGS	421309111174401	Rainbow Canal at Center Street Bridge near Dingle, Idaho	42.21925	-111.2956389	na
40	USGS	10046000	Rainbow Inlet Canal near Dingle, Idaho	42.22992858	-111.2960363	na
41	USGS	10054600	St. Charles Creek above Diversion near St. Charles, Idaho	42.10965114	-111.459098	na
42	USGS	420715111175701	Mud Lake at Causeway Breach	42.12075	-111.2990833	na
43	USGS	10059500	Bear Lake Outlet Canal near Paris, Idaho	42.2165949	-111.3438159	na
44	USGS	10046500	Bear River Below Stewart Dam near Montpelier, Idaho	42.25305556	-111.2897222	na
45	USGS	10058600	Bloomington Creek at Bloomington, Idaho	42.18527778	-111.4308333	na
46	USGS	10047500	Montpelier Creek at Irrigation Weir near Montpelier, Idaho	42.32965061	-111.2374243	na
47	ERI	BLM	Bear Lake: Middle Station (Platform)	41.994719	-111.2985	200
48	ERI	U1	U1-Bear Lake causeway	42.120147	-111.298889	n/a
49	ERI	B1	Stewart Dam	42.252137	-111.288415	n/a
50	ERI	B2	Bear Lake outlet	42.305295	-111.359038	n/a
51	ERI	Big Creek-01	Big Creek, above streambank restoration project	41.838747	-111.328929	n/a
52	ERI	Big Creek-02	Big Creek, below streambank restoration project	41.839025	-111.329057	n/a
53	ERI	RC1	Lifton	42.123264	-111.313259	n/a
54	ERI	RC2	Bear Lake inlet	42.184348	-111.29626	n/a
55	ERI	Swan	Swan Creek	41.986047	-111.422308	n/a

Site #	Agency	Site ID	Site Name	Latitude (NAD83)	Longitude (NAD83)	Approx. Lake Depth, ft
56	Utah BLM	420912	Otter Creek	41.753330	-111.280560	n/a
57	WCE	Causeway	Bear Lake, Causeway	42.120214	-111.299269	n/a
58	WCE	Swan	Swan Creek Outfall	41.984367	-111.427944	n/a
59	WCE	State	Bear Lake, State Marina	41.9663	-111.395117	n/a

4.1. Bear Lake Data

There was available data for thirty-two sites in or on Bear Lake(Table 3). Sampled parameters included physical parameters for water and atmosphere, nutrient concentrations, chlorophyll-a and pheophytin, bacterial data, and major ion concentrations. The complete data inventory for Bear Lake itself included information collected either continuously or discontinuously between 1903 and 2025. Not all sample parameters were collected at all sites at the same frequency, and most datasets consisted of either general water quality collected for a monitoring period, or parameters collected for a specific study for a shorter period.

The AWQMS data for Bear Lake included discrete samples, collected discontinuously in June through October for 1993 through 2023. Not all sample parameters were collected at all sites at the same frequency. Data was collected by the USGS at six sites for Bear Lake throughout the year from 1903 – 2025, one of which was the BLM site Not all sample parameters were collected at all sites at the same frequency. Additionally, data collected at the BLM site from 2018 through 2024 is considered preliminary and is subject to change. ERI both continuously and discontinuously monitored physical parameters, nutrient concentrations, and primary production indicators at two Bear Lake sites from 1991 to 2004. One of the ERI monitoring sites was the BLM site. Finally, surface samples (for nutrient concentrations, primary production indicators, and major ion concentrations) and physical parameter measurements were collected in the lake during April, May, and June of 2019, at the Causeway and off State Marina sites by WCE.

Table 3. Bear Lake water quality site information and data ranges.

Site #	Agency	Site ID	Site Name	# of Samples	Range of Years	Range of Months
1	AWQMS	4907050	Bear Lake south of Gus Rich Point, at State Route 30 Mile Point 114.17	138	2017 - 2023	May - Oct
2	AWQMS	4907072	Bear Lake State Park at Bluewater Beach	128	2017 - 2023	May - Oct
3	AWQMS	4907082	Bear Lake State Park at Camp Hunt BSA	30	2017 - 2019	May - Oct
4	AWQMS	4907085	Bear Lake State Park at Rendezvous Beach	132	2017 - 2023	May - Oct
5	AWQMS	4907092	Bear Lake State Park at Cisco Beach	126	2017 - 2023	May - Oct
6	AWQMS	4907180	Bear Lake 1 mile offshore from North Eden Canyon	7442	1993 - 2023	May - Oct

Site #	Agency	Site ID	Site Name	# of Samples	Range of Years	Range of Months
7	AWQMS	4907170	Bear Lake east-southeast of Lakota Resort	1106	1993 - 2017	Jun - Oct
8	AWQMS	4907160	Bear Lake near Pickleville	1046	1993 - 2017	Jun - Oct
9	AWQMS	4906980	Bear Lake off North Beach	426	1993 - 2016	Jun - Oct
10	AWQMS	4907000	Bear Lake off State Marina	1560	1993 - 2018	Jun - Oct
11	AWQMS	4907150	Bear Lake South End (06) 1 Mile offshore	824	1993 - 2017	Jun - Oct
12	AWQMS	4906960	Bear Lake southeast of St. Charles	1928	1993 - 2023	May - Oct
13	AWQMS	4906620	Bear Lake at Lifton (Summer), Near St. Charles, Idaho	6	2001	Aug - Aug
14	AWQMS	4917190	Bear Lake USGS Platform 1.6 miles east of Gus Rich Point	4011	2019 - 2023	May - Oct
15	AWQMS	4906945	Bear Lake 1 mile east of shoreline halfway (1.2 miles north) from Idaho state line to Fish Haven	1635	2020 - 2022	May - Oct
16	AWQMS	4907088	Bear Lake near east shore 1.3 miles northwest of South Eden Canyon	1661	2021	May - Sep
17	AWQMS	4907005	Bear Lake 2.8 miles east of Bear Lake State Park boat ramp	1052	2022	May - Sep
18	AWQMS	4906964	Bear Lake 3.0 miles south of Lifton (Bear Lake) outlet	699	2023	May - Sep
19	AWQMS	4906962	Bear Lake southeast of St. Charles Replicate of 4906960	323	2019 - 2023	May - Oct
20	AWQMS	4907010	Bear Lake 3.0 miles east-southeast of State Park Marina	2982	2019 - 2023	May - Oct
21	AWQMS	4906965	Bear Lake 3.0 miles south of Lifton (Bear Lake) outlet Replicate of 4906964	78	2023	Jun - Sep
22	AWQMS	4906950	Bear Lake 3.0 miles east of Fish Haven	405	2019	Sep - Oct
29	USGS	415411111201601	Bear Lake 1.6 miles east of Gus Rich Point	1,289,690	2018	May - Dec
30	USGS	420407111201201	Bear Lake 3.6 miles northeast of Fish Haven, Idaho	495,237	2019	Apr - Aug
31	USGS	415941111175401	Bear Lake near east shore 0.4 miles south of Utah-Idaho border	6,689,662	2018 - 2024	Apr - Dec

Site #	Agency	Site ID	Site Name	# of Samples	Range of Years	Range of Months
32	USGS	415231111174701	Bear Lake near Laketown, Utah	42	2009 - 2009	Mar - Mar
33	USGS	10055500	Bear Lake at Lifton near St. Charles, ID	8765	1982 - 2006	Jan – Dec
34	USGS	10055000	Bear Lake at State Park Marina near Garden City, Utah	40588	1903 - 2025	Jan - Dec
47	ERI	BLM	Bear Lake: Middle Station	11,462	1991 - 2004	Jan - Dec
48	ERI	U1	U1-Bear Lake causeway	337	1991 - 1995	Jan - Dec
57	WCE	Causeway	Bear Lake, Causeway	111	2019	Apr-Jun
59	WCE	State	Bear Lake, State Marina	111	2019	Apr-Jun

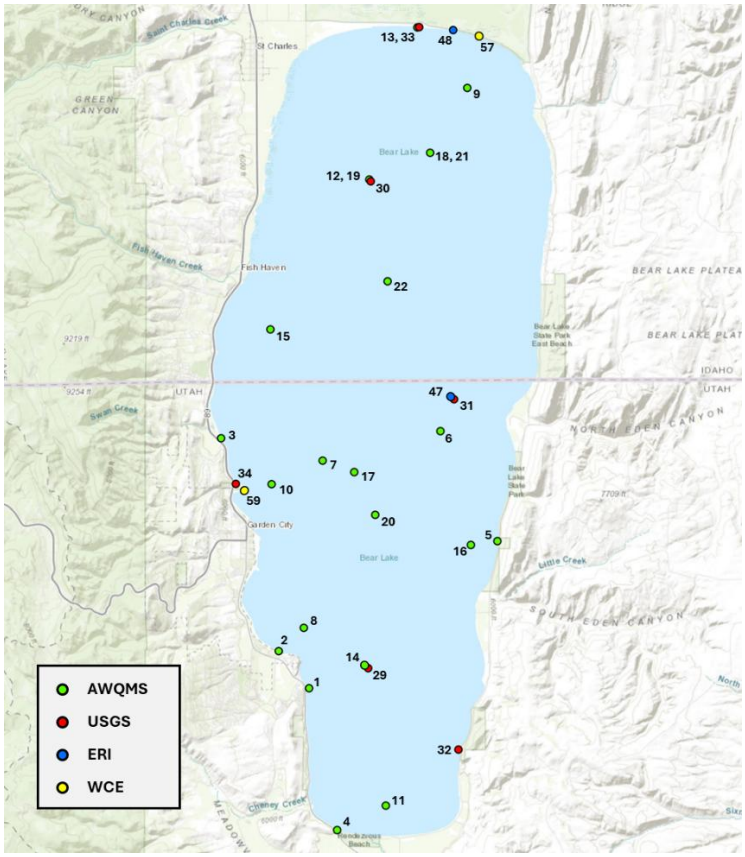


Figure 5. AWQMS (green), USGS (red), ERI (blue), and WCE (yellow) monitoring sites in Bear Lake.

4.2. Data from Area Surrounding Bear Lake

Physical measurements, nutrient concentrations, primary production indicators, and major ion concentrations were collected at various sites in the tributaries to Bear Lake and from its primary inflow and outflow locations. Samples from the AWQMS database included data for six sites surrounding the lake, collected discontinuously from 1974 – 2015. (

Table 4). In addition to the AWQMS data, samples of discontinuously monitored physical parameters, flow, and nutrient concentrations were collected by USGS from twelve sites surrounding the lake, collected both continuously and discontinuously from 1922 – 2023. PacifiCorp collected discontinuously monitored physical parameters, nutrient concentrations, and primary production indicators at seven sites surrounding the lake from 1991 through 1996. Also, samples were collected for physical parameters, nutrient concentrations, major ions, and bacterial indicators at Swan Creek during April, May, and June of 2019, by WCE.

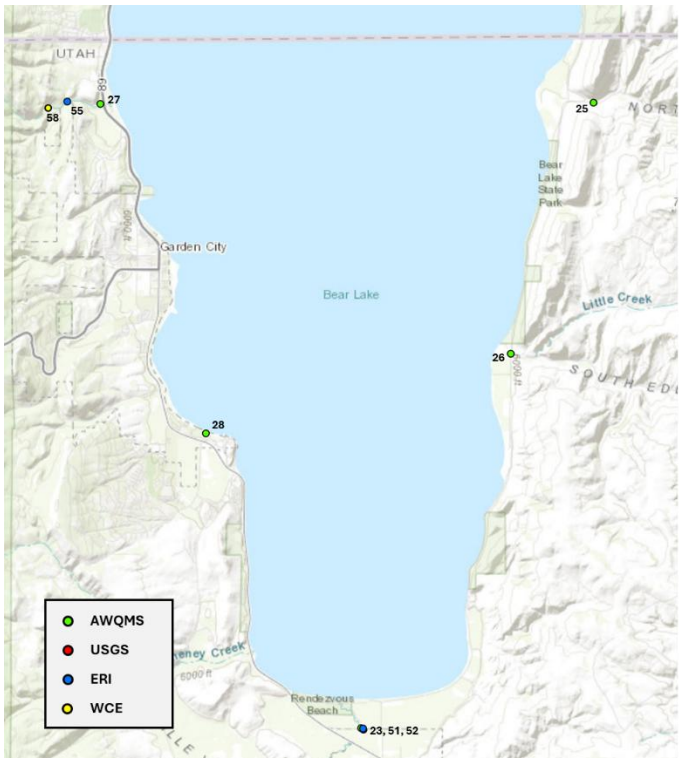
Table 4. Bear Lake tributary water quality site information and data ranges.

Site #	Agency	Site ID	Site Name	# of Samples	Range of Years	Range of Months
23	AWQMS	4907100	Big Creek above Bear Lake	918	1974 - 2015	Jan - Dec
24	AWQMS	4907550	Inflow to Dingle Marsh from Bear River (Rainbow Canal)	12	2001	Mar - Aug
25	AWQMS	4907120	North Eden Canyon Creek at Cisco Road Crossing	534	1974 - 2015	Jan - Dec
26	AWQMS	4907140	South Eden Canyon Creek at Bridge, 0.3 miles northwest of Nebeker Ranch	42	1975	Apr - Aug
27	AWQMS	4907200	Swan Creek above Bear Lake	924	1974 - 2015	Jan - Dec
28	AWQMS	4907230	Sweetwater Stream above confluence with Bear Lake at Lodge	12	1984	May
35	USGS	421457111162201	Bear River near Dingle, Idaho	55	2001	Mar - Aug
36	USGS	420722111185501	Lifton Pump Station at Lifton, Idaho	316	2023	Aug
37	USGS	421819111213301	Mud Lake Outlet Canal near Montpelier, Idaho	100	2001	Mar - Aug
38	USGS	421943111220601	Ovid Creek near Ovid, Idaho	31	2001	Mar - Aug
39	USGS	421309111174401	Rainbow Canal at Center Street Bridge near Dingle, Idaho	1,305	2023	May - Nov
40	USGS	10046000	Rainbow Inlet Canal near Dingle, Idaho	664	1965 - 1971	Jan - Dec
41	USGS	10054600	St. Charles Creek above Diversion near St. Charles, Idaho	105	1967 - 1968	Jan - Sep
42	USGS	420715111175701	Mud Lake at Causeway Breach	16,851	2019 - 2023	Apr - Nov
43	USGS	10059500	Bear Lake Outlet Canal near Paris, Idaho	39,035	1922 - 2006	Jan - Dec

Site #	Agency	Site ID	Site Name	# of Samples	Range of Years	Range of Months
44	USGS	10046500	Bear River Below Stewart Dam near Montpelier, Idaho	18,627	1942 - 1993	Sep - Oct
45	USGS	10058600	Bloomington Creek at Bloomington, Idaho	9,496	1960 - 1986	Sep - Oct
46	USGS	10047500	Montpelier Creek at Irrigation Weir near Montpelier, Idaho	13,452	1942 - 1979	Sep - Dec
49	ERI	B1	Stewart Dam	330	1994 - 1996	Jan - Dec
50	ERI	B2	Bear Lake outlet	270	1991 - 1996	Jan - Dec
51	ERI	Big Creek-01	Big Creek, above streambank restoration project	139	1991 - 1992	Jan - Nov
52	ERI	Big Creek-02	Big Creek, below streambank restoration project	136	1991 - 1994	Jan - Nov
53	ERI	RC1	Lifton	405	1994 - 1995	Jan - Dec
54	ERI	RC2	Bear Lake inlet	241	1994 - 1996	Jan - Dec
55	ERI	Swan	Swan Creek	100	1991 - 1995	Jan - Dec
58	WCE	Swan	Swan Creek Outfall	111	2019	Apr - Jun

4.3. Data Summary

Overall, considerable physical parameter (temperature, dissolved oxygen, and pH), nutrient (including multiple forms of nitrogen and phosphorus), primary production indicators (primarily e.g., chlorophyll-*a*), bacterial indicators (e.g., E. coli, fecal coliform), and major ion concentration (including calcium, magnesium and many other ions) data were available at multiple sites throughout the Bear River Basin. Fifty-eight water quality sites are in Bear Lake, its tributaries, or at the primary inflow and outflow locations. One meteorological site is located near Bear Lake. The data density (both in terms of sampling frequency and available depths) vary by site and by date. The PacifiCorp site BLM (Bear Lake: Middle Station) had the most data, and included parameters such as air temperature, relative humidity, solar radiation, water temperature, dissolved oxygen, pH, specific conductance, turbidity, and primary production indicators at various depths. The Middle Station site corresponded to the deepest part of the lake (approximately 200 ft). Other sites must be consulted for data concerning nutrients and major ions. A summary of the data is provided in Appendix A.



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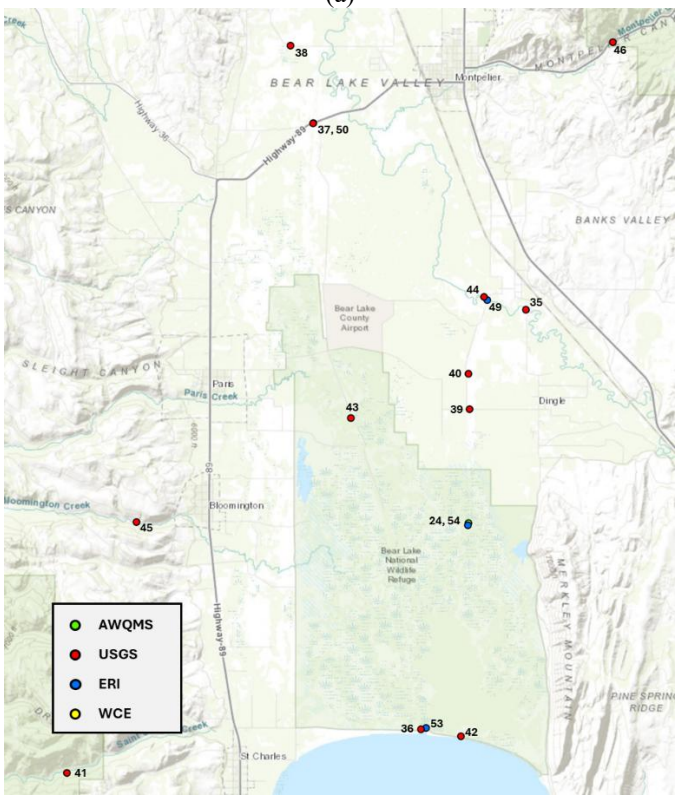


(b)

Figure 6. AWQMS (green), USGS (red), ERI(blue), and WCE (yellow) monitoring sites in Bear Lake tributaries and inflow and outflow (a) surrounding lake and (b) north of lake.

5. Analysis

5.1. Bear Lake Water Quality

Bear Lake water quality reflects local watershed inflow, both surface and groundwater, and diversions from the Bear River into the lake. Basic limnological attributes of Bear Lake, based on selected physical, chemical, and biological conditions are outlined herein, with the general trophic state summarized. Available water quality data for Bear Lake was derived AWQMS and USGS site records, though not all sites had the same parameters available. Other Bear Lake water quality data was derived from the Ecosystems Research Institute (ERI) monitoring efforts performed for PacifiCorp from 1989 through 2006. The ERI reports were available in pdf form, and not all reports had data tables included, nor did all reports include data for all PacifiCorp monitoring sites. However, data was available from the ERI reports from 1991 to 2005. During this period, systematic monitoring of vertical conditions near the deepest location in Bear Lake for a range of physical parameters, nutrients, and chlorophyll-*a* provide a useful baseline to describe the limnology of the lake. The limnology discussion also includes other data.

5.1.1. Bear Lake Tributaries

Bear Lake tributaries include Big Creek, Swan Creek, North Eden Canyon Creek, South Eden Canyon Creek, Sweetwater Stream, Fish Haven Creek, St. Charles Creek, Indian Creek, and Little Creek. These tributaries can have different hydrologic and water quality characteristics reflecting surface or groundwater (e.g., springs) sources, watershed size, and overall runoff. Principal tributaries are Swan, St. Charles, Fish Haven, North Eden, and Big Creeks (Lamarra, 1986; ERI, 1995). Watershed contributions (surface and groundwater) currently contribute approximately 37 percent of Bear Lake inflow; Bear River diversions contribute 40 percent, and the remaining 23 percent comes from precipitation (Lamarra, 1986). Groundwater contributions are poorly understood (Dean *et al*., 2007; 2009).

Based on ERI and AWQMS data, these streams exhibit seasonal variations in temperature between zero in winter and 23°C in summer. Streams dominated by springs, such as Swan Creek, which exhibit relatively cooler summer temperatures and relatively warm winter temperatures with an annual range of approximately 5°C to 13°C. Dissolved oxygen conditions are generally at or near saturation. pH ranges from 6 to over 9, with lower values reflecting rainfall or snowmelt runoff conditions, and higher values reflecting low flow conditions where baseflow is predominately groundwater (reflecting the geology of the basin). The tributaries are generally low in nutrient concentration, but at times higher than Bear Lake concentrations. Groundwater quality is largely unknown.

5.1.2. Bear River Diversions to Bear Lake

Bear River diversions from Stewart Dam are conveyed through the Rainbow Canal into Dingle Marsh and Mud Lake, then into Bear Lake. The majority of the flow into Bear Lake from the Causeway and Lifton occurs in the spring and fall months (Table 5). Field data indicate that water quality conditions can change as waters are conveyed from the river through the wetland setting and into Bear Lake.

Table 5. Average three-month and annual inflow into Bear Lake for 1994-1996.

	Three-Month Average Flow (af)				Annual (af/yr)
	Jan-Mar	Apr-Jun	Jul-Sep	Oct-Nov	
Lifton	37,131	36,099	12,298	70,106	155,634
Causeway	13,199	100,040	29,699	14,028	156,966
Total	50,331	136,140	41,996	84,134	312,600

*Source: ERI (1994; 1995)

Bear River diversions are a source of nutrients and suspended solids to Bear Lake. Both nitrogen and phosphorus concentrations are higher than in Bear Lake, and suspended solids and turbidity during spring runoff or other periods of inflow are also notable. Tributary total dissolved solids are sometimes higher and sometime lower than Bear Lake, which is consistent with the strongly alkaline nature of Bear Lake (maintaining a more stable total dissolved solid concentration within the lake) and the fact that the river and lake share regional geology to some extent. pH fluctuates around 8 by approximately ±0.5 pH units. During diversion periods (winter and spring), the river at Stewart Dam is often warmer than the lake, a condition that is exacerbated by transit through Mud Lake.

Waters conveyed through Dingle Marsh and Mud Lake en route to Bear Lake are impacted by the transit time and shallow wetland-like environment. In general, this reach can act as sink or source of nutrients, with nitrogen (ammonia and nitrate) generally increasing through the reach and phosphorus (orthophosphate) experiencing little change. Suspended solids and turbidity decrease through the reach, consistent with wetland impacts on these two constituents (Crites and Tchobanoglous, 1998). In 1996-98, nitrate inputs from Mud Lake were notably higher than the diversions at Stewart Dam, indicating that during this period the reach between the diversion dam and Bear Lake acted as a notable source of nitrate (ERI, 1997; 1998; 1999). When introduced into Bear Lake, these waters can remain in the near surface waters of the lake, most likely due to being warmer (less dense) and entering the lake after the onset of thermal stratification. Turbidity can be passed through the system and into Bear Lake (Figure 7), also introducing organic matter to the lake (ERI, 1992). pH changes little and as mentioned above, water temperature generally is warmer during discharges to Bear Lake than measured at the Bear River at Stewart Dam.

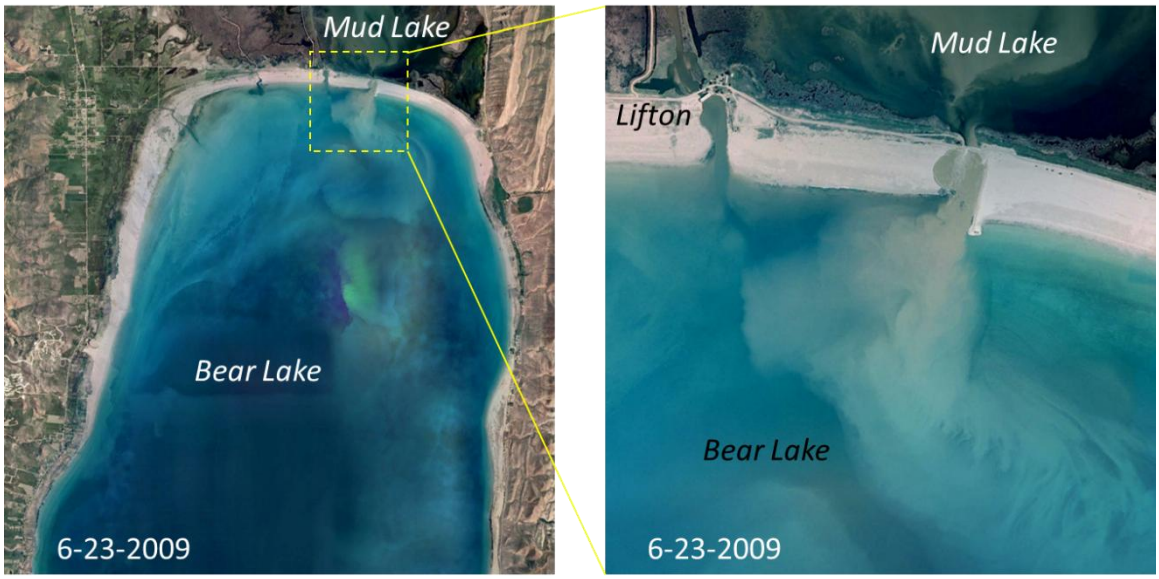


Figure 7. Turbidity plume associated with inflow from Mud Lake to Bear Lake: 6-23-2009.

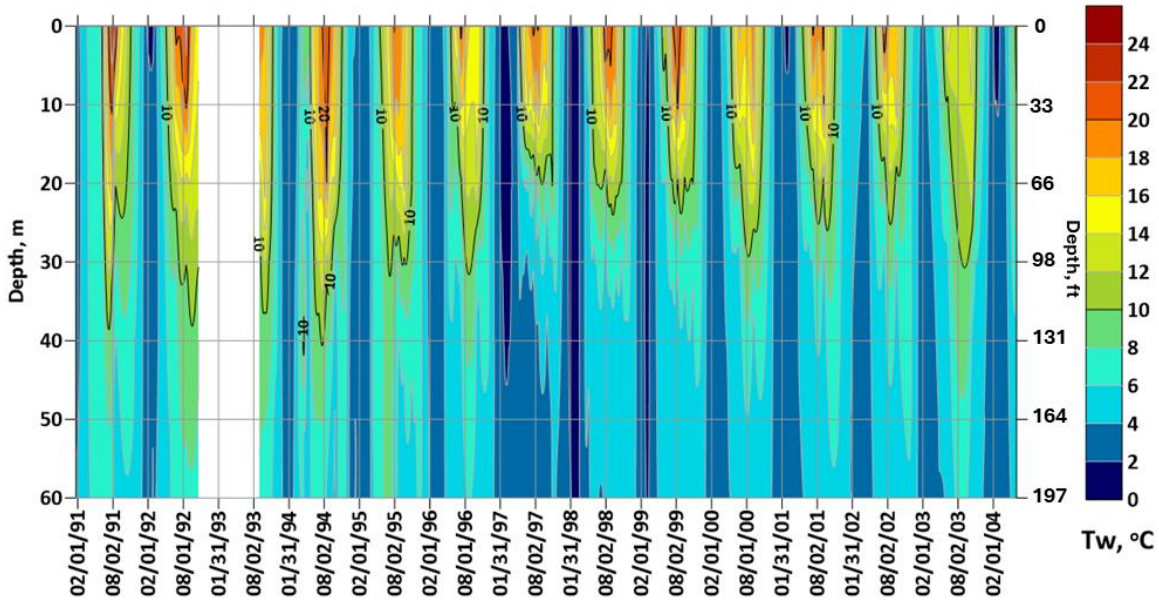
5.1.3. Bear Lake

Bear Lake water quality reflects watershed inflow from the Bear River and multiple tributaries, as well as local land and water use, and urban inputs. Basic limnological attributes of Bear Lake, based on selected physical, chemical, and biological conditions are outlined herein, with the general trophic state summarized.

5.1.3.1. Temperature and Stratification

Bear Lake is primarily classified as a monomictic lake, meaning it typically mixes thoroughly once per year. However, in years when significant ice cover forms, the lake functions as dimictic[1], characterized by 'inverted stratification,' where colder water floats above slightly warmer, sensor bottom water (Woolway et al. 2022). Once the ice cover melts, Bear Lake returns to an isothermal condition. Stratification onset typically occurs in April; thereafter lake stratification strengthens through mid-summer with surface temperatures over 20°C and bottom temperatures remaining around 4°C. Stratification breaks down in the fall period with surface temperatures typically below 8°C in November. Persistent seasonal stratification separated by isothermal winter conditions is illustrated for several years in Figure 8. Detailed USGS continuous monitoring station data for 2018 (Figure 9) illustrates the onset of stratification in April, strengthening of stratification in spring, persistence and magnitude of seasonal stratification through summer, and breakdown of stratification in the fall and return to isothermal conditions.

[1] Dimictic lakes mix from top to bottom twice per year: once in the fall and once in the spring. Dimictic lakes are most common in temperate regions and experience ice cover in winter. Bear Lake generally experiences isothermal conditions in December (3°C to 6°C), and in March (2°C to 4°C). When there is ice cover, surface waters range from 0°C to 2°C while bottom waters are approximately 4ºC. There are years when Bear Lake does not freeze. Under these conditions the lake takes on monomictic lake characteristics, mixing from top to bottom once per year.



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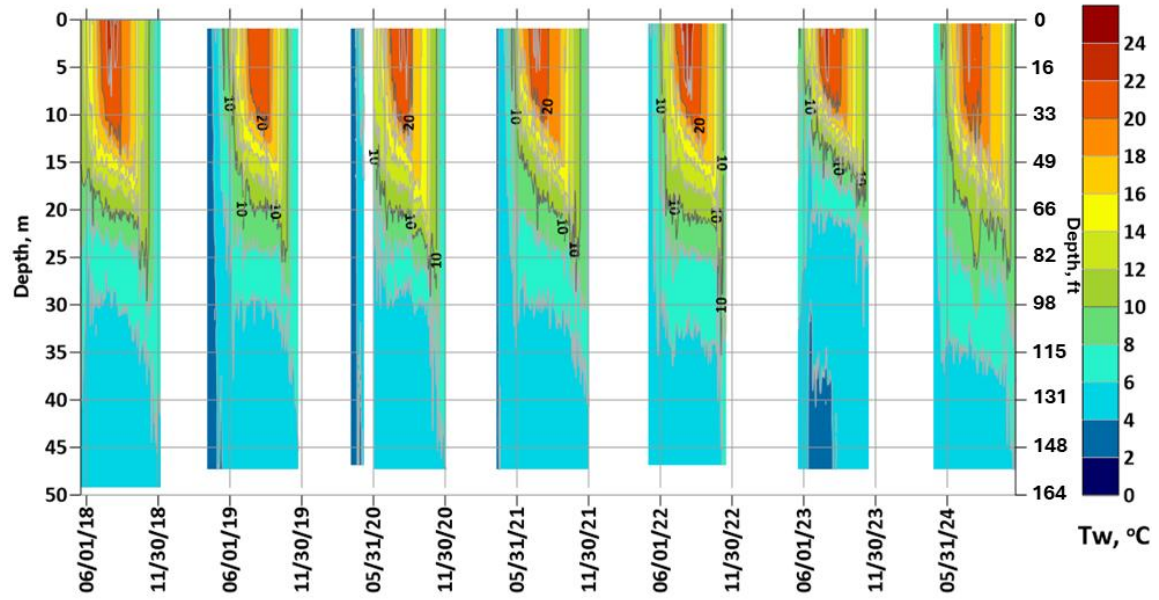


(b)

Figure 8. Water temperature (Tw, °C) in Bear Lake at Middle Station (BLM) from (a) 1991-2004 (ERI reports[2]) and (b) 2018 – 2024 (USGS 415941111175401 dataset, collected at permanent platform). (Note: Depth is presented in meters, spanning 0 to 60 m (0 to 197 ft). Profiler does not return to zero depth during 2018 -2024 period. The USGS data in (b) is considered preliminary and is subject to change.)

[2] ERI reports refers to the annual water quality monitoring reported produced by ERI for the Bear Lake Regional Commission (ERI 1990; 1991; 1992; 1993; 1994; 1995; 1996; 1997; 1998; 1999; 2000; 2001; 2002; 2003; 2004a; 2004b; 2006).

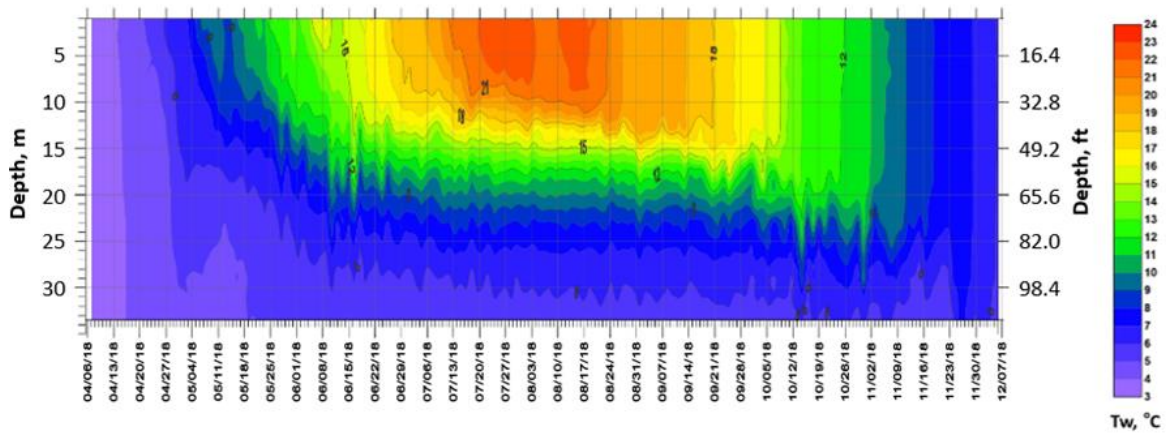


Figure 9. Water temperature (Tw, °C) in Bear Lake 1.6 miles east of Gus Rich Point (USGS 415411111201601) from April through December 2018. (Note: Depth is presented in meters, spanning 0 to 30 m (0 to 98.4 ft). This USGS data is considered preliminary and is subject to change.)

The theoretical stability and the potential for weak stratification can be determined by calculating the Richardson and Wedderburn numbers. Richardson number (*R**), a dimensionless parameter that relates the shear stress produced by wind mixing to the buoyancy forces of the water (Kalff, 2002; Horne and Goldman, 1994), represents the ability of the surface layer to resist wind mixing. The stability of epilimnetic stratification can be calculated with the Wedderburn number (*We#*), a dimensionless parameter that relates the stability of stratification (density, depth) to mixing energy (wind velocity) (Kalff, 2002; Horne and Goldman, 1994; Fisher *et al*., 1979) and represents short-term mixing patterns in the epilimnion.

The summertime Richardson and Wedderburn numbers for Bear Lake were calculated using the USGS data collected in 2018. A *R** of greater than 0.25 indicates stability of stratified layers and a minimal amount of mixing over depth (Wetzel, 2001). Bear Lake *R** exceeded 0.25 during the entire period of record except in December, when the lake had turned over and was mixed. A *We#* greater than 1.0 indicates a lake is prone to stratification within the epilimnion. Such stratification can impede deeper mixing (Horne and Goldman, 1994; Fisher *et al.*, 1979). The *We#* for Bear Lake only equaled or exceeded 1.0 in July and August of 2018, and the vertical profiles demonstrate that during those months that the upper 30 ft of the lake experienced stratification. This stratification occurred within the epilimnion and well above the seasonal thermocline that was located approximately 50 to 65 ft in July and August.

Table 6. Richardson (*R) Wedderburn (*We#*) numbers for Bear Lake (2018).**

Date	Richardson Number (*R**)	Wedderburn Number (*We#*)
4/15/18	0.80	0.00
5/15/18	499.60	0.12
6/15/18	1951.50	0.45
7/15/18	4317.00	1.00
8/15/18	4795.80	1.11
9/15/18	3175.40	0.74
10/15/18	1107.50	0.26
11/15/18	293.60	0.07
12/6/18	0.00	0.00

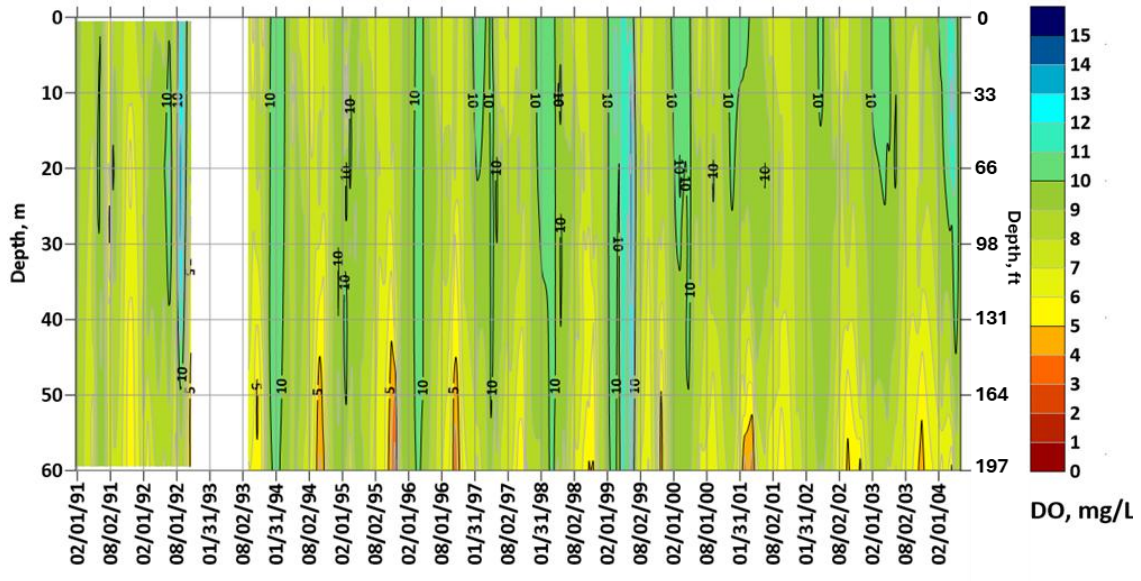
As supported by vertical profile data and the *R** and *We#* calculations, Bear Lake experiences strong summer stratification. Typical onset of stratification for Bear Lake occurs in April or May and persists through November but may vary depending on weather conditions. During the summer months, the lake can experience epilimnion stratification, limiting the mixing of the water in the upper depths. Such limited mixing impacts the plankton community and possibly the chemistry of the epilimnetic water. When the epilimnion is well mixed, algae and zooplankton remain distributed throughout the upper layer of the lake. When intermittent stratification occurs in the epilimnion, algae in the epilimnion below the surface mixed layer can settle into the hypolimnion (Horne and Goldman, 1994). These mixing processes can also impact water chemistry and mineral precipitation.

5.1.3.2. Dissolved Oxygen

Overall Bear Lake experiences stable dissolved oxygen conditions throughout the year, but concentrations depend on water temperature, and there are deviations from saturation in deeper water under stratified conditions (Figure 10). Dissolved oxygen concentration will vary based on water temperature and atmospheric pressure (salinity is not an issue in Bear Lake), with the solubility of oxygen decreasing as temperature increases. Thus, warmer water retains less dissolved oxygen at 100 percent saturation (i.e., in equilibrium with atmospheric oxygen) than cooler water. At the elevation of Bear Lake, surface waters at 4°C yield a dissolved oxygen saturation of approximately 11 mg/L and at 20°C dissolved oxygen saturation is approximately 7.6 mg/L (Wetzel, 2001).

With the onset of stratification in mid-spring, deeper waters in the hypolimnion of Bear Lake are segregated from the atmosphere. Surface water dissolved oxygen remains near saturation throughout the year. Seasonal primary production is low from mid-spring into fall and supersaturation of near surface waters does not occur to any significant degree. In deeper waters, below the photic zone, photosynthesis sources of oxygen are absent during stratified periods. While seasonal primary production is low in Bear Lake, the seasonal accumulation of algal growth in the photic zone and settling of algae (either directly or associated with mineral precipitation) vertically into the hypolimnion result in an oxygen demand (organic matter decomposition and subsequent nitrification). Further, organic matter imported via diversion from Bear River (see above), can introduce particulate

organic matter, and its associated oxygen demand, into the deeper waters of the lake. This oxygen demand leads to sub-saturation conditions in the hypolimnion of Bear Lake in late summer and early fall for most years, with dissolved oxygen levels of bottom waters below 5 mg/L (Figure 10). Fall turnover results in isothermal conditions and the lake mixes vertically, distributing oxygen throughout the water column. Detailed USGS continuous monitoring station data (Figure 11) illustrate these conditions for 2018. Dissolved oxygen in bottom waters did not fall below 5 mg/L.



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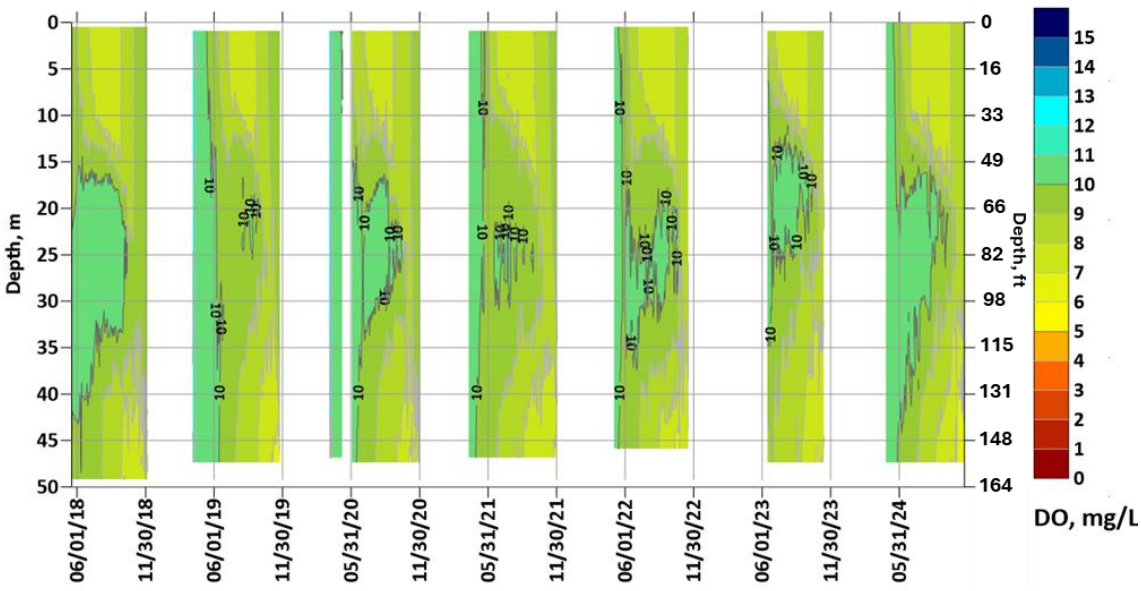


(b)

Figure 10. Dissolved Oxygen (DO, mg/L) in Bear Lake at Middle Station (BLM) from (a) 1991-2004 (ERI reports, see footnote 2) and (b) 2018 – 2024 (USGS 415941111175401 dataset, collected at permanent platform). (Note: Depth is presented in meters, spanning 0 to 60 m (0 to 197 ft). Profiler does not return to zero depth during the 2018-2024 period. The USGS data in (b) is considered preliminary and is subject to change.)

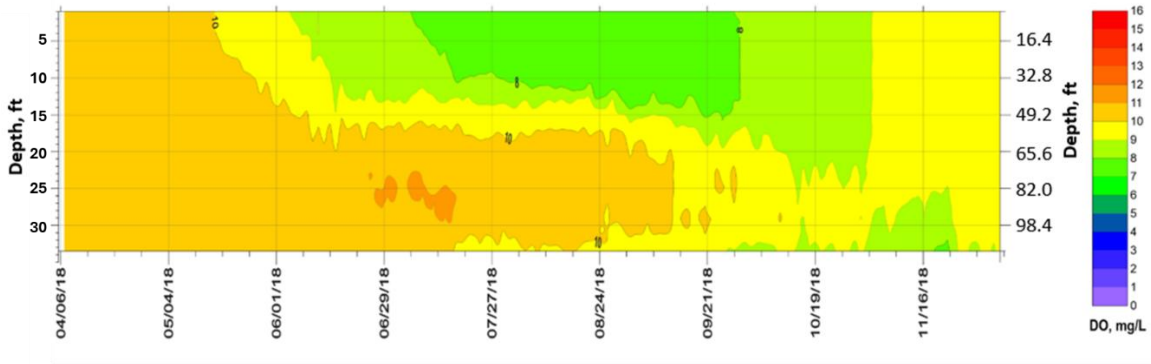
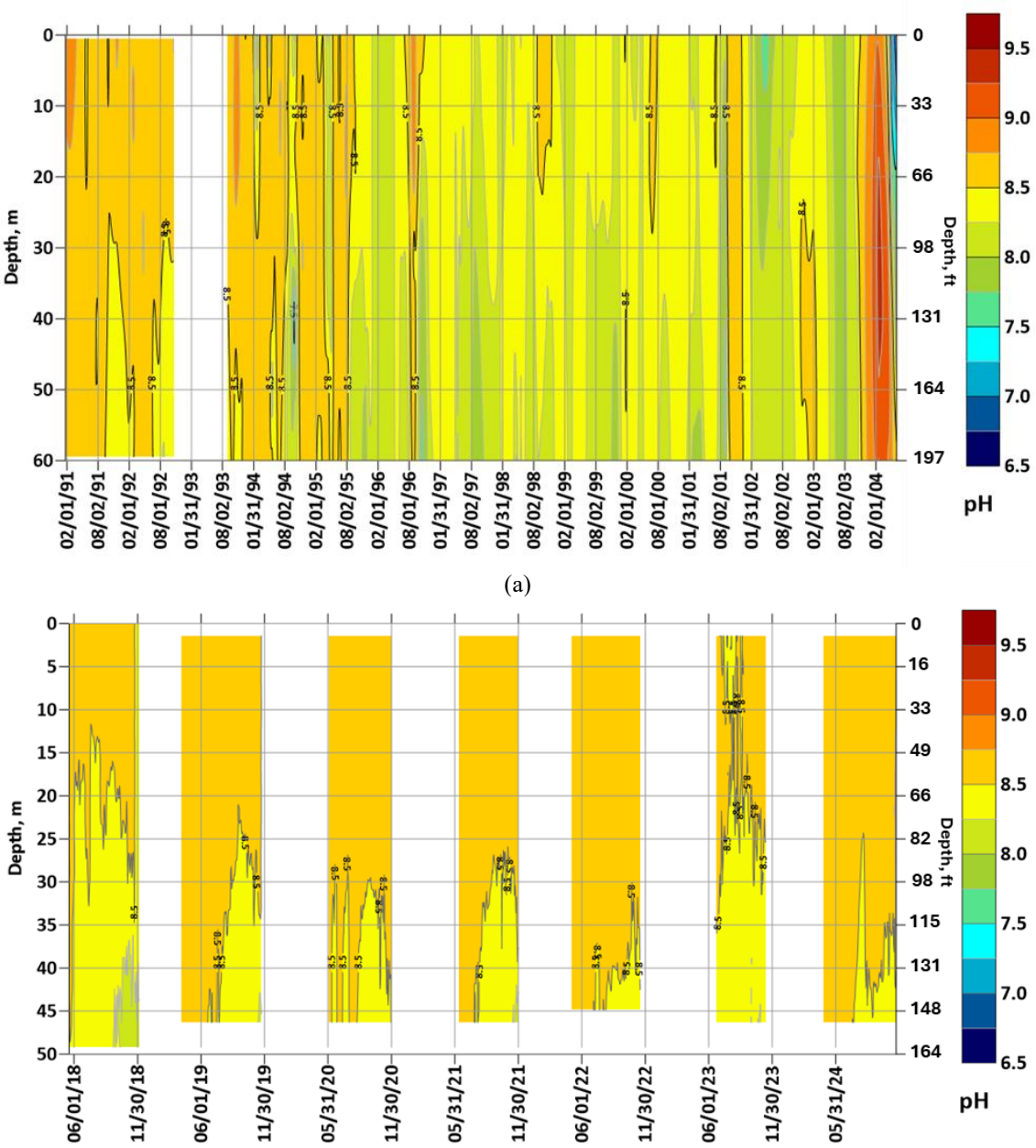


Figure 11. Dissolved oxygen (DO, mg/l) in Bear Lake 1.6 miles east of Gus Rich Point (USGS 415411111201601) from April through December 2018. (Note: Depth is presented in meters, spanning 0 to 30 m (0 to 98.4 ft). The USGS data is considered preliminary and is subject to change.)

5.1.3.3. pH

Bear Lake is an alkaline lake, reflecting the geologic, hydrologic, and geographic nature of the watershed. The pH of the lake is typically above 8 units (approximately 8.25 to 8.75) throughout the year. Exceptions occur in high runoff years when snowmelt runoff, with a lower pH due to dilution of surface water with precipitation, is diverted from the Bear River into Bear Lake. In deeper waters, particularly during late summer and early fall when dissolved oxygen conditions fall below 5 mg/L, pH will occasionally fall below 8 units in response to production of CO_2 associated with organic matter decay. When isothermal conditions are achieved, pH returns to the range typically found year-round in surface waters of Bear Lake. In 2003, there was a period of time when the pH was above 9.0 during lake turnover, but this does not occur at other times in the available data record. Throughout the record there is notable interannual variability in pH (Figure 12).



(a)

(b)

Figure 12. pH in Bear Lake at Middle Station (BLM) from (a) 1991-2004 (ERI reports, see footnote 2) and (b) 2018 – 2024 (USGS 415941111175401 dataset, collected at permanent platform). (Note: Sampling depth spacing was 10 m intervals. The profiler does not return to zero depth during 2018-2024 period. The USGS data in (b) is considered preliminary and is subject to change.)

5.1.3.4. Nitrogen

Inorganic forms of nitrogen include ammonia, nitrite[3], and nitrate. In summer and fall ammonia values are typically low (on the order of 0.03 mg/L[4]). In fall through winter and into spring, ammonia values are often higher, with these elevated values most likely associated with diversions from the Bear River into Bear Lake. There is generally little vertical variation in ammonia; however, inputs from Mud Lake can have notable concentrations of ammonia. With sufficient oxygen distributed vertically throughout the water column for nitrification to proceed, there is no accumulation of ammonia in the deep waters of Bear Lake.

Nitrate is typically low throughout the year (on the order of 0.02 mg/L), except as noted above in the 1996-98 period when larger inorganic nitrogen fluxes were produced in Mud Lake. Nitrate concentrations in the deeper waters of Bear Lake under stratified conditions are often elevated. The contribution of organic matter (and ammonia) from algal and mineral precipitated settling, coupled with sufficient oxygen for nitrification, will lead to an accumulation of nitrate in bottom waters where there is no primary production and thus no uptake. Further, denitrification will not occur because anoxia is largely absent from Bear Lake. Winter concentration of total inorganic nitrogen is useful in identifying background level of bioavailable nitrogen in lake systems. Using January and February data (based on ERI reports[2]) when diversions are lower than during spring runoff (minimizing the impacts of imported nutrients from the Bear River), average winter total inorganic nitrogen was 0.04 mg/L. Winter average of total nitrogen is 0.24 mg/L.

5.1.3.5. Phosphorus

Inorganic phosphorus consists of orthophosphate, which is typically low (on the order of 0.003 mg/L) throughout the year and at all depths. Winter concentration of inorganic phosphorus (orthophosphate) is useful in identifying background level of bioavailable nitrogen in lake systems. Using January and February data (based on ERI reports[2]), when diversions are lower than during spring runoff (minimizing the impacts if imported nutrients from the Bear River), average winter orthophosphate was 0.002 mg/L. Winter average of total phosphorus is 0.012 mg/L.

5.1.3.6. Nitrogen:Phosphorus Ratio

Bear Lake is typically identified as phosphorus limited or co-limited (ERI 1995, 1996, 1997, 1999, 2000, 2001, 2002, 2004a, 2004b, 2006) with nitrogen:phosphorus (N:P) ratios based on inorganic forms of nitrogen (ammonia, nitrite, nitrate) and phosphorus (orthophosphate). There was a period in the early 1980's when the lake was phosphorus limited (ERI, 1992), which could have been associated with several years with large diversions at Stewart Dam, or other factors and associated, relatively high nitrogen concentrations.

[3] Nitrite is an intermediate form of inorganic nitrogen that is short-lived in the environment and will not be discussed herein.

[4] Ammonia (NH4), nitrite (NO2), nitrate (NO3), and orthophosphate (PO4) concentrations are in terms of milligrams of NH4-N, NO2-N, NO3-N, and PO4-P per liter (respectively), and are presented herein as mg/L.

5.1.3.7. Chlorophyll-a

Primary production, as represented by chlorophyll-*a*, in Bear Lake is low, with an average of 0.9 µg/L. Reasons for low primary production are related to the low nutrient characteristics of inflows to the lake, from both local inflows and diversions, and the unique chemistry of Bear Lake, without which the lake would probably not be oligotrophic. The supersaturation of carbonate results in nearly continuous precipitation of calcium carbonate and other minerals. This condition results in several coincidental processes that limit the growth of algae, including:

- Sequestering orthophosphate in the precipitation of hydroxyapatite, and coprecipitation of orthophosphate in carbonate precipitation, effectively removing this nutrient from the water column.
- Algae serving as nucleation sites for crystal formation, potentially removing algal cells from the water column,
- Extensive seasonal mineral precipitation occurring in Bear Lake enhances the settling of organic matter, including algae.
- Extensive mineral precipitation limiting light and therefore reducing algal production.

The coprecipitation of phosphorus may be a principal reason that primary production is constrained by phosphorus limitation in Bear Lake.

5.1.3.8. Secchi Depth

Secchi depth is variable at Bear Lake, ranging from 4.6 ft to 39.4 ft with a mean of 17.7 ft. While there is considerable interannual variability in Secchi depth, values generally vary seasonally with maximum values typically occurring in spring and fall and minimum values in winter. Bear Lake is oligotrophic, and the transparency is more related to the abiotic turbidity (e.g., precipitation of $CaCO_3$ and other minerals) rather than biological factors (e.g., chlorophyll-*a*). Relative light limitation (low Secchi depth) and low productivity are unique features of alkaline lakes such as Bear Lake (Wetzel, 2001). However, with an average Secchi depth of 17.7 ft, there is sufficient light to support primary production.

5.1.3.9. Trophic State

Lakes can be categorized into three types: oligotrophic, eutrophic, and mesotrophic. Oligotrophic lakes are characterized by having low nutrient levels and low rates of primary productivity. Low rates of productivity of oligotrophic lakes are frequently determined by low inputs of nutrients from external sources. Oligotrophic lakes often have a morphometry characterized by being deep relative to surface area. This yields a high ratio of hypolimnion to epilimnion volumes which subsequently affects nutrient cycling. Hypolimnetic and surface sediment oxygen levels tend to be near saturation throughout the year. The low production of organic matter, resultant low rates of decomposition, and oxidizing hypolimnetic conditions result in relatively low rates of nutrient release from the sediments. Low concentrations of relatively readily

decomposable dissolved organic substrates from both planktonic and littoral sources result in small bacterial populations and slow rates of microbial metabolism.

Eutrophic lakes are characterized by having high winter levels and a high supply rate of nutrients and high primary productivity. These lakes are generally shallow with gently sloping sides resulting in a low ratio of hypolimnion to epilimnion volumes. Dissolved oxygen in the hypolimnion is often reduced while supersaturation can occur in the epilimnion. The high production of organic matter and anoxic hypolimnetic conditions result in relatively high rates of nutrient release from the sediments (internal nutrient loading). Mesotrophic lakes are intermediate between oligotrophic and eutrophic lakes.

Bear Lake falls into the oligotrophic status. The lake is relatively deep, compared to its surface area. Bear Lake has low algal productivity, with no anoxia present. Average winter nutrient concentrations for total inorganic nitrogen, orthophosphate, and total phosphorus are low. The low production of organic matter, low decomposition and oxidizing hypolimnetic conditions result in low rates of nutrient release from the sediments and most likely slow rates of microbial metabolism. While the Secchi depth is small enough to be considered mesotrophic, reduced water transparency is due to the precipitation of particulate within the water column, and not due to high organic matter concentrations. Trophic state metrics are summarized in Table 7.

Table 7. Summary of trophic state metrics in Bear Lake.

Parameter	Units	Trophic Status			Bear Lake	
		Oligotrophic (O)	Mesotrophic (M)	Eutrophic (E)	Value	Status
Inorganic Nitrogen (ammonia+nitrite+nitrate)– winter average	mg/L	<0.05	0.05-0.11	>0.11	0.04	O
Orthophosphate – winter average	mg/L	<0.02	0.02-0.042	<0.042	0.002	O
Total P – winter average	mg/L	<0.02	0.02-0.042	<0.042	0.01	O
Secchi depth (growth season minimum)	feet	>26	8-26	<8	10	M
Chlorophyll-*a* (annual average)	µg/L	<1	1-3	>3	0.9	O
Anoxia Presence	Yes/No	Typically not present	Typical in stratified systems	Almost always in stratified systems–	Not present	O

5.2. Additional Bear Lake Analyses

In addition to assessing water quality and trophic state of Bear Lake, nitrogen and phosphorus loading, carbonate chemistry, and particulate matter composition and settling rates were also examined. Nitrogen and phosphorus loadings were assessed. Carbonate chemistry relates to mineral precipitation in Bear Lake and use of an equilibrium chemistry model was used to ascertain the mineral balance of Bear Lake. Finally, a limited study was conducted using samples from the 2019 field program to determine if

particulate matter could be quantified to provide additional insight into mineral precipitation at Bear Lake.

5.2.1. Total Nitrogen and Total Phosphorus Loading

Loading values illustrate the overall nutrient contributions of water sources of varying concentrations and flows. Total nitrogen (TN) and total phosphorus (TP) loads were determined for the Bear River diversion into Bear Lake. Based on 1994 to 1996 data, the loading rates for the diversion into Bear Lake were estimated. Current lake conditions (e.g., coprecipitation of orthophosphate, light limitation etc.) are sufficient to maintain Bear Lake color and low productivity.

Table 8. Annual total nitrogen and total phosphorus loading rates (lbs/yr) for the Bear River diversion into Bear Lake from 1994 to 1996.

	Total Nitrogen Loading (lb/yr)	Total Phosphorus Loading (lb/yr)
Bear River Diversion into Bear Lake	748,900	64,150

5.2.2. Saturation Indices and pH Effects

Applying the equilibrium chemistry model MINTEQ[5], various mineral precipitation conditions in the lake were examined through the calculation of mineral saturation indices. The saturation index identifies the potential of a mineral to form precipitate[6]. The modelled system was assumed to be open to the atmosphere with a partial pressure of carbon dioxide corrected for the elevation of Bear Lake. pH was a user-specified model input, along with water temperature. Additionally, measured concentrations of several major ions were used in the input, including total dissolved carbonate, calcium, magnesium, chloride, ammonia, nitrate, phosphate, sodium, potassium, sulfate, silica, fluoride, iron, manganese, arsenic, boron, copper, and zinc.

A reversible chemical reaction is in equilibrium when the concentrations of reactants and products are constant, and the ratio of the reactants and products does not vary. Under such circumstances the forward and reverse reactions occur at equal rates (products ↔ reactants). Natural systems are rarely in equilibrium, but equilibrium chemistry analyses can provide understanding into systems that exhibit equilibrium characteristics. In the case of Bear Lake, the large volume compared to Bear River annual diversions and the fact that lake chemistry is dominated by regional geology, saturated with calcite, aragonite, and dolomite, and produces vast amounts of carbonate minerals (Dean *et al*., 2009), suggest that equilibrium modeling would prove insightful. Further, MINTEQ was used to calculate the charge balances for Bear Lake data. The low charge balance value produced in the analysis suggested that equilibrium assumptions were appropriate for Bear Lake (Marina: 7.9, North Eden, 5.2). MINTEQ was used to explore Swan Creek

[5] MINTEQ is "MINTEQ is a freeware chemical equilibrium model for the calculation of metal speciation, solubility equilibria, sorption etc. for natural waters. It combines state-of-the-art descriptions of sorption and complexation reactions." (https://vminteq.com/)

[6] A positive saturation index indicates super-saturation and the potential to form precipitate, and a negative saturation index indicates sub-saturation and the preference of a mineral to remain in solution.

data as well and MINTEQ charge balance calculations were generally higher than Bear Lake, suggesting they were further from equilibrium conditions (Swan Creek: 45).

5.2.2.1. Calcium Carbonate Minerals in Water

Calcium carbonate chemistry is complicated when it comes to the forms that will crystallize out of solution (e.g., aragonite or calcite). The process of mineral precipitation is common in nature because neither mineral is highly soluble, and the presence of dissolved carbon dioxide (CO_2) in water encourages calcium and carbonate to precipitate. In water, CO_2 exists in balance with the bicarbonate ion, HCO_3^-, and carbonic acid, H_2CO_3, all of which are highly soluble. Changing the level of CO_2 affects the levels of the other two compounds. However, in the presence of calcium (Ca^{2+}), $CaCO_3$ typically precipitates as a mineral when pH is above 8.3.[7] Importantly, $CaCO_3$ cannot dissolve quickly and return to the water. The arrangement of the calcium ions and carbonate ions as they join into $CaCO_3$ depends on conditions in the water. In fresh water, calcite predominates, especially in cool water.

5.2.2.2. Saturation Indices

Mineral precipitation, measured by a positive saturation index, of various minerals was examined. While any mineral that was super-saturated in any modeling output was assessed for changes in mineral precipitation under various conditions, the analysis focused on aragonite ($CaCO_3$), calcite ($CaCO_3$), dolomite (disordered and ordered) ($CaMg(CO_3)_2$), hydroxyapatite ($Ca_5(PO_4)_3(OH)$) and quartz (SiO_2), because these five minerals are most prevalent in Bear Lake (Dean *et al*., 2007; Dean *et al.*, 2009). Aragonite and calcite have the same chemical formula, $CaCO_3$, but their atoms are stacked in different configurations. Aragonite has an orthorhombic structure and calcite a trigonal structure (Bullock 1981). Note that hydroxyapatite incorporates the bioavailable orthophosphate molecule (Birdsey 1985), and, as shown below, is a mineral that most strongly precipitates at all sites.

MINTEQ was used to estimate the saturation indices of Bear Lake and Swan Creek, examining the lateral, vertical, inter-annual and intra-annual variation in mineral precipitation. Lateral variability of saturation indices was examined with data collected from six sites on September 9, 2008, and showed minimum spatial differences (Figure 13), except for Bear Lake off North Beach , where iron minerals were more likely to form precipitate than in other locations within the lake. At all six sites on that date, aragonite, calcite, dolomite (disordered and ordered), hydroxyapatite, and quartz were supersaturated and likely to form precipitate.

[7] In water between pH 4.3 and 8.3, the CO2 from the atmosphere is converted to HCO_3; while between pH 8.3 and 10.2, HCO_3 is being converted to CO_3; above pH 10.2, all carbon is essentially CO_3. Therefore, for $CaCO_3$ to precipitate, the pH needs to be above 8.3 to provide CO_3 for the chemical reaction.

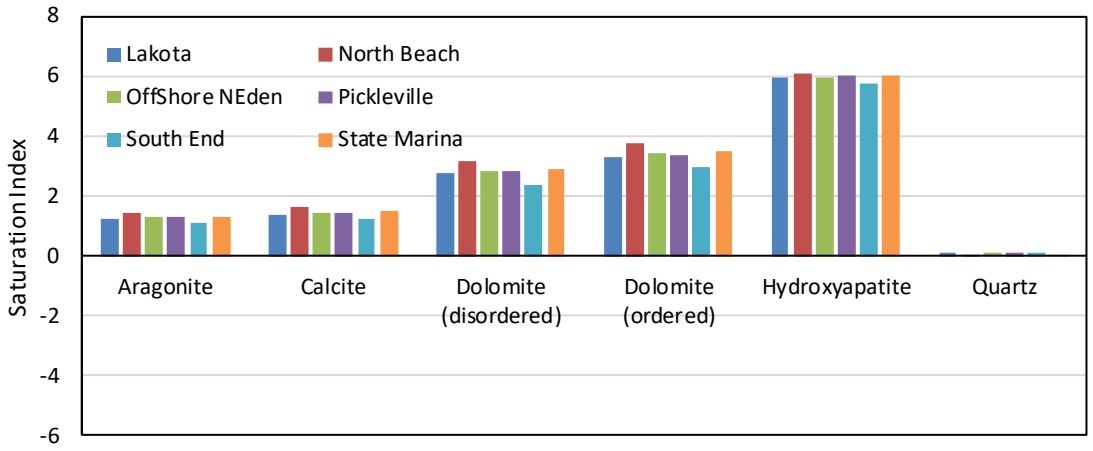


Figure 13. Saturation Index comparison showing lateral variability for selected minerals in Bear Lake at six sites[8] on September 9, 2008.

Bear Lake Offshore of North Eden Creek was the only site that had sufficient data for both vertical and temporal variation assessment. There was some vertical variation in saturation indices calculated for data collected at three depths in Bear Lake on September 24, 1993, most likely due to the decrease in measured pH over depth (Figure 14). At the surface (with a pH of 8.6), aragonite, calcite, dolomite (disordered and ordered), hydroxyapatite and quartz were all supersaturated and likely to precipitate, but at a depth of 35 m (with a pH of 8.4), aragonite, calcite, and dolomite (disordered) were sub-saturated and at a depth of 55 m (with a pH of 8.3), aragonite, calcite and dolomite (disordered or ordered) were sub-saturated, and only hydroxyapatite and quartz were all supersaturated and likely to precipitate.

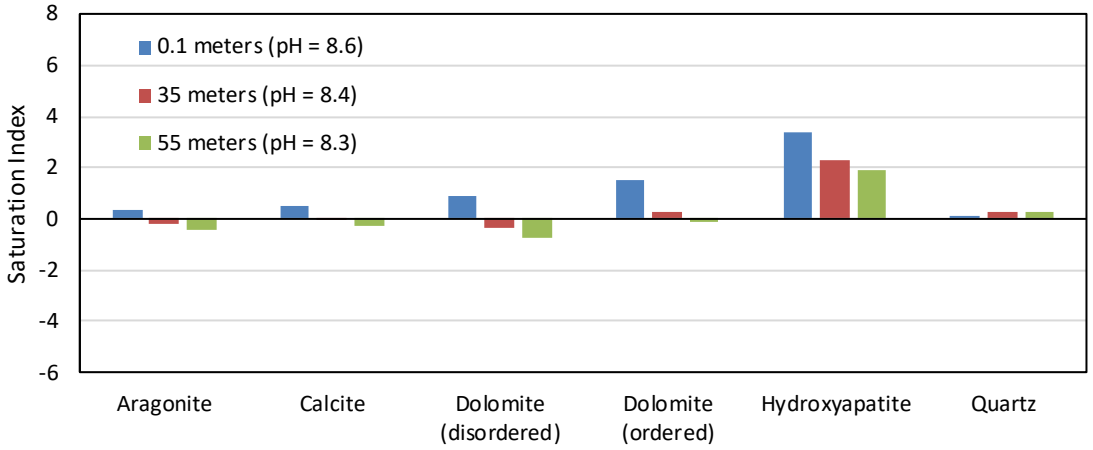


Figure 14. Saturation Index comparison showing vertical variability for selected minerals at Bear Lake Offshore North Eden Creek on September 24, 1993.

[8] Bear Lake, East-Southeast of Lakota Resort (Lakota), Bear Lake, Off North Beach (North Beach), Bear Lake, 1 Mile Offshore from North Eden Creek (Offshore NEden), Bear Lake, Near Pickleville (Pickleville), Bear Lake, South End 1 Mile Offshore (South End), and Bear Lake, Off State Marina (State Marina).

Sufficient data to be analyzed for saturation indices was collected for the Bear Lake Offshore of North Eden Creek site on ten dates from 1993 through 2005 (Figure 15). For all ten dates, aragonite, calcite, dolomite (disordered and ordered), hydroxyapatite, and quartz were supersaturated and likely to precipitate, except on July 1, 1993, when the pH was 8.1, and aragonite, calcite and dolomite (disordered and ordered) were sub-saturated. This low pH contrasted with the other nine pH measurements associated with the data, ranging from 8.6 to 8.74.

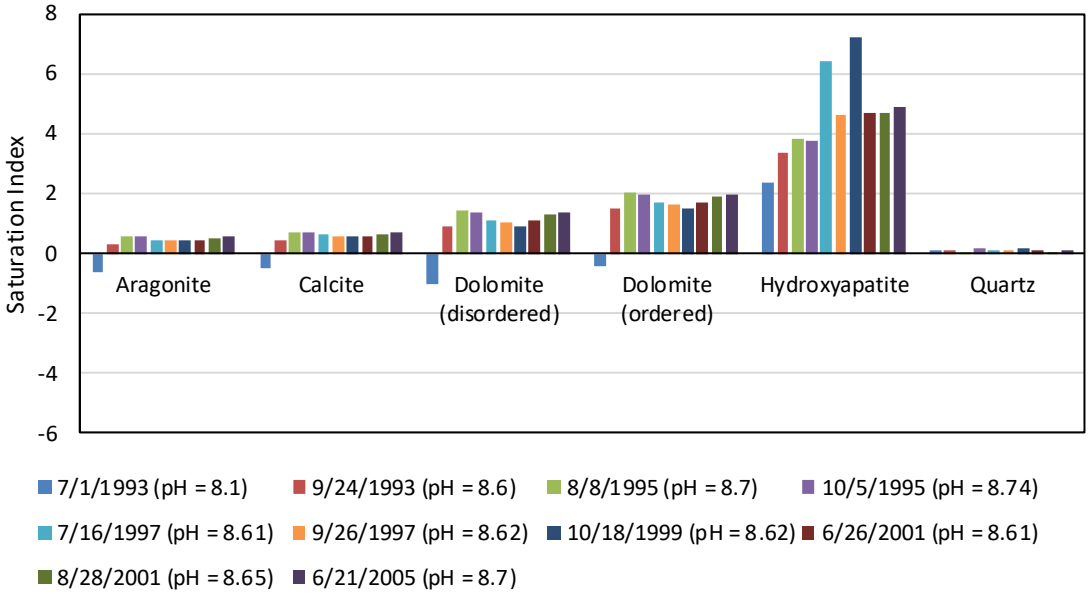


Figure 15. Saturation Index comparison showing inter-annual variability for selected minerals at Bear Lake Offshore North Eden Creek on ten separate sampling dates.

Saturation indices in Swan Creek, unlike Bear Lake, indicate that only hydroxyapatite and quartz were typically supersaturated. Exceptions were directly related to pH. Recall, the charge balance at these sites was generally higher than Bear Lake sites. While pH sensitivity is useful information, the dynamic conditions in Swan Creek (related to variable runoff and other, unquantified processes) make these results more difficult to interpret. Results for four dates at Swan Creek are shown in Figure 16, for completeness, but this small data set should be used with caution.

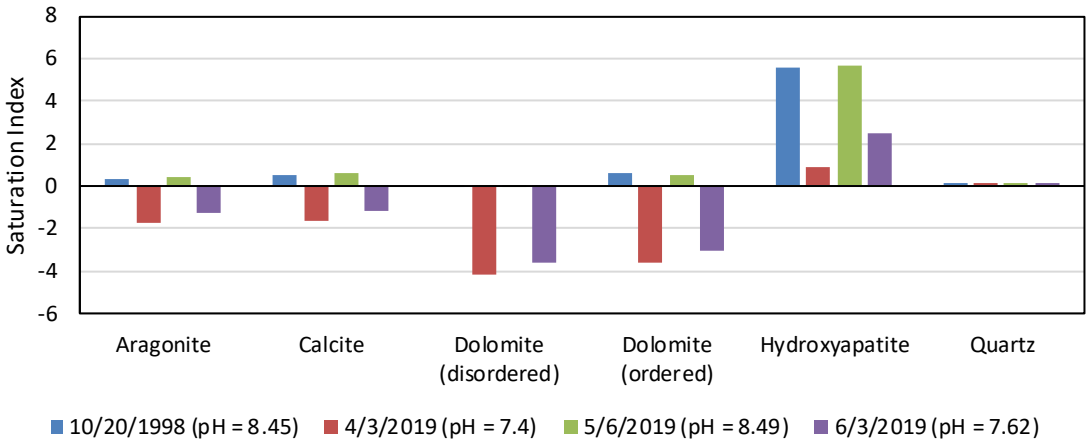


Figure 16. Saturation Index comparison showing inter-annual variability for selected minerals in Swan Creek on four separate sampling dates.

Based on the saturation indices estimated by MINTEQ, the mineral precipitation of aragonite, calcite, dolomite, hydroxyapatite, and quartz in Bear Lake requires a minimum pH of approximately 8.4 to 8.5 to occur. Mineral precipitation of hydroxyapatite and quartz in Bear Lake requires a minimum pH of approximately 8.0 to occur. Sensitivity analysis demonstrated that if the pH of the lake drops below 8.5, mineral precipitation would not consistently occur for aragonite, calcite, dolomite, and the result could be a change in mineral precipitation frequency and magnitude. There have been times when Bear Lake falls below a pH of 8.5 (e.g., winter and high spring runoff (or diversion) periods (see Figure 12), but summer and early fall conditions generally produce higher pH conditions, particularly in recent years, as the Bear Lake stratifies (both seasonally and within the epilimnion) and experiences seasonal primary production (which can further increase pH). This elevated pH increases mineral precipitation, and algal cells can act as nucleation sites, effectively increasing removal of nutrients and algae from the water column. Important in this process is that mineralization is not readily reversed, i.e., if pH decreases, these solid forms do not readily return to solution.

5.2.3. Particulate Studies

Limited surface samples collected in 2019 in Bear Lake (Causeway and State Marina) and Swan Creek were assessed to quantify particulate matter by size and settling rates, and composition. Settling rates determine how fast particles settle out of the water column, or portions of the water column (e.g., photic zone, epilimnion under stratified conditions). The composition of the particles (in terms of particulate nitrogen (PN), particulate phosphorus (PP), particulate inorganic phosphorus (PIP), and particulate carbon (PC)) can be used to determine the nutrient content and organic matter content.

5.2.3.1. Particle Size Distribution and Settling Rates

Particle size distribution and settling rates were measured by Watercourse using a Laser In-Situ Scattering and Transmissometry (LISST) instrument developed by Sequoia Scientific, Inc. (2005). The LISST measured particle size ranging from 2.5 microns to 500 microns using laser diffraction. Though particle size distribution was determined for the sample at Bear Lake off Marina, concentrations were too low to determine settling

rates. Concentrations at State Marina ranged from below the detection limit to 0.35 µL/L. This finding does not translate into a paucity of particles settling in Bear Lake. The shoreline site at the marina was a surface sample and as such was subject to wave action, interaction with the breakwater, and represents near surface near shore concentrations. Waves and shoreline interaction can break up crystal formation, and as particles settle in deeper water they can increase in size (and, in theory, settling rate). Deeper, mid-lake samples may have provided a more representative sample. Sample waters from the State Marina, viewed via microscopy, indicated crystals within the water column of Bear Lake (Figure 17).

Figure 17. Microscopy sample with crystals visible.

Swan Creek particle sizes were below the detection limit of the equipment and thus no settling rates were available. Being a spring, this is not unexpected. Test results for Swan Creek are not presented herein.

Two of the three Causeway samples provided sufficient material to determine particle size distribution. Concentrations at the Causeway were higher than Bear Lake off Marina, ranging from 0.02 µL/L to 5.7 µL/L and settling rates ranged from 0.2 cm/s to 2.7 cm/s. The increase in particulate concentration between Bear Lake off State Marina (Bear) and Bear Lake off North Beach (Causeway) indicates the influence of Bear River water on Bear Lake near the interface between Bear River, Dingle Marsh, Mud Lake, and Bear Lake.

5.2.3.2. Particulate Organic Matter: Stoichiometry

Organic matter is composed of approximately 35 to 50 percent carbon, 7.0 to 9.0 percent nitrogen, and 0.05 to 1.5 percent phosphorus (other major elements include oxygen and hydrogen) by concentration (Bowie *et al*., 1985). This stoichiometry can be used to estimate particulate organic matter (POM) for the sampled study sites. Particulate nitrogen (PN), particulate carbon (PC), particulate phosphorus (PP), and particulate inorganic phosphorus (PIP) sampling indicated that concentrations at the Causeway were higher than at the State Marina (Table 9). Overall, PN, PC, PP, and PIP concentrations at

the Causeway increased from April through June but remained relatively stable at State Marina.

Table 9. Particulate nitrogen, particulate carbon, particulate phosphorus, and particulate inorganic phosphorus concentrations (mg/L) in Bear Lake at Causeway (Causeway), Bear Lake Off State Marina (State), and Swan Creek (Swan) in April, May, and June of 2019.

Sampling Site	Particulate Nitrogen (mg/L)			Particulate Carbon (mg/L)			Particulate Phosphorus (mg/L)			Particulate Inorganic Phosphorus (mg/L)		
	Apr	May	Jun	Apr	May	Jun	Apr	May	Jun	Apr	May	Jun
Causeway	0.048	0.148	0.253	0.388	1.590	2.330	0.008	0.022	0.035	0.004	0.015	0.025
State	0.026	0.026	0.026	0.097	0.171	0.175	0.002	0.002	0.002	0.002	0.002	0.002
Swan	0.026	0.026	0.026	0.063	0.063	0.112	0.002	0.002	0.003	0.002	0.002	0.003

Using values in Table 9 and a particulate nitrogen, carbon, and inorganic phosphorus fractions of 0.072, 0.45, and 0.01, respectively, average particulate organic matter (POM) concentrations were determined for the four sampling locations. While these results represent a small sample set (too small for a loading assessment), the values suggest that Bear Lake and Swan Creek have consistently low POM, while the Causeway (upper Bear River diversions from Stewart Dam) has notable concentrations.

Table 10. Estimated particulate organic matter concentration based on particulate nitrogen, particulate carbon, and particulate inorganic phosphorus concentrations (mg/L) in Bear Lake at Causeway (Causeway), Bear Lake Off State Marina (State), and Swan Creek (Swan) in April, May, and June of 2019.

	POM = f(PN) (mg/L)	POM = f(PC) (mg/L)	POM = f(PIP) (mg/L)
Sampling Site	Apr	May	Jun
Causeway	0.64	2.36	3.73
State	0.26	0.31	0.32
Swan	0.23	0.23	0.30

6. Conclusion and Next Steps

The studies discussed above present a preliminary assessment of the historical and existing water quality conditions of Bear Lake, the Bear River upstream and downstream of Bear Lake and tributaries to the river and other influences within the watershed. Products of this study included a literature compilation, the development of a database of available water quality data, MINTEQ model and model files. A summary of key findings and outcomes are outlined below.

6.1. Conclusions

This report evaluates the water quality conditions of Bear Lake, and finds that its blue color results from its unique chemistry and oligotrophic state with low nutrients and primary production.

Principal water quality concerns relate to maintaining the:

- Carbonate chemistry conditions within Bear Lake. Specifically, retaining an environment wherein pH is sufficient that mineral precipitation continues to be a dominant condition. Mineral precipitation plays multiple roles, including:
    - Sequestering nutrients in persistent mineral form (i.e., removing nutrients from the water column).
    - Sequestering and settling algae from the water column, keeping primary production low (mineral precipitation probably also plays a similar role for organic matter in the lake).
    - Promoting light limitation to limit primary production.
    - Creating the unique blue color of Bear Lake.
- Oligotrophic state of the lake for the long-term with regards to nutrient inputs. Chemical precipitation is an important process in maintaining the trophic state of Bear Lake. However, other factors play a role, including the relatively modest nutrient inputs to the lake. The upper Bear River diversions introduce nitrogen and phosphorus, as well as organic matter[9]. Addition of nutrients can lead to eutrophication.

Bear Lake is unique in the ability to maintain an oligotrophic status, largely through the geologically derived alkaline source waters.

6.2. Next Steps

The current state of the basin suggests that a long-term monitoring program would be a prudent activity to assess potential changes into the future, i.e., changes in development or anthropogenic activities in the basin; modifications to current operations of diversions from and to the Bear River; alterations in upstream Bear River water quality; climate change, invasive species, or other modifications or activities that could impact the characteristics of the lake.

There has been considerable data collected over the past decades that represents a broad baseline to compare future conditions. The principal recommendation for future monitoring is that local resource agencies and entities assess available resources and identify a baseline program that monitors water quality at an appropriate frequency (e.g., every 3 to 5 years) at selected sites and depths that are representative of the lake, its inflows, and outflows. The goal is to collect data on an ongoing basis to assess anomalous short-term deviations from the past and current state of the lake and to assess long-term trends (e.g., decadal) to capture cumulative changes. Maintenance of existing programs (hydrology, meteorology, water quality) is important to consider in the design and implementation of a long-term monitoring program. Basic elements of such a program include:

[9] Diversions have also changed the chemistry of lake waters through dilution from a high to a low magnesium-to-calcium ratio (Mg:Ca). This impact appears to have modified the form of the precipitate from aragonite to high-Mg calcite (Dean *et al*., 2007). However, the overall ability of the lake to produce large amounts of carbonate minerals does not appear to have changed (Dean *et al*., 2009).

- Hydrology (inflows and outflows from the lake, lake water surface elevation, etc.)
- Meteorology (air temperature, wind speed and direction, precipitation, etc.)
- Physical, chemical, and biological water quality conditions (water temperature, dissolved oxygen, and pH, turbidity, conductance, nitrogen and phosphorus species, chlorophyll-*a* and algae, and major ions, including total dissolved carbonate, bicarbonate, calcium, and magnesium)

Frequency, location, and depth of sampling will vary among monitoring parameters and constituents. Resources to collect and analyze this data, as well as provide quality assurance and data management are necessary. Finally, data interpretation, appropriate metric development to track Bear Lake conditions through time (e.g. calculation of trophic state) and creating pathways to adapt the program in response to new information are important elements of a successful long-term management program.

Other activities that would lend insight to Bear Lake water quality include groundwater studies to quantify the relationship of the lake with the groundwater system, studies to quantify sedimentation and mineral precipitation rates, studies to explore algae as nucleation sites for precipitates, and ongoing MINTEQ modeling to complement the existing or future monitoring program.

Ongoing monitoring activities can be developed through local stakeholders and agency groups to track conditions at Bear Lake into the future to identify changes and seek remedial actions to ensure the water quality benefits of Bear Lake are protected.

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Appendix A. Data

This appendix contains a summary of the physical, nutrient, chlorophyll-*a*, and major ion data collected by the various entities within Bear Lake and its tributaries.

A.1. AWQMS

The Utah Division of Water Quality's Ambient Water Quality Monitoring System (AWQMS) Database is maintained by the Utah Division of Water quality. The AWQMS data was collected by various agencies for various purposes. Data is accessible in electronic format online to those who have obtained an account to the online Utah AWQMS Portal system. Account creation requires the completion of a User Account Request Form (providing a personal name, an organization name, an address, a valid email address, and the purpose and/or usage of data).

A.2. Watercourse Engineering, Inc. (PacifiCorp)

The dataset compiled by Watercourse Engineering, Inc. (WCE) for PacifiCorp in 2019 was collected by RedFish Environmental LLC to fill in some gaps in the existing datasets available for Bear Lake and its watershed. The dataset presented in Table B-2 below is maintained by WCE and is available by request in electronic format.

A.3. USGS

The USGS vertical profile and meteorological dataset was collected by the U.S. Geological Survey (USGS) in cooperation with Bear Lake Watch, PacifiCorp, Utah Department of Environmental Quality and Idaho Department of Environmental Quality. This data is accessible freely online in electronic format through the USGS National Water Information System (NWIS).

A.4. Western Regional Climate Center

Otter Creek – The Otter Creek meteorological dataset was collected by the Remote Automated Weather Stations (RAWS) system. The Otter Creek data is accessible in electronic format, for a price, through the Western Regional Climate Center (WRCC).

A.5. Ecosystems Research Institute (PacifiCorp)

The ERI dataset was collected by Ecosystems Research Institute (ERI) for PacifiCorp and the Bear Lake Regional Commission. The data was collected to provide water quality data pertaining to Bear Lake.

A.6. Other Data

The results from the MINTEQ and LISST analyses are available upon request.

Appendix B. Watercourse Sampling Plan & Summary

In 2019, water samples were collected from Bear Lake and Swan Creek. Samples were gathered in April, May and June and analyzed for general water quality constituents as well as major ion concentrations and particulate concentrations. Physical measurements were made at the time of each sample collection and additional water samples were collected for settling rate and particle size analysis. Three laboratories were employed for analysis: Ecosystems Research Institute, ChemTech-Ford Laboratories and Chesapeake Bay Laboratory. Field work was carried out by RedFish Environmental LLC (RedFish). Settling rate and particle size analysis was carried out by Watercourse Engineering, Inc (Watercourse).

B.1. Introduction

As part of the effort to understand the limnology of Bear Lake, located in Utah and Idaho states, and provide data which is not present in the existing Bear Lake historical dataset, samples were collected in 2019 at three locations: (1) Bear Lake at the marina, (2) Bear Lake downstream of the Causeway Dam and (3) Swan Creek below the spring head. Samples were collected in April, May and June and were analyzed for multiple parameters at three laboratories. Physical measurements were made at the time of sample collection and additional water samples were collected for settling rate and particle size analysis carried out by Watercourse.

This document contains details of the field crew, laboratory selection, laboratory parameters and limits, sampling dates and times, field measurements, and laboratory data.

B.2. Field Crew

The field crew selected for the 2019 Bear Lake sampling was RedFish. Once Watercourse provided a project requirement summary, including desired site list, sampling frequency and required parameters, RedFish determined bottle lists, sampling dates, and site visit logistics for the 2019 sampling, as well as assisted with the selection of appropriate, local laboratories for analysis for samples. RedFish carried out all sampling for this project, using their internal sampling SOPs for general water quality and major ion sampling, as well as shipped or delivered samples to the appropriate laboratories using approved sample preservation methods and COCs. The primary project contact at RedFish was Justin Barker.

B.3. Laboratory Details

Several laboratories were considered for the analysis of the 2019 Bear Lake sampling project. Laboratory criteria included method detection limits and reporting limits that were appropriate for the project, short turnaround time, and expertise in the analysis of interest. Ease of sample delivery by the field crew was also considered. Three laboratories were selected to carry out the required analysis for the project: Ecosystems Research Institute (ERI), ChemTech-Ford Laboratories (ChemTech), and Chesapeake Bay Laboratory (CBL). Settling rate and particulate size analysis were performed by Watercourse in house. Parameters analyzed by each laboratory, as well as methods, method detection limits (MDLs) and reporting limits (RLs) are presented below.

B.4. Sampling Details

2019 Watercourse Bear Lake Sampling occurred once a month in April, May, and June. Sampling dates, times and physical measurements collected in 2019 for all four sites are presented in Table B-2, as part of the 2019 Watercourse Bear Lake data set.

Table B-1. Laboratory methods, MDLs and RLs. MDL and RL have units of mg/l unless otherwise noted.

		ERI			ChemTech			CBL		
Constituent Name	**Constituent ID**	**Method**	**MDL**	**RL**	**Method**	**MDL**	**RL**	**Method**	**MDL**	**RL**
Ammonia	NH3	EPA 350.3	0.007	0.014	-	-	-	-	-	-
Nitrite	NO2	EPA 354.1	0.0002	0.0003	-	-	-	-	-	-
Nitrate+Nitrite	NO3+NO2	EPA 353.3	0.003	0.005	-	-	-	-	-	-
Orthophosphate	PO4	EPA 365.2	0.001	0.002	-	-	-	-	-	-
Total Phosphorus	TP	EPA 365.2	0.002	0.004	-	-	-	-	-	-
pH[1]	-	-	-	-	SM 4500 H-B	0.1	0.1	-	-	-
Total Kjeldahl Nitrogen	TKN	-	-	-	SM 4500 Norg	0.6	1.0	-	-	-
Dissolved Organic Carbon	DOC	-	-	-	SM 5310 C	0.2	0.5	-	-	-
Total Organic Carbon	TOC	-	-	-	SM 5310 C	0.2	0.5	-	-	-
Total Suspended Solids	TSS	-	-	-	SM 2540 D	3	4	-	-	-
Total Volatile Solids[2]	TVS	-	-	-	SM 2540 E	0.1	0.1	-	-	-
Total Dissolved Solids	TDS	-	-	-	SM 2540 D	20	20	-	-	-
Bicarbonate	HCO3	-	-	-	SM 2320 B	0.2	1.0	-	-	-
Carbonate	CO3	-	-	-	SM 2320 B	0.2	1.0	-	-	-
Turbidity[3]	Turb	-	-	-	EPA 180.1	0.01	0.02	-	-	-
Calcium	Ca	-	-	-	EPA 200.7	0.005	0.2	-	-	-
Magnesium	Mg	-	-	-	EPA 200.7	0.01	0.2	-	-	-
Sodium	Na	-	-	-	EPA 200.7	0.01	0.5	-	-	-
Potassium	K	-	-	-	EPA 200.7	0.04	0.5	-	-	-
Sulfate	SO4	-	-	-	EPA 300.0	0.2	1.0	-	-	-
Chloride	Cl	-	-	-	EPA 300.0	0.07	1.0	-	-	-
Silica	SiO2	-	-	-	EPA 200.7	0.05	0.1	-	-	-
Fluoride	F	-	-	-	EPA 300.0	0.02	0.1	-	-	-
Iron	Fe	-	-	-	EPA 200.7	0.005	0.02	-	-	-
Manganese	Mn	-	-	-	EPA 200.7	0.0002	0.005	-	-	-

		ERI			ChemTech			CBL		
Constituent Name	**Constituent ID**	**Method**	**MDL**	**RL**	**Method**	**MDL**	**RL**	**Method**	**MDL**	**RL**
Arsenic	As	-	-	-	EPA 200.8	0.00008	0.0005	-	-	-
Boron	B	-	-	-	EPA 200.7	0.01	0.05	-	-	-
Copper	Cu	-	-	-	EPA 200.8	0.00003	0.0010	-	-	-
Zinc	Zn	-	-	-	EPA 200.7	0.005	0.01	-	-	-
Particulate Carbon	PC	-	-	-	-	-	-	EPA 440.0	0.0633	0.1899
Particulate Inorganic Phosphorus	PIP	-	-	-	-	-	-	EPA 365.1	0.0021	0.0063
Particulate Phosphorus	PP	-	-	-	-	-	-	EPA 365.1, ASPILA	0.0021	0.0063
Particulate Nitrogen	PN	-	-	-	-	-	-	EPA 440.0	0.0263	0.0789

[1] – pH is reported in pH units
[2] – TVS is reported as a percentage of TSS.
[3] – Turbidity is reported in NTU.

Table B-2. 2019 Watercourse Bear Lake data set.

		Bear Lake (marina)			Causeway (north beach)			Swan Creek		
Date (2019)		**4/3**	**5/6**	**6/3**	**4/3**	**5/6**	**6/3**	**4/3**	**5/6**	**6/3**
Time (hh:mm)		**9:20**	**9:50**	**9:00**	**7:45**	**8:40**	**7:50**	**8:45**	**9:30**	**8:30**
Tw	C	6.5	7.9	11.9	4.5	13.3	15.5	8.1	6.9	6.3
DO	mg/l	11.64	10.13	9.13	13.88	8.97	7.14	9.21	9.42	9.61
Specific Cond.	uS/cm	658	674	678	615	700	638	365	373	308
pH	-	8.34	8.69	8.6	7.75	8.43	7.94	7.4	8.49	7.62
Ammonia	mg/l	0.0147	0.0136	0.015	0.0179	0.0192	0.0189	0.0123	0.0128	0.0143
NO2	mg/l	0.000828	0.000431	<0.0003	0.00132	0.000643	0.00125	<0.0003	<0.0003	<0.0003
NO3+NO2	mg/l	0.0272	0.00718	<0.005	0.0668	<0.005	0.012	0.22	0.263	0.244
PO4	mg/l	<0.002	0.00309	<0.002	0.00259	0.00509	0.00704	0.0165	0.0151	0.0206
TP	mg/l	0.00552	0.00826	0.0111	0.0194	0.0327	0.0405	0.0169	0.017	0.0236
pH	-	8.6	8.5	8.5	8.4	8.5	8.3	8.1	7.7	7.8
TKN	mg/l	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
DOC	mg/l	3.7	2.3	3.2	2.6	4	5.6	1.4	<0.5	1.7
TOC	mg/l	3.4	3.5	3.1	2.5	5.5	5.8	0.5	1.2	1.4
TSS	mg/l	<4.0	<4.0	<4.0	5	18	32	<4.0	<4.0	9
TVS	%	<0.1	60	40	<0.1	41.7	<0.1	<0.1	33.3	66.7
TDS	mg/l	348	340	340	328	408	372	208	200	156
HCO3	mg/l	232	234	228	209	226	226	185	178	151
CO3	mg/l	<1.0	3.5	2.3	<1.0	3.4	<1.0	<1.0	<1.0	<1.0
Turb	NTU	0.53	0.97	1.1	5.3	15	32	0.04	1	4
Ca	mg/l	30.4	32.5	33	58.6	52.4	60.3	44.6	51.8	49.8
Mg	mg/l	43.7	46.2	43.2	32.9	33.1	27.1	16.8	10.8	8.5
Na	mg/l	38.7	39.3	34.6	35	40.8	31.6	4.3	5.5	3.2
K	mg/l	4.2	4.3	4	2.6	3.9	3.2	0.5	<0.5	0.7
SO4	mg/l	68	69	69	69	79	58	4	3	2
Cl	mg/l	45	46	46	39	51	39	8	15	6
SIO2	mg/l	8.8	10.2	8.6	8.7	10.4	14.4	6.5	6.3	7.2
F	mg/l	0.2	0.2	0.2	0.2	0.2	0.2	<0.1	<0.1	<0.1
Fe	mg/l	0.03	<0.02	<0.02	0.14	0.25	0.47	0.03	0.03	0.16
Mn	mg/l	<0.005	<0.005	<0.005	0.011	0.024	0.039	<0.005	<0.005	<0.005
As	mg/l	0.0018	0.0019	0.0022	0.0011	0.0018	0.0017	<0.0005	<0.0005	<0.0005
B	mg/l	0.06	0.08	0.07	<0.05	0.08	<0.05	<0.05	<0.05	<0.05
Cu	mg/l	<0.001	<0.001	<0.0010	<0.001	0.0012	0.0011	0.0024	<0.001	<0.0010
Zn	mg/l	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
PC	mg/l	0.0972	0.171	0.175	0.388	1.59	2.33	0.0633	0.0633	0.112
PN	mg/l	0.0263	0.0263	0.0263	0.0478	0.148	0.253	0.0263	0.0263	0.0263
PP	mg/l	0.0021	0.0021	0.0021	0.0081	0.0222	0.0350	0.0021	0.0021	0.0030
PIP	mg/l	0.0021	0.0021	0.0021	0.004	0.0147	0.0248	0.0021	0.0021	0.0248