APPENDIX E to the 2023 Cutler 5-year Report

2018 Water Quality Analysis and Summary Report for Cutler Reservoir, Utah

MAY 2020

PREPARED FOR

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2018 WATER QUALITY ANALYSIS AND SUMMARY REPORT FOR CUTLER RESERVOIR, UTAH

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EXECUTIVE SUMMARY

The water quality monitoring dataset collected by PacifiCorp around Cutler Reservoir over the current license period (1994-present) covers a variety of tributaries and reservoirs as well as a variety of physical and chemical water quality constituents. Water quality monitoring sites comprised of the Logan River, Little Bear River, Spring Creek, Cutler Reservoir south of Swift Slough, Cutler Reservoir at Benson Marina, Bear River at Summit Creek, Cutler Reservoir at Highway 23, and Bear River below dam sites are shown on Figure 2. Chemical parameters include nutrient concentrations of phosphorus (total and orthophosphate) and nitrogen as NO_3, NO_2, NH_3, and total Kjeldahl nitrogen (TKN). Physical parameters include temperature, total suspended solids (TSS), specific conductivity, pH, and dissolved oxygen (DO) values. The samples were collected during five hydroperiods (1996–1998, 2000–2003, 2008, 2013, and 2018). Per the established study and reporting timeline, the data that was collected during the 2018 hydroperiod will be included in the 2023 Cutler Resource Management Plan (RMP) 5-Yr Report. Water quality monitoring and resultant data collection is required at 5-year intervals; reporting of those results is included in the subsequent Cutler RMP 5-Yr Report, resulting in 2018 water quality data being included in the 2023 report.

The five hydroperiods are characterized by varied hydrologic conditions based on water discharged from Cutler Reservoir to the Bear River during those periods. The 1996–1998 hydroperiod was characterized by wet conditions and high flows; 2000–2003 was characterized by dry conditions with low flows; and 2008 was the driest of these moderate flow years. The 2013 period was characterized by low flows with season averages between 1 percent and 69 percent of the previous hydroperiods. The 2018 period was one of the driest ever recorded. As noted, future sampling will continue in the next 5-year interval with a repeat of quarterly sampling in 2023.

Differences in water quality sampling results between the five hydroperiods are most likely related to the marked differences in hydrologic conditions. Data collected between 2013 and 2018 generally indicate for 2018 cooler temperatures, lower organic nitrogen, and lower turbidity with higher levels of bacteria, inorganic nitrogen, total suspended solids, and phosphorus. It should be noted however, that phosphorus levels collected in 2013 (and reported in Appendix G of the 2018 Cutler RMP 5-Yr Report) raise questions because the levels are considerably lower than those measured in 2018 and the preceding hydroperiods. Water quality varied by season and hydroperiod for most parameters analyzed across hydroperiods; however, this variation appears to be site-specific, with different patterns emerging in the Bear River and Cutler Reservoir portion of the system (the northern section) compared to the southern tributaries.

Data collected over the various hydroperiods between 1996 and 2018 indicate that water quality in the southern tributaries, specifically Spring Creek and the Little Bear River, have some influence on water quality throughout Cutler Reservoir. Spring Creek continues to have significantly higher bacteria concentrations compared to the other sampling locations in the watershed. Water quality in the southern (south of Benson Marina) and northern (north of Benson Marina) sections of the reservoir remains markedly different, with the south having higher bacteria and nutrient concentrations than the northern monitoring sites.

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CONTENTS

Appendices

Figures

Tables

INTRODUCTION

Cutler Reservoir and Dam are in Cache Valley, Utah, 6 miles west of Logan. The reservoir is at an approximate elevation of 4,407 feet. Cutler Dam impounds water from the Bear River, as well as from the Logan River, Little Bear River, Spring Creek, and several small tributaries and sloughs. Wheelon Dam was constructed on the Bear River before 1896 in the Narrows upstream of the present-day Cutler Dam. Wheelon Dam was used to convey irrigation water to support sugar beet production and to produce power for the U&I Sugar Plant. Cutler Dam was constructed approximately 1 mile downstream in 1927 by a predecessor company to PacifiCorp. Doing business in Utah as Rocky Mountain Power, PacifiCorp operates Cutler Dam and Reservoir (Project) to provide water for agricultural use, flood control, and power generation. Wheelon Dam was inundated when Cutler Reservoir filled shortly after completion of Cutler Dam, and the Wheelon irrigation diversions were transferred to Cutler.

The Federal Energy Regulatory Commission (FERC) license for Cutler Dam as a hydropower facility was renewed in 1994 and amended with a supplement in 2002. The amended license included the establishment of an operational elevation range (conservation pool) at which the reservoir would be maintained to support fish and wildlife in the reservoir, and development of the *Cutler Hydro Project No. 2420 Resource Management Plan* (hereafter referred to as the Cutler RMP) (PacifiCorp 1995). The Cutler RMP outlines specific requirements for wildlife habitat improvements, agricultural lease modifications, buffer establishment, bank stabilization, recreation site improvements, and other natural resources projects and monitoring. Cutler Reservoir has a maximum storage capacity of 13,200 acre-feet of water at reservoir elevation 4,407.5 ft-msl, with a large surface area and shallow depth (averaging 3 feet deep), resulting in a Project of approximately 10,000 acres of open water and associated wetlands and uplands. The reservoir is operated in run-of-river mode such that water surface elevation is maintained between 4,406.25 and 4,407.75 feet from March 1 through December 1, and from 4,405.50 to 4,407.75 feet from December 2 through February 28. These ranges are required by PacifiCorp's FERC license but can be temporarily suspended to provide critical maintenance or to attend to an emergency that would require a reservoir drawdown.

The Project watershed encompasses 2,201 square miles and is within the larger 6,900-square-mile Bear River basin. The Bear River basin drains portions of northeastern Utah, southwestern Wyoming, southeastern Idaho, and northern Utah, and terminates in the Great Salt Lake. The Bear River is the largest river in North American that does not drain to an ocean (Bear River Watershed Information System 2019). The watershed consists of a stream network that extends 2,022 linear miles, 16 percent of which consists of ditches or canals. Steep terrain (with slopes as high as 85 degrees) characterizes the mountains surrounding the relatively flat Cache Valley, where soils are made up of alluvium and ancient Lake Bonneville lacustrine sediments. The dominant land use types in the Project watershed are forest and shrubland in the mountains, and agricultural land in the river valleys, including Cache Valley which surrounds the Project. The dominant crops include irrigated pasture, hay, alfalfa, and corn; all are used locally to feed cattle and dairy cows. Developed land uses also occupy a large portion of Cache Valley, especially along the U.S. Highway 89 corridor, and particularly concentrated around the city of Logan, Utah.

As required under Section 303(d) of the Clean Water Act, the Utah Division of Water Quality (DWQ) performed a total maximum daily load (TMDL) study of the Middle Bear River and Cutler Reservoir. In this study, Cutler Reservoir was identified as water quality–limited because of low dissolved oxygen (DO) levels from excess phosphorus loading to the rivers and reservoir from the surrounding watershed. The designated beneficial uses determined by DWQ for Cutler Reservoir are (DWQ 2018):

- Secondary contact recreation (2B)
- Warm-water game fish and their associated food chain (3B)
- Waterfowl and shorebirds and their associated food chains (3D)
- Agricultural water supply (4)

In 2002, the reservoir was found to be unsupportive of the warm-water game fish designated use (3B) as identified on Utah’s 2008 Integrated 303(d) list (DWQ 2010). Secondary contact recreation (2B) and agricultural water supply (4) beneficial uses were deemed to be fully supported in the reservoir in 2008 and are the same beneficial uses identified in the previous paragraph. However, the 2010 *Middle Bear River and Cutler Reservoir Total Maximum Daily Load* (TMDL) study identified that the recreational (2B) and the waterfowl and shorebirds (3D) beneficial uses in Cutler Reservoir may also be impaired based on narrative water quality criteria (DWQ 2010). This TMDL was developed by the DWQ and approved by the U.S. Environmental Protection Agency (EPA) in 2010 with nutrient reduction targets identified for point and non-point sources to the Cutler Reservoir and Middle Bear River (DWQ 2010).

PacifiCorp is actively working to improve wildlife habitat, water quality, and recreational uses on and around Cutler Reservoir through wetland mitigation, erosion control, grazing management, agricultural land management, and shoreline reclamation. As part of these efforts, and in compliance with the current FERC license, PacifiCorp monitors water quality at the confluence of several tributaries to Cutler Reservoir and in the reservoir quarterly, every 5 years. Water quality monitoring was conducted quarterly for the initial three-year hydroperiods 1996–1998 and 2000–2003; thereafter at 5-year intervals, in 2008, 2013, and again in 2018. Future monitoring will be repeated once more in 2023 leading up to the end of the current license period (2024). The data cover a wide range of watershed locations and a variety of physical and chemical water quality constituents.

In this report, water quality data collected during the fifth hydroperiod (2018) are summarized and compared spatially, seasonally, and by hydroperiod to the four previous hydroperiods (1996–1998, 2000–2003, 2008, and 2013). This report will be attached as an Appendix to the 2023 Cutler RMP 5-Year Report, which covers the period 2018-2022 and is planned for submittal to the FERC in March 2023. Additional information from the four previous hydroperiods is provided in the 2013 *Water Quality Analysis and Summary for Cutler Reservoir, Utah*, found as Appendix G (corrected) to the 2018 Cutler RMP 5-Yr Report (PacifiCorp 2018; corrected and re-submitted to FERC in April 2020).

WATER QUALITY DATA COLLECTION

SWCA Environmental Consultants (SWCA) collected water quality samples for PacifiCorp from January 2018 to December 2018. Seven sample trips were made in 2018: four baseflow samples (defined by at least 3 dry days prior), one fall storm sample, one spring storm sample, and one spring runoff sample. The following subsections describe the sampling methods that were used to collect samples, analyze them, and integrate temporal and spatial coverage of samples and results.

Sampling Methods

Water quality samples were collected from just below the water surface at each monitoring site. Where possible, most samples were collected from bridges or at bank edges using a bucket that was pre-rinsed multiple times. A HANNA® water quality tester was placed directly in the water to measure DO, turbidity, conductivity, temperature, and pH values. Water samples for laboratory analysis were collected in clean, unused sample containers that were provided by the laboratory and labeled prior to sampling. After samples were collected, they were immediately placed in an ice-filled cooler for transport to the laboratory. Samples were delivered to the laboratory within 8 hours of sampling and within sample holding times (APHA (2017).

Analytical Methods

Samples were analyzed by two different laboratories during the 2018 hydroperiod. American West Analytical Laboratory in Salt Lake City, Utah, was used for all nutrient samples throughout 2018. The Utah State Department of Health Unified Laboratory in Taylorsville, Utah, was used for all bacteria and chlorophyll *a* samples. Analyses for fecal coliform were not performed in 2018 because laboratory analysis standards shifted to *Escherichia coli* (*E. coli*). As a result, fecal coliform was removed from the Cutler Reservoir sampling plan in 2013, and fecal coliform prior to 2008 was converted to *E. coli* (see Bacteria section). All samples were analyzed using standard EPA and American Public Health Association (APHA) methods (EPA 1986) (Table 1). It is important to note that the expected precision of analytical results near the parameter reporting limit may require additional interpretation.

Table 1. Laboratory Methods for 2018 Water Quality Sample Analysis

Parameter	Analysis Type	Utah State Department of Health Unified Laboratory	American West Analytical Laboratory
Chlorophyll *a*	–	SM 10200	Not applicable (N/A)
Coliform, fecal	Total	N/A	N/A
Coliform, total	Total	SM 9223B	N/A
E. coli	Total	SM 9223B	N/A
Nitrogen, ammonia as N	Total	N/A	EPA Method No. 350.1
Nitrogen, nitrate (NO_3) as NO_3	Total	N/A	EPA Method No. 353.2
Nitrogen, nitrite (NO_2) as NO_2	Total	N/A	EPA Method No. 353.2
Phosphorus as P	Total	N/A	SM 4500-P-F
Phosphorus, orthophosphate as P	Dissolved	N/A	EPA Method No. 365.1
Solids, total dissolved (TDS)	Dissolved	N/A	SM 2540-C
Solids, total suspended (TSS)	Total	N/A	SM 2540-D
Total Kjeldahl nitrogen (TKN)	Total	N/A	EPA Method No. 351.2

Data Handling

Quality Assurance and Quality Control

The precision of the data was assessed to ensure data were of sufficient quality for purposes of this analysis. The precision, or reproducibility, of field samples and field sample duplicates (field sampling precision) was evaluated based on relative percent difference (RPD), as follows:

$$RPD = \frac{(D_1 - D_2)}{(D_1 + D_2)/2} \times 100$$

where D_1 is the first duplicate field sample value and D_2 is the second duplicate field sample value. For field duplicates, a calculated RPD of greater than ± 20 percent is deemed unacceptable, and the results could be excluded from analysis unless there are valid reasons to retain the results.

At least one duplicate sample was collected for quality assurance/quality control (QA/QC) purposes during each sampling event from 2000–2003, 2008, 2013, and 2018. In 2018, no duplicate samples were collected during the January sampling event due to an oversight. If a sample and sample duplicate had a difference of greater than 20 percent, the data were closely examined. In 2018, 104 non-detects were evident, including duplicate samples. Of these, there were 16 instances with RPD exceedances (of greater than 20 percent) but because of the low number of RPDs and the potential natural variability, these incidences were not excluded from further analyses.

Non-Detect Treatment

Several analytical results for total phosphorus, orthophosphate, ammonia, nitrate, nitrite, total Kjeldahl nitrogen (TKN), sediment, coliform, and chlorophyll *a* were identified as below detection limits. In such cases, a value of one-half the reporting limit was used in the data analysis. Using values of half the reporting limit is a common practice because values of zero may underestimate the true concentration, whereas values of the reporting limit itself may overestimate the true concentration. A summary of non-detect entries for data collected in 2018 is presented in Table 2.

Table 2. Summary of Non-detect Entries for Data Collected in 2018

Parameter	Number of Non-detects	Percentage of Dataset
Chlorophyll *a*	0	0%
Coliform, total	0	0%
E. coli	2	4%
Nitrogen, ammonia as N	23	48%
Nitrogen, nitrate as N	8	23%
Nitrogen, nitrite as N	11	17%
Phosphorus as P	6	13%
Phosphorus, orthophosphate as P	31	65%
Solids, total suspended (TSS)	1	2%
TDS	0	0%
Total Kjeldahl nitrogen (TKN)	22	46%

Treatment of Outliers

To identify non-representative data or outliers in the dataset, a threshold of ± three standard deviations from the mean was applied to all datasets collected by PacifiCorp to determine those data that should be excluded from the analysis. A threshold of ± three standard deviations is often applied to identify outliers in environmental data. Following this methodology, identified outliers from the previous hydroperiods were excluded from subsequent analyses. For 2018, no outliers were identified.

Seasonal Coverage

Water quality monitoring was completed in five hydroperiods: 1996–1998, 2000–2003, 2008, 2013, and 2018. In general, samples were collected quarterly; however, before 2008, samples were not collected during several additional sampling seasons that were added in 2008 to better assess water quality conditions at the Project (Table 3). Before 2008, coverage was generally better during winter, spring, and fall months. Physical water quality characteristics (e.g., DO, turbidity, temperature, conductivity, and pH concentrations) measured during all monitoring events for a particular season are assumed to be representative of season-specific watershed conditions.

Table 3. Water Quality Sampling Over Time

Hydroperiod	Year	Winter			Spring			Summer			Fall		
		Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.
1996–1998	1996												X
	1997	X			X						X		
	1998					X				X		X	
2000–2003	2000	X									X		
	2001			X			X						
	2003	X		X				X			X		
2008 (2008–2009)	2008					SR	BF			BF	BF		ST
	2009		BF										
2013	2013	BF				BF	SR			BF	ST	BF	
2018	2018		BF		BF	ST	SR			BF		ST	BF

Notes: X = sampled (likely during baseflow conditions); BF = baseflow; ST = storm; SR = spring runoff

Hydrologic Coverage

The Bear River-Cutler Reservoir hydrologic system is highly modified. Flow patterns observed in the Bear River are influenced by the many diversions and impoundments upstream of Cutler Reservoir. These structures reshape the hydrograph, decreasing the intensity and increasing the duration of spring runoff flows while extending summer flows (Figure 1). The hydrograph for Bear River in Figure 1 illustrates flows that are modified by the diversions, whereas the flows for the Logan River are essentially natural or unmodified.

During the 2018 hydroperiod, the Bear River represented most of the water flowing into Cutler Reservoir at 79 percent of the annual average inflow. The Logan River supplied 16 percent of the average annual flow to Cutler Reservoir, whereas the Little Bear River/Spring Creek supplied 5 percent. This analysis does not include all the tributary inputs; however, these three tributaries supply the vast majority of the flow to Cutler Reservoir. Discharge data from Cutler Reservoir to the Bear River are available during the 2018 hydroperiod; so are flow data collected by the U.S. Geological Survey along the Bear River near the Utah-Idaho state line. Hydrographs for each flow sampling location during the 2018 water quality hydroperiod are provided in Figure 1.

The water quality monitoring program established by PacifiCorp for the Project provides moderate distribution of water quality data across space and time. To better examine seasonal and temporal trends, 2013 and 2018 water quality sampling was also tied to hydrologic events (i.e., storm events). The resulting analyses are more easily compared across time and allow for a more nuanced understanding because water quality is largely dependent on water quantity (e.g., flow).

To maintain the quarterly sampling plan established by PacifiCorp, seasonal baseflow (defined by at least 3 dry days prior) samples were collected in the winter, spring, summer, and fall of 2018. A winter baseflow sample was collected on January 18, 2018. Spring baseflow samples (March 29, 2018) were collected prior to irrigation, and a summer baseflow sample (August 21, 2018) was collected during irrigation. A fall baseflow sample (November 16, 2018) was collected following peak irrigation. In addition, water quality samples were collected during a fall storm (October 4, 2018) that resulted in 0.48 inch of rainfall, as well as during the peak of spring melt runoff (May 10, 2018). Note that many of the tributaries are not gaged; therefore, runoff from these tributaries is not well represented in Figure 1.

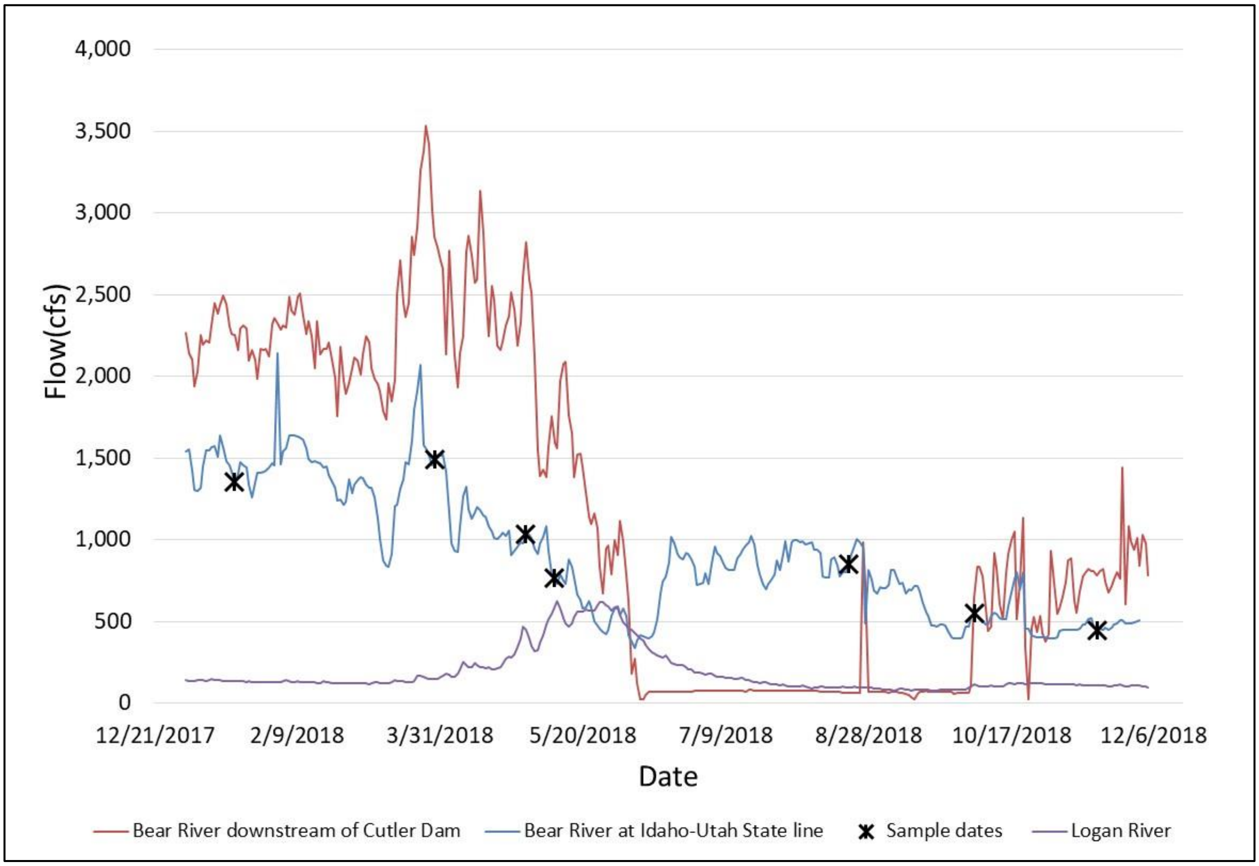

Figure 1. Bear River (below Cutler Dam and at the Idaho-Utah state line) and Logan River hydrograph for the 2018 calendar year with water quality sampling dates.

Spatial Coverage

In past hydroperiods, water quality samples were collected from Cutler Reservoir at Benson Marina, from four tributary sites entering the reservoir (Logan River, Little Bear River, Spring Creek, and Bear River), and from the Bear River downstream of Cutler Dam (Figure 2). In 2008, two additional reservoir monitoring sites were added: one in the north section of the reservoir (Cutler Reservoir at Highway 23) and one in the south section of the reservoir, above the confluence with Swift Slough (Cutler Reservoir at Swift Slough). The north section was added to assess the influence of the Bear River, whereas the south section was added to assess the influence of the southern tributaries on water quality in Cutler Reservoir.

Sampling at the original sites and the additional sites continued through 2013 and into 2018. All water quality monitoring sites are shown on Figure 2 and are listed in Table 4.

Table 4. Surface Water Monitoring Sites around Cutler Reservoir

Site ID	Site Name	Monitoring Site Key	Segment Location
4901980	Bear River below Cutler Reservoir at UP&L Bridge	Bear River below dam	Cutler Reservoir outflow
4903400	Bear River below confluence with Summit Creek	Bear River at Summit Creek	Bear River
4904900	Spring Creek at CR 376 (Mendon) Crossing	Spring Creek	Southern tributary
4905000	Little Bear River at CR376 (Mendon) Crossing	Little Bear River	Southern tributary
4905040	Logan River above confluence with Little Bear River at CR376 Crossing	Logan River	Southern tributary
5901000	Cutler Reservoir at Benson Marina Bridge	Cutler Reservoir at Benson Marina	Southern reservoir
5900980	Cutler Reservoir at Highway 23 Bridge	Cutler Reservoir at Highway 23	Northern reservoir
PacifiCorp1	Cutler Reservoir south of Swift Slough near island	Cutler Reservoir at Swift Slough	Southern reservoir

Note: Numbered sites correspond to Utah Department of Environmental Quality monitoring sites.

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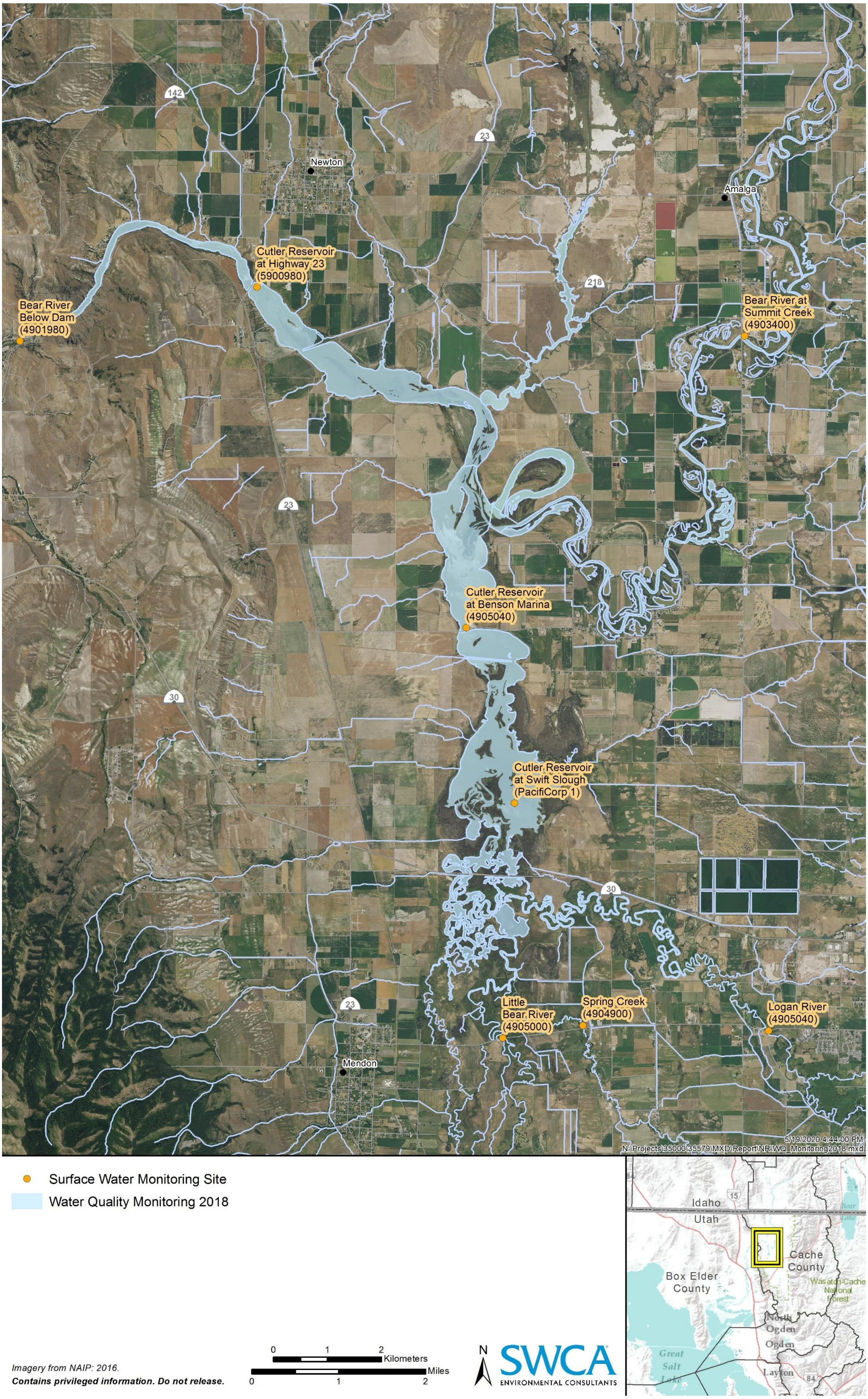

Figure 2. Cutler Reservoir surface water monitoring sites.

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RESERVOIR HYDROLOGY

PacifiCorp water quality monitoring data were collected over a range of hydrologic conditions in the Project watershed. Notable changes in the hydrologic conditions of Cutler Reservoir are evident in the flows from the reservoir throughout the entire monitoring effort (1996–2018) as compared to flow (i.e., the volume) during each water year (Table 5). Comparison between low (> 80 percentile), average (20–80 percentile), and high (< 20 percentile) years based on average annual flows shows that 2001–2003 was a low flow period; 1996, 2000, and 2004–2018 were mostly average; and 1997–1999, 2011, and 2017 were high. Flows increase in the spring by an average of 75 percent because of runoff before decreasing in the summer and fall due to a receding hydrograph and irrigation withdrawals. Annual precipitation values collected at the Cutler Dam range from 9.39 inches in 2008 to 30.08 inches in 2005 (see Table 5) (Utah State University Climate Center 2018) and explain approximately 36 percent of the variability in annual reservoir releases. Precipitation in 2018 tied the second lowest annual precipitation period.

Table 5. Average Annual Precipitation and Cutler Reservoir Releases by Water Year and Season

Water Year	Annual Precipitation (inches)†	Average Annual (cfs)	Fall (cfs)	Spring (cfs)	Summer (cfs)	Winter (cfs)	1996–2018 Flow Release Percentile (high < 20%; average 20 -80%; low > 80%)
1996	12.70	1,104	456	2,360	785	817	42%
1997	25.75	2,262	965	3,796	2,309	1,977	16%
1998	17.89	2,507	1,947	3,961	1,903	2,218	5%
1999	15.30	2,290	1,923	3,410	1,691	2,135	11%
2000	11.56	1,012	1,099	1,191	68	1,688	53%
2001	11.34	407	288	703	44	594	84%
2002	15.65	369	184	701	48	545	89%
2003	10.63	345	217	580	31	550	95%
2004	17.18	418	230	850	114	478	79%
2005	30.08	1,535	540	3,506	1,057	1,037	26%
2006	20.15	1,521	774	3,548	397	1,365	32%
2007	11.96	807	822	1,241	31	1,135	58%
2008	9.39	699	417	1,123	414	841	68%
2009	10.36	1,230	554	2,388	981	995	37%
2010	12.49	721	555	1,057	457	816	63%
2011	24.66	2,255	748	3,951	3,010	1,312	21%
2012	11.44	1,052	1,372	1,208	28	1,599	47%
2013	12.79	555	397	1,019	5	799	74%
2014	19.43	696	763	979	116	924	71%
2015	17.68	640	541	1,041	121	854	75%
2016	22.93	967	836	1,823	74	1,076	54%
2017	18.61	1,281	2,035	4,787	720	2,928	4%
2018	10.36*	1,146	621	1,729	90	2,191	38%

Notes: cfs = cubic feet per second. * Total up to December 1, 2018. † Data from Utah State University Climate Center (2018)

The hydrographs of average daily discharges from Cutler Reservoir during water quality hydroperiods are shown in Figure 3, which illustrates the variability in the timing and magnitude of flow to the Bear River. Comparing releases from Cutler Reservoir during hydroperiods, the 1997–1998 and 2011 hydroperiods were characterized by high average flows (2,328 cfs), whereas the 2001–2004, 2008, and 2010 hydroperiod was characterized by low average flows (493 cfs). The 1996, 2000 2005, 2006, 2009, 2012. 2017, and 2018 water years were average flow years (averaging 1,235 cfs). The magnitude of releases during the 1997–1998, and 2011 periods were between 57 percent higher than the lowest average flow year (2000) and 85 percent higher than the lowest low flow year (2003). Minimum daily releases or the lowest recorded flows across the hydroperiods range from 5 cfs (due to a flowline outage in September 2013) to 159 cfs (1997–1999). Average precipitation totals during the five hydroperiods are presented in Table 6 and reflect the trend in flows shown in six water year groups (Figure 3) (Utah State University Climate Center 2018). For 2018, June through September 2018 precipitation was the lowest in last 30 years. September had zero precipitation, which has not been observed in the past 30 years. In addition, June through September 2018 average air temperature was 4.0 degrees Fahrenheit (°F) above the 30-year average.

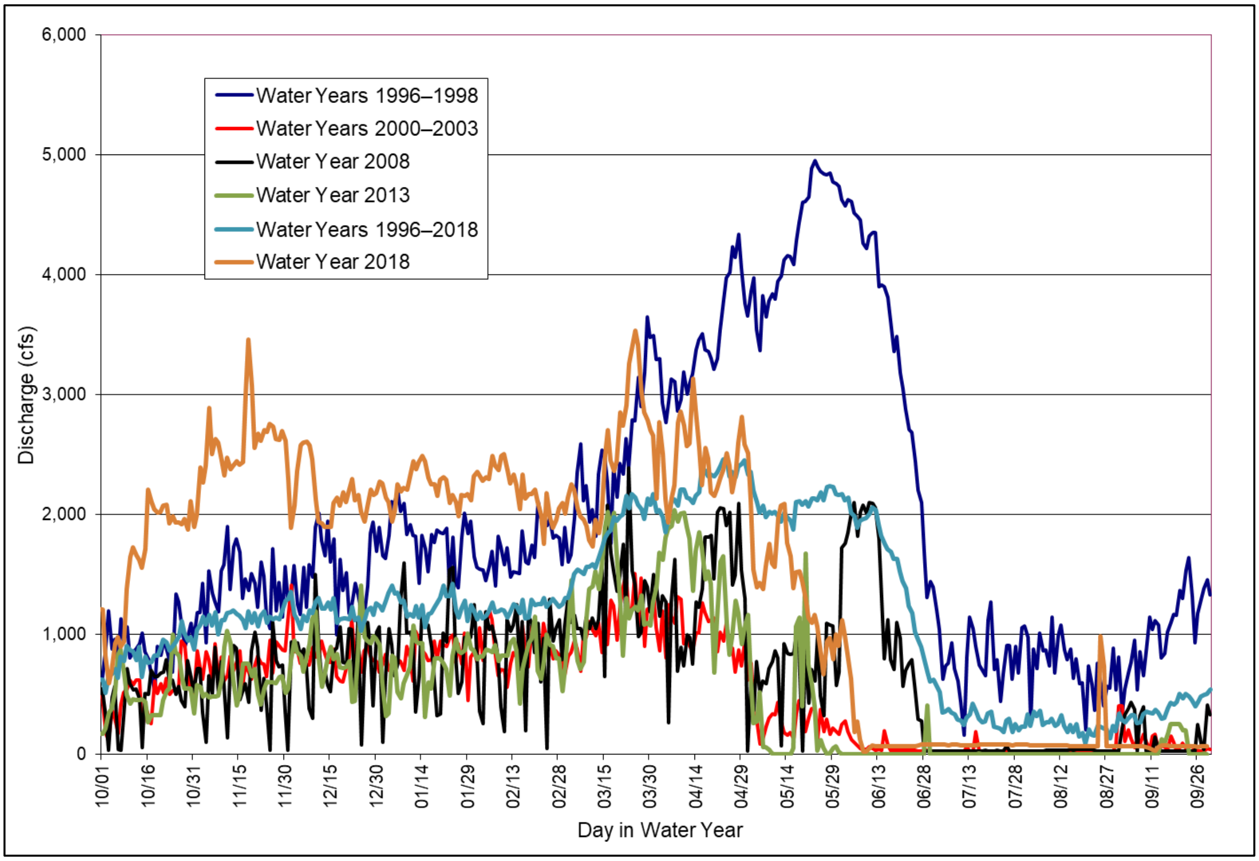

Figure 3. Hydrograph for average daily releases from Cutler Reservoir during the five *monitoring* periods only (six water year periods including the summary average of all years).

Table 6. Average Annual Precipitation and Annual Flow (for the Bear River at Collinston Gage) during the five *monitoring* hydroperiods only

Hydroperiods	Precipitation (inches)	Average Annual Flow (cfs)
Water years 1996–1998	18.78	1,226

Hydroperiods	Precipitation (inches)	Average Annual Flow (cfs)
Water years 2000–2003	12.29	583
Water year 2008	9.39	699
Water year 2013	12.79	555
Water year 2018	10.36	1,146
Water years 1996–2018 (Summary)	13.52	791

Source: Utah State University Climate Center (2018)

WATER QUALITY RESULTS

Temperature

Water temperature determines whether a waterbody can support warm-, cool- or cold-water aquatic species. High water temperatures can be harmful to fish at all life stages, especially if those temperatures occur in combination with other habitat limitations such as low DO or poor food supply (Dodds 2002). Elevated water temperatures can result in lower body weight, poor oxygen exchange, and reduced reproductive capacity of adult fish. Extremely high temperatures can result in death if they persist for an extended period. Juvenile fish are more sensitive to temperature variations and duration than adult fish and can experience negative impacts at a lower threshold value than adults (Dodds 2002); although sensitivity can vary by species (Dodds 2002) Temperature is an important indicator of water and wetland habitat quality. Water temperature is affected by vegetative cover, thermal inputs, flow alterations, ambient air temperatures, groundwater recharge, and direct sunlight. Average annual temperatures in the Cutler Reservoir system during the five hydroperiods were highest in 2008, and lowest during the 1996–1998 period (Table 7). Combinations of years with particularly low flows and high temperatures can produce particularly challenging conditions for native fisheries; unfortunately, these periods are often linked causally, and increasing in frequency in the Cutler watershed as they are globally (e.g., nine of the ten warmest years ever recorded beginning in 1880 have occurred since 2005) (NOAA 2020; Truecost blog 2012).

Table 7. Water Temperature (Degrees Celsius) in the Cutler Reservoir System during the five monitoring hydroperiods

Hydroperiod and Site	Spring Baseflow	Spring Runoff	Summer Baseflow	Fall Baseflow	Fall Storm	Winter Baseflow	Annual Average	Annual Maximum	Annual Minimum	Annual Standard Deviation
1996–1998										
Logan River	5.2	–	13.3	7.9	–	5.0	7.5	13.3	3.3	3.4
Little Bear River	5.4	–	17.2	9.8	–	7.1	9.2	17.2	3.0	4.8
Spring Creek	6.8	–	18.1	9.5	–	6.1	9.5	18.1	4.2	4.8
Cutler Reservoir at Benson Marina	7.2	–	27.5	10.9	–	7.2	11.7	27.5	4.7	8.3
Bear River at Summit Creek	5.4	–	23.3	9.8	–	5.9	9.9	23.3	3.3	7.3
Bear River below dam	5.8	–	24.2	10.3	–	5.9	10.4	24.2	3.5	7.4

Hydroperiod and Site	Spring Baseflow	Spring Runoff	Summer Baseflow	Fall Baseflow	Fall Storm	Winter Baseflow	Annual Average	Annual Maximum	Annual Minimum	Annual Standard Deviation
2000–2003										
Logan River	10.8	–	11.9	14.1	–	2.7	7.7	14.5	1.8	5.5
Little Bear River	15.9	–	20.2	15.1	–	2.6	9.6	20.2	1.7	7.7
Spring Creek	15.7	–	18.2	14.4	–	3.9	9.8	18.2	3.1	6.4
Cutler Reservoir at Benson Marina	21.5	–	21.2	20.7	–	1.8	11.4	21.5	0.3	10.3
Bear River at Summit Creek	17.8	–	20.9	17.9	–	1.0	9.8	20.9	–	9.5
Bear River below dam	20.8	–	22.0	19.5	–	2.2	11.3	22.0	1.2	9.9
2008										
Logan River	9.9	7.0	17.3	10.9	9.7	2.5	9.5	17.3	2.5	4.9
Little Bear River	17.4	6.9	19.7	11.4	10.7	1.3	11.2	19.7	1.3	6.7
Spring Creek	17.4	8.5	20.1	12.1	11.1	3.2	12.0	20.1	3.2	6.1
Cutler Reservoir south of Swift Slough	–	–	–	14.1	–	–	14.1	14.1	14.1	–
Cutler Reservoir at Benson Marina	20.0	9.4	24.9	15.2	11.0	0.9	13.6	24.9	0.9	8.4
Bear River at Summit Creek	15.5	8.5	23.3	14.6	10.6	0.9	12.2	23.3	0.9	7.5
Cutler Reservoir at Highway 23	19.0	9.3	24.9	16.0	10.9		16.0	24.9	9.3	6.3
Bear River below dam	18.4	10.0	27.0	17.5	10.6	0.1	13.9	27.0	0.1	9.2
2013										
Logan River	5.4	9.6	18.0	10.9	9.3	0.0	8.9	18.0	0.0	6.0
Little Bear River	5.3	15.4	18.6	12.0	9.0	0.2	10.1	18.6	0.2	6.7
Spring Creek	6.7	14.4	18.6	11.3	9.5	0.2	10.1	18.6	0.2	6.4
Cutler Reservoir south of Swift Slough	9.2	16.3	21.9	12.7	–	0.7	12.2	21.9	0.7	8.0
Cutler Reservoir at Benson Marina	6.1	19.2	22.9	13.9	11.6	0.1	12.3	22.9	0.1	8.4
Bear River at Summit Creek	7.0	14.6	21.0	14.3	11.6	0.7	11.5	21.0	0.7	7.0
Cutler Reservoir at Highway 23	5.5	18.9	22.0	13.5	11.8	0.2	12.0	22.0	0.2	8.2
Bear River below dam	7.4	20.4	21.8	13.0	13.8	0.1	12.7	21.8	0.1	8.1
2018										
Logan River	6.8	10.3	15.8	3.2	12.6	3.8	8.8	15.8	3.2	4.6
Little Bear River	5.6	14.6	16.5	2.5	14.2	3.4	9.5	16.5	2.5	5.8
Spring Creek	8.4	16.9	16.4	4.0	15.1	5.2	11.0	16.9	4.0	5.3
Cutler Reservoir south of Swift Slough	7.1	14.3	19.2	2.8	16.0	3.4	10.5	19.2	2.8	6.3
Cutler Reservoir at Benson Marina	8.4	17.9	21.5	2.9	16.2	3.2	11.7	21.5	2.9	7.2
Bear River at Summit Creek	6.6	15	20.5	3.3	15.4	2.6	10.6	20.5	2.6	6.8
Cutler Reservoir at Highway 23	7.3	16.7	21.2	2.8	16.2	2.4	11.1	16.7	2.4	7.3

Hydroperiod and Site	Spring Baseflow	Spring Runoff	Summer Baseflow	Fall Baseflow	Fall Storm	Winter Baseflow	Annual Average	Annual Maximum	Annual Minimum	Annual Standard Deviation
Bear River below dam	7.5	17.9	16.1	2.9	16.1	2.2	10.4	17.9	2.2	6.5

pH

The pH of a waterbody is a measure of its acidity or alkalinity. A pH value of 7 is neutral, values 0 to 7 are acidic, and 7 to 14 are alkaline. Extremely acidic or alkaline waters can be problematic for fisheries. Extreme levels of pH can be directly toxic to aquatic life. Each species of fish has a distinct range of pH tolerance, and levels outside that range can cause aluminum toxicity, reproductive problems, and death (Dodds 2002). Substantial diurnal shifts in pH that result mainly from photosynthesis are stressful and damaging to the health of aquatic organisms. Changes in pH also affect the toxicity and availability of dissolved compounds such as heavy metals. For example, pH on the acidic side (< 7.0) can cause heavy metals to go into solution, thus increasing the heavy metal readings in water samples and incidence of heavy metals in fish tissue (Dodds 2002). Measured pH values in the 6.5–9.0 range are generally supportive of aquatic life (Utah Water Quality Standards, Rule R317-2-18). Results for pH by hydroperiod, including summary statistics for the five monitoring hydroperiods, are presented in Table 8, where 6 percent of samples exceeded 9.0 prior to 2013, with a maximum value of 9.2 at Cutler Reservoir north of Benson Marina. pH levels in the reservoir system are generally alkaline (greater than 7.0) in nature.

Table 8. pH in the Cutler Reservoir System during the five monitoring hydroperiods

Hydroperiod and Site	Spring Baseflow	Spring Runoff	Summer Baseflow	Fall Baseflow	Fall Storm	Winter Baseflow	Annual Average	Annual Max	Annual Min	Annual Standard Deviation
1996–1998										
Logan River	7.7	–	7.9	8.2	–	7.8	8.0	8.3	7.5	0.3
Little Bear River	8.0	–	7.7	8.1	–	8.2	8.0	8.2	7.7	0.2
Spring Creek	7.7	–	7.6	8.0	–	8.0	7.9	8.1	7.6	0.2
Cutler Reservoir at Benson Marina	8.2	–	8.4	8.3	–	8.4	8.3	8.4	8.0	0.2
Bear River at Summit Creek	8.0	–	8.0	8.2	–	8.3	8.1	8.3	7.9	0.2
Bear River below dam	8.0	–	8.0	8.2	–	8.3	8.1	8.3	7.9	0.2

Hydroperiod and Site	Spring Baseflow	Spring Runoff	Summer Baseflow	Fall Baseflow	Fall Storm	Winter Baseflow	Annual Average	Annual Max	Annual Min	Annual Standard Deviation
2000–2003										
Logan River	8.1	–	8.1	7.8	–	8.2	8.1	8.3	7.6	0.2
Little Bear River	8.0	–	7.8	7.9	–	8.1	8.0	8.3	7.8	0.2
Spring Creek	7.8	–	7.8	7.6	–	8.0	7.9	8.1	7.6	0.2
Cutler Reservoir at Benson Marina	8.3	–	8.4	8.5	–	8.1	8.2	8.7	7.7	0.3
Bear River at Summit Creek	8.1	–	7.9	7.9	–	8.1	8.0	8.4	7.7	0.3
Bear River below dam	8.1	–	7.9	7.9	–	8.1	8.0	8.4	7.7	0.3
2008										
Logan River	8.7	8.7	–	8.5	8.0	–	8.5	8.7	8.0	0.3
Little Bear River	8.5	8.8	8.8	8.4	7.9	–	8.5	8.8	7.9	0.3
Spring Creek	8.5	8.7	8.7	8.4	7.8	–	8.4	8.7	7.8	0.3
Cutler Reservoir south of Swift Slough	–	–	–	8.9	–	–	8.9	8.9	8.9	–
Cutler Reservoir at Benson Marina	8.8	8.9	9.2	8.5	8.4	–	8.8	9.2	8.4	0.3
Bear River at Summit Creek	8.8	8.8	9.1	8.8	8.3	–	8.7	9.1	8.3	0.3
Cutler Reservoir at Highway 23	9.0	8.9	9.0	9.1	8.5	–	8.9	9.1	8.5	0.2
Bear River below dam	8.5	8.8	8.5	9.0	8.5	–	8.6	9.0	8.5	0.2
2013										
Logan River	8.4	8.3	7.9	8.3	8.3	8.3	8.3	8.4	7.9	0.2
Little Bear River	8.3	8.1	8.2	8.2	8.3	8.0	8.2	8.3	8.0	0.1
Spring Creek	8.3	8.1	8.1	8.1	8.2	8.2	8.2	8.3	8.1	0.1
Cutler Reservoir south of Swift Slough	8.5	8.2	8.2	8.3	–	8.1	8.3	8.5	8.1	0.2
Cutler Reservoir at Benson Marina	8.6	8.4	8.7	8.7	8.8	8.2	8.5	8.8	8.2	0.2
Bear River at Summit Creek	8.5	8.3	8.5	8.6	8.6	8.3	8.5	8.6	8.3	0.1
Cutler Reservoir at Highway 23	8.5	8.5	8.6	8.7	8.8	8.2	8.6	8.8	8.2	0.2
Bear River below dam	8.6	8.4	8.5	8.7	8.5	8.3	8.5	8.7	8.3	0.1
2018										
Logan River	8.4	8.4	7.7	8.3	8.2	8.2	8.2	8.4	7.7	0.2
Little Bear River	8.4	8.2	8.2	8.3	8.4	8.2	8.3	8.4	8.2	0.1
Spring Creek	8.2	8.2	8.1	8.2	8.2	8.2	8.2	8.2	8.1	0.0
Cutler Reservoir south of Swift Slough	8.4	8.2	8.3	8.6	8.4	8.4	8.4	8.6	8.2	0.1
Cutler Reservoir at Benson Marina	8.4	8.6	8.4	8.7	8.8	8.6	8.6	8.8	8.4	0.1
Bear River at Summit Creek	8.3	8.4	8.9	8.7	8.6	8.4	8.6	8.9	8.3	0.2
Cutler Reservoir at Highway 23	N/A	8.4	8.7	8.7	8.8	8.5	8.6	8.8	8.4	0.1
Bear River below dam	8.5	8.5	8.5	8.6	8.8	8.5	8.6	8.8	8.5	0.1

Bacteria

Waterborne pathogenic organisms include bacteria (e.g., dysentery), viruses (e.g., hepatitis), protists (e.g., *Giardia*), and parasites. Some pathogens and indicator bacteria can live in bottom sediments of streams and be resuspended during high flows. Pathogenic organisms are costly and difficult to test for in natural waters because of their low concentrations and diversity.

E. coli is a species of fecal coliform that is used as an indicator of fecal contamination. Most *E. coli* strains are not pathogenic to humans (Nataro and Kaper 1998). However, some strains of *E. coli*, such as *E. coli* 157:H7, are responsible for hemorrhagic colitis (severe diarrhea) and hemolytic uremic syndrome (kidney failure) (Nataro and Kaper 1998), both of which cause mild to extreme symptoms in humans and can be fatal if left untreated. *E. coli* has recently been found to be a more reliable indicator of pathogens originating from fecal matter than fecal coliforms. In 1986, the EPA recommended that *E. coli* or enterococci replace fecal coliform bacteria in state water-quality standards (EPA 1986). The EPA's recommendation for *E. coli* as an indicator of fecal contamination in water and wastewater is because 1) *E. coli* occurs in human and warm-blooded animal feces in greater quantities than pathogens, 2) it shows minimal growth in aquatic systems, 3) it is easily detectable, and 4) it is consistently present when pathogens are present (Elmund et al. 1999).

Based on the previous coliform standards established by the State of Utah in assessing water quality, high total coliform would be those greater than 5,000 organisms per 100 mL (org/100 mL). The new pathogen standard for the State of Utah relates to *E. coli* and requires waterbodies designated for secondary recreation (i.e., Cutler Reservoir) not to exceed *E. coli* values of 668 org/100 mL. The 30-day standard for waterbodies designated for secondary recreation is a geometric mean of *E. coli* not to exceed 206 org/100 mL.

There are noteworthy differences for coliform bacteria and *E. coli* in the Cutler Reservoir system between hydroperiods and season. These differences are discussed in the following sections. Pathogen data collected before 2008 were sampled as total coliform or fecal coliform, but because of the change to *E. coli* standards, many laboratories no longer perform fecal coliform analyses. Although *E. coli* was collected in 2008, 2013, and 2018, fecal coliform results before this were converted to *E. coli* using a standard conversion by dividing fecal coliform results by1.59 as identified by DWQ (DWQ 2005). Collection of *E. coli* data is recommended for future hydroperiods in order to assess compliance with new state water quality criteria.

Differences in Bacteria between Monitoring Hydroperiods

A comparison of *E. coli* (for baseflow samples only) across the five monitoring hydroperiods suggests that bacteria concentrations generally decreased from the first hydroperiod (1996–1998) to the second hydroperiod (2000–2003), increased in the third hydroperiod (2008), then decreased slightly in the fourth hydroperiod (2013). In 2018, bacteria concentrations decreased from the 2013 levels except at the Logan River site where the values were slightly higher than in 2013 (Figure 4; Table 9). This comparison of baseflow samples allows for a comparison of bacteria concentrations during similar hydrologic conditions. Wet years (such as 1996) can result in the dilution of bacteria concentrations in surface waters. Monitoring years 2008, 2013, and 2018 were relatively to very dry years, and it is possible that the dryer conditions resulted in less dilution and higher *E. coli* concentrations. Because of low precipitation, 2018 was the driest year on record. The highest average concentrations ever recorded were collected at Spring Creek, which is downstream of the JBS meat-packing plant. *E. coli* concentrations were higher than previously recorded at the other southern monitoring sites as well (Little Bear, Logan River, and Swift Slough). Point sources such as JBS and Swift Slough (Logan City's effluent discharge location) can be continuous sources of pollution to surface waters; however, little is known about the changes in management or production suggested by the TMDL at the JBS facility. The other large point source is the Logan Regional Wastewater Treatment Plant, whose outfall is located at Swift Slough on Cutler Reservoir. Large increases in *E. coli* were observed at this site in 2018. The City of Logan has started construction of their tertiary treatment facility. Although average *E. coli* concentrations in 2018 did not exceed the State of Utah pathogen instantaneous maximum standard of 668 org/100 mL designated for secondary recreation, samples collected from Spring Creek and Logan River exceed the 30-day standard of 206 org/100 mL. Additional sampling over a 30-day period is needed to determine if those waterbodies exceed that standard.

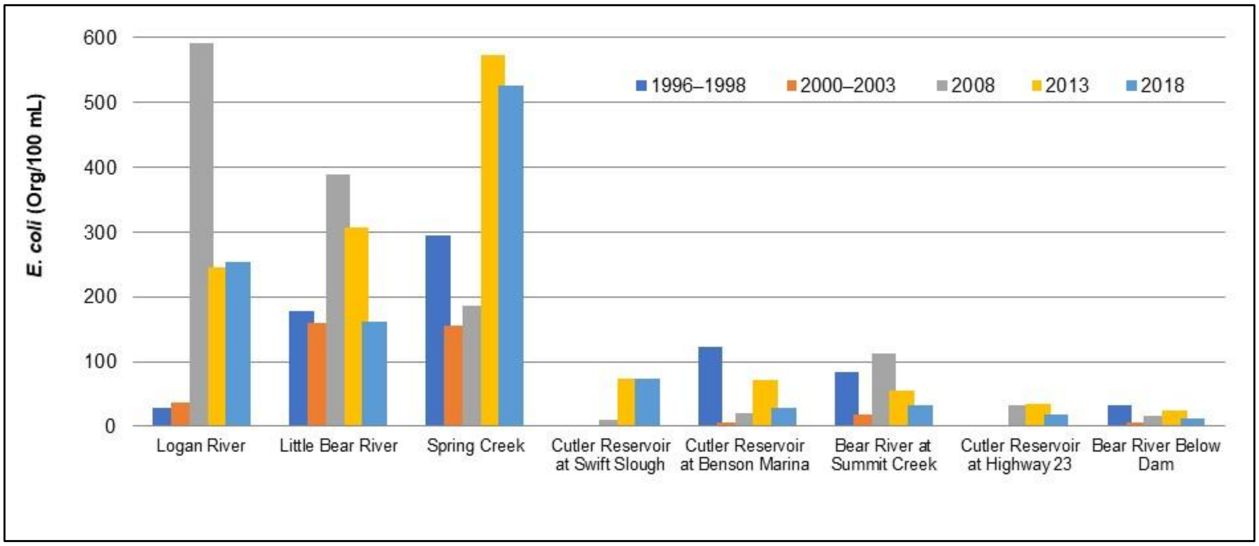

Figure 4. Average *E. coli* concentrations in the Cutler Reservoir system during baseflow for all monitoring hydroperiods.

Table 9. Average *E. coli* Concentrations (organisms/100 mL) during Summer Baseflow Monitoring Hydroperiods in the Cutler Reservoir System

Monitoring Site	1996–1998	2000–2003	2008	2013	2018
Logan River	29	36	591	246	921
Little Bear River	177	159	389	308	436
Spring Creek	295	156	186	574	1733
Cutler Reservoir at Swift Slough	N/A*	N/A*	10	73	272
Cutler Reservoir at Benson Marina	124	5	20	72	14
Bear River at Summit Creek	84	18	112	56	78
Cutler Reservoir at Highway 23	N/A*	N/A*	33	36	18
Bear River below dam	33	5	16	24	8

* N/A = site not included during hydroperiod.

Average total coliform concentrations during baseflow conditions vary through time but were generally higher in 2018 than in previous years (Table 10). Average total coliform concentrations across sites were greater than the detection limit of 2,419.6 org/100 mL. The next highest levels occurred in 2013 followed by 1996–1998 (1,019 org/100 mL) and 2000–2003 (450 org/100 mL). The lowest levels occurred in 2008 (220 org/100 mL) (Table 10). Of the 53 total coliform samples collected across sites in 2018, all sample results for the summertime baseflow had concentrations exceeding the lab's detection limit of > 2,400 org/100 mL. The cause of the overall increase in total coliform concentrations seen in 2018 is unclear, but there appears to be a clear upward trend since 2008. Additional sampling locations over different hydrologic conditions could aid in identifying sources.

Table 10. Average Total Coliform concentrations (organisms/100 mL) during Summer Baseflow in the Cutler Reservoir System during all Monitoring Hydroperiods.

Monitoring Site	1996–1998	2000–2003	2008	2013	2018
Logan River	281	407	245	1,586	> 2,419.6
Little Bear River	860	448	325	1,926	> 2,419.6
Spring Creek	2,537	1,278	205	> 2,419.6	> 2,419.6
Cutler Reservoir at Swift Slough	N/A*	N/A*	410	1,356	> 2,419.6
Cutler Reservoir at Benson Marina	1,702	115	84	1,275	> 2,419.6
Bear River at Summit Creek	499	208	220	1,476	> 2,419.6
Cutler Reservoir at Highway 23	N/A*	N/A*	103	1,723	> 2,419.6
Bear River below dam	237	246	167	2,211	> 2,419.6

* N/A = site not included during hydroperiod.

Seasonal Variation of Bacteria

E. coli concentrations in the Cutler Reservoir system varied throughout the 2018 hydroperiod, a relatively low flow period. In general, average *E. coli* concentrations were highest during the summer baseflow periods with the exception of Bear River below dam, Cutler Reservoir at Highway 23, and Cutler Reservoir at Benson Marina. *E. coli* numbers during the runoff period in May were generally higher than during the fall storm hydroperiod except at Spring Creek (Figure 5). During the previous hydroperiod in 2013, these observations were generally reversed. The summer baseflow is a very low flow period so the presence of *E. coli* can occur in higher numbers because there is less dilution occurring. The general increase in *E. coli* from baseflow conditions is expected because surface runoff, including storms, is the process that can transport bacteria to surface waters (e.g., runoff from agricultural sources). Additionally, high concentrations during fall storms are also expected because of surface runoff and warmer temperatures, which increase the survivability of bacteria relative to colder runoff conditions. However, at three of the monitoring sites, baseflow concentrations were greater than runoff or storm concentrations. The most notable of these sites is Spring Creek, which, as discussed, is located downstream of the JBS meat-packing plant. Average *E. coli* concentrations at tributary sites during baseflow, runoff, and storm events were 391 percent, 400 percent, and 664 percent higher than the average concentrations at Cutler Reservoir sites during the same conditions. These results suggest that the flushing of terrestrial areas, especially during storms, can concentrate bacteria prior to subsequent dilution in Cutler Reservoir.

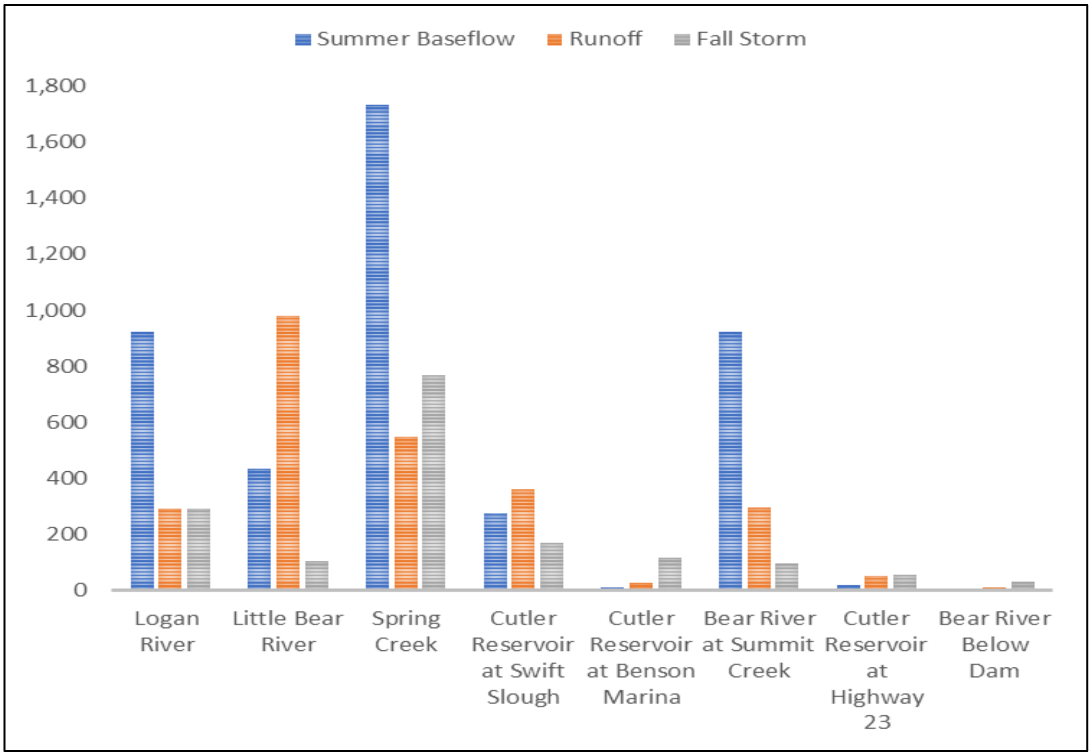

Figure 5. *E. coli* concentrations in the Cutler Reservoir system during the 2018 hydroperiod.

Nutrients

Concerns associated with excessive nutrient concentrations in fresh waters relate to both direct and indirect effects. Direct effects include nuisance algae and periphyton growth. Indirect effects include low DO, increased methylmercury production, elevated pH, cyanotoxins from cyanobacteria (blue-green algae) production, trihalomethane production in drinking water systems, and maintenance issues associated with domestic water supplies (though Cutler Reservoir is not used as a drinking water source). The 2010 Cutler Reservoir TMDL defined seasonal (May–October) total phosphorus targets for the northern reservoir and southern reservoir as 0.07 mg/l and 0.09 mg/l, respectively, and an annual target of 0.075 mg/L for reservoir outfall. Similarly, the TMDL defined DO targets as 1-day minimum (3.0 mg/L), 7-day average (> 4.0 mg/L), and a 30-day average (> 5.5 mg/L) needed to support beneficial uses (DWQ 2010). Nuisance algae growth, including phytoplankton (water column algae), periphyton (attached algae), and macrophytes (rooted plants), can adversely affect both aquatic life and recreational water uses. Algal blooms occur where nutrient concentrations (nitrogen and phosphorus) are sufficient to encourage excessive growth. The nutrient levels necessary for algae growth may occur at concentrations well below the identified water quality thresholds and criteria. Nutrient concentrations, flow rates, velocities, water temperatures, and sunlight penetration in the water column are all factors that influence algae and macrophyte growth. When conditions are appropriate and nutrient concentrations exceed the quantities needed to support algal growth, excessive blooms may develop. These blooms can appear as layers or algal mats on the surface of the water.

Algal blooms often create objectionable odors in waters for recreation use and can produce intense coloration of both the water and shorelines. Waterbodies demonstrating high nutrient concentrations can experience excessive algal growth and are said to be eutrophic. However, algae are not always damaging to water quality. The extent of the effect is dependent on both the type(s) of algae present and the size, extent, and timing of the bloom. In many systems, algae provide a critical food source for many aquatic insects, which in turn serve as food for fish.

Algal growth also has indirect effects on water quality. When algae die, they sink through the water column and collect in bottom sediments. As the algae decompose, the biochemical processes remove oxygen from the surrounding water (known as chemical oxygen demand). Because most of the decomposition occurs near the bottom of the water column, DO concentrations near the bottom of lakes and reservoirs can be depleted. Low DO in these areas can lead to decreased fish habitat and even fish kills if other areas of water with sufficient DO are not available for fish to take refuge.

Nutrient Differences between Monitoring Hydroperiods

Total phosphorus data collected in 2018 show an overall increase across all sites from data collected in 2013 (Figure 9; note that the 2013 data, as reported in 2018 [PacifiCorp 2018, corrected in 2020] and as detailed below showed very low, anomalous P levels). Phosphorus concentration increases between 2013 and 2018, range from a 93 percent increase at Cutler Reservoir south of Swift Slough to a 51 percent increase at Bear River at Summit Creek. It is important to note that 92 percent of the 2013 total phosphorus results were below the detection limit of 0.05 mg/L, which was a deviation from the overall trend in phosphorus concentrations. However, comparing 2018 data to the other hydroperiods (except 2013), they are not substantially different and, in some years, the previous phosphorus levels were greater than in 2018. There is no obvious explanation for the very low levels of phosphorus levels in 2013. Before the 2018 monitoring program, SWCA and PacifiCorp had a discussion with staff at DWQ to understand why phosphorus levels were so low in 2013. SWCA reviewed the 2013 data in an attempt to explain the results. One idea at the beginning of the 2018 monitoring effort was that improvements made at the various point sources could have resulted in the lower 2013 readings. However, given that 2013 and 2018 were both dry years for precipitation, if the 2013 data accurately reflected a drop in phosphorus at Cutler, it seemed reasonable that the 2018 phosphorus levels would remain low like in 2013; however, that was not the case. This indicates that the 2013 data were indeed, anomalous, and did not accurately reflect a trend downward in phosphorus levels at Cutler Reservoir.

Nitrate nitrogen concentrations varied from one site to another in 2018. Nitrate nitrogen generally remained about the same or was slightly higher than 2013 at the monitoring sites (Figure 7). Total nitrogen in the Cutler Reservoir system during baseflow conditions increased from 2013 to 2018 at the southern monitoring sites and decreased from Cutler Reservoir at Benson Marina to the Bear River below dam (Figure 8). Note that total nitrogen was not collected prior to 2008.

The most notable increase in total nitrogen was at Spring Creek, which can be affected by the aforementioned land use practices and the upstream JBS facility. Based on the changes in phosphorus and nitrogen over time, the trend in nutrient concentrations has not followed the trajectory downward that was hoped for in 2013, but instead has remained at relatively similar levels of concentration as in the other previous hydroperiods (except 2013). Based on that, the nutrient management plans in the Cutler Reservoir system associated with implementation of the 2010 Cutler Reservoir TMDL (DWQ 2010) may need to be revisited.

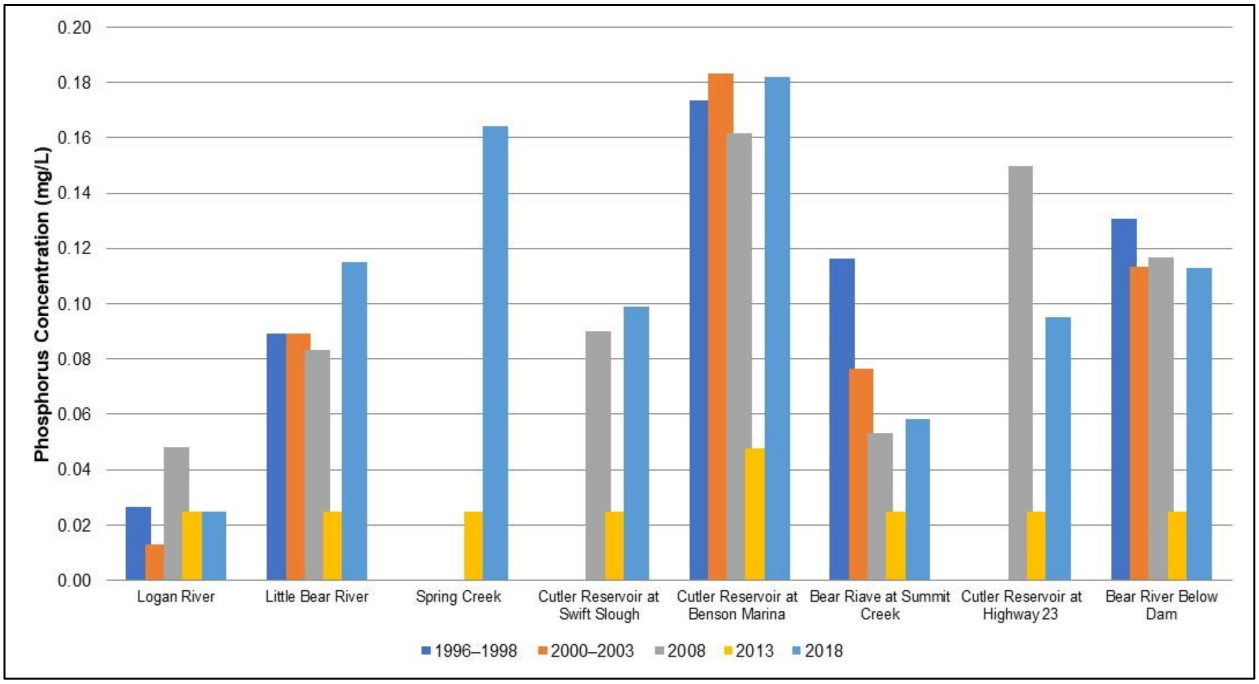

Figure 6. Total phosphorus concentrations in the Cutler Reservoir system during baseflow for all monitoring hydroperiods.

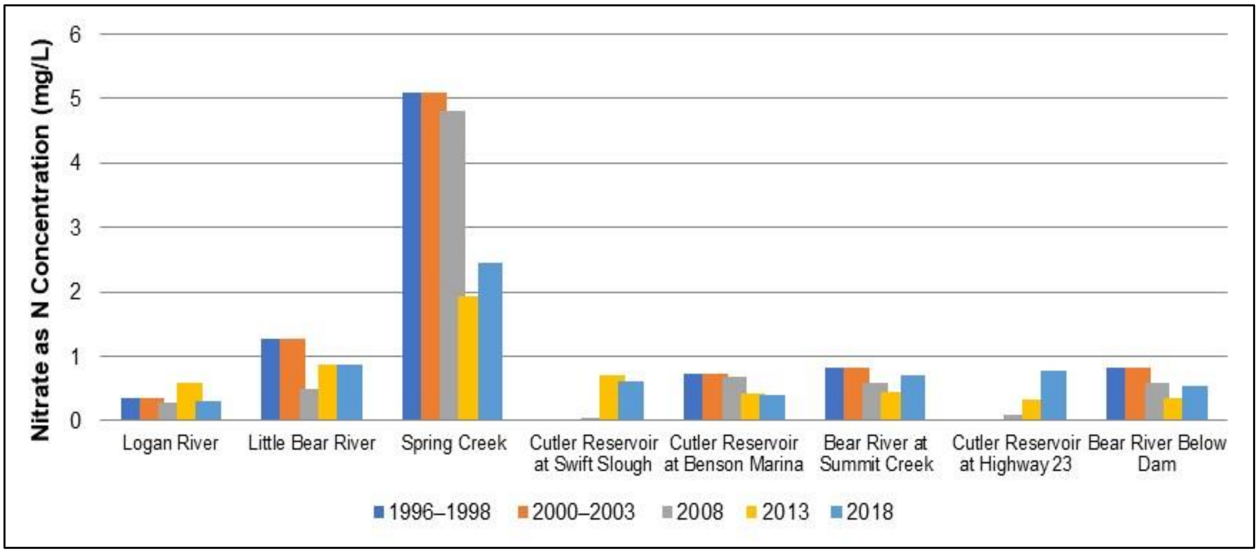

Figure 7. Nitrate nitrogen concentrations in the Cutler Reservoir system during baseflow for all monitoring hydroperiods.

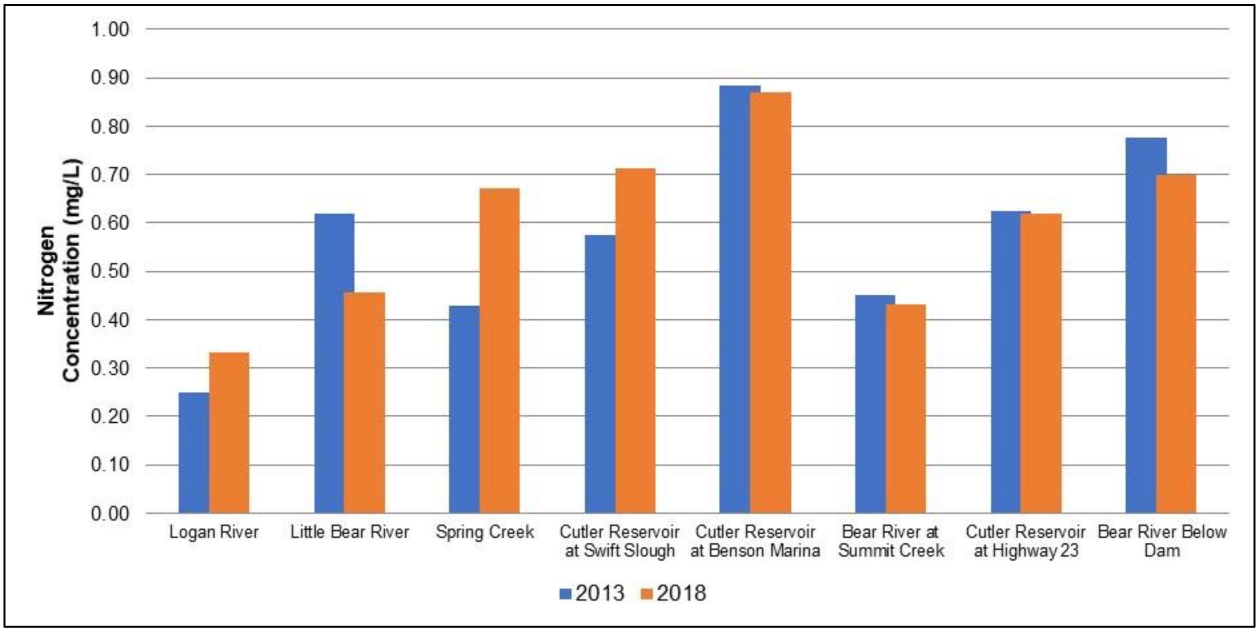

Figure 8. Total nitrogen concentrations in the Cutler Reservoir system during baseflow for the 2013 and 2018 hydroperiods.

Dissolved Oxygen

DO is important to the health and viability of fish and other aquatic life. High concentrations of DO (6–8 mg/L or greater) are necessary for the health of aquatic life. Low concentrations of DO (below 4 mg/L) can result in stress to aquatic species, lowered resistance to environmental stressors, and even death at very low levels (less than 2 mg/L). Cutler Reservoir and its associated wetlands and tributaries contain a diverse and mostly non-native fish community of common carp (*Cyprinus carpio*), fathead minnow (*Pimephales tenellus*), Utah sucker (*Catostomus ardens*), black bullhead (*Ameirus melas*), channel catfish (*Ictalurus punctatus*), green sunfish (*Lepomis cyanellus*), bluegill sunfish (*Lepomis macrochirus*), smallmouth bass (*Micropterus dolomieu*), largemouth bass (*Micropterus salmoides*), and black crappie (*Pomoxis nigromaculatus*) (Budy et al. 2006). Thresholds of DO for fish vary by species, as do a number of environmental conditions such as water temperature and hardness. Generally, fish are more tolerant of low oxygen levels at cold temperatures and low hardness.

Low DO often results from high nutrient, organic, or algal loading to a surface water system. Nutrients fuel algal growth, which in turn consumes oxygen from the water column during respiration in nighttime hours, and produce oxygen as a part of photosynthesis during daylight hours (D’Avanzo and Kremer 1994). There are circumstances where algae presence could be beneficial or detrimental to aquatic organisms depending on time of day and proximity of fish and other aquatic organisms to the low-DO region of the waterbody. Organic sediment inputs and algae generated in a reservoir can also result in reduced DO levels. When algae die and settle to the bottom of the water column or when organic matter enters a reservoir, aerobic decomposition depletes the oxygen supply in the overlying water (known as chemical oxygen demand).

DO measurements were taken during all water quality sampling events, except during summer baseflow and the fall storm in 2008 because of equipment failure, and during the fall storm in 2013 at Cutler Reservoir south of Swift Slough because the site was not accessible. Additionally, the data suggest potential additional equipment failure during the 2013 summer baseflow sampling event and the 2018 winter baseflow, thus these values were not used to calculate summary statistics (Table 11). DO values were generally high below Cutler Dam and throughout the Cutler Reservoir system at all sampling times, but highest during fall baseflow. The lowest values recorded were at Cutler Reservoir at Benson Marina and Little Bear River during 2018, at Cutler Reservoir at Benson Marina in 2008, and at Cutler Reservoir south of Swift Slough in 2013. However, these minimum values are still considered to be protective of fisheries, although Cutler Reservoir at Benson Marina in 2018 was only marginally beneficial at 4.9 mg/L.

It should be noted that all of the DO sampling occurred during the daylight hours when oxygen levels are expected to be elevated from photosynthetic activity. Conversely, DO levels drop each night when phytoplankton and macrophytes are not actively respiring, and no photosynthetic activity is occurring to replenish the oxygen supply. Therefore, values of 6 mg/L or below during daylight hours could correlate to nighttime DO concentrations that are harmful to biota.

As expected, DO values fluctuated by hydroperiod throughout the Cutler Reservoir system. In 2018, the DO decreased from spring baseflow to spring runoff, which might be related to timing of the spring runoff sampling, which occurred during the rising limb of a May runoff event. This event had higher flows but also exhibited considerably higher temperatures which reduced the oxygen capacity in the water relative to the colder spring baseflow.

Table 11. Dissolved Oxygen (mg/L) in the Cutler Reservoir System during all Monitoring Hydroperiods

Hydroperiod and Site	Spring Baseflow	Spring Runoff	Summer Baseflow	Fall Baseflow	Fall Storm	Winter Baseflow	Annual Average	Annual Maximum	Annual Minimum	Annual Standard Deviation
1996–1998										
Logan River	9.6	–	8.2	9.5	–	10.5	9.5	10.5	8.2	0.8
Little Bear River	9.3	–	6.3	8.6	–	9.3	8.6	10.0	6.3	1.3
Spring Creek	8.8	–	5.8	8.4	–	10.5	8.4	10.5	5.8	1.6
Cutler Reservoir at Benson Marina	9.8	–	10.0	8.6	–	10.2	9.4	10.6	7.4	1.2
Bear River at Summit Creek	9.7	–	8.2	8.1	–	10.1	8.9	10.8	6.7	1.3
Bear River below dam	9.7	–	8.2	8.1	–	10.0	8.9	10.8	6.7	1.3
2000–2003										
Logan River	8.9	–	9.8	9.6	–	12.3	10.9	13.3	8.1	1.8
Little Bear River	7.7	–	6.5	8.2	–	11.9	9.8	13.4	6.0	2.8
Spring Creek	7.4	–	7.4	8.4	–	10.5	9.2	11.5	6.6	1.8
Cutler Reservoir at Benson Marina	8.3	–	6.8	11.7	–	11.1	10.4	14.9	6.8	2.7
Bear River at Summit Creek	7.0	–	7.1	8.5	–	11.7	9.8	13.0	7.0	2.4
Bear River below dam	7.0	–	7.1	8.5	–	11.7	9.8	13.0	7.0	2.4

Hydroperiod and Site	Spring Baseflow	Spring Runoff	Summer Baseflow	Fall Baseflow	Fall Storm	Winter Baseflow	Annual Average	Annual Maximum	Annual Minimum	Annual Standard Deviation
2008										
Logan River	8.4	10.5	–	8.8	–	11.6	9.8	11.6	8.4	1.5
Little Bear River	7.6	9.7	–	8.3	–	11.2	9.2	11.2	7.6	1.6
Spring Creek	7.1	9.9	–	8.2	–	10.3	8.9	10.3	7.1	1.5
Cutler Reservoir south of Swift Slough	–	–	–	13.1	–	–	13.1	13.1	13.1	–
Cutler Reservoir at Benson Marina	8.7	9.8	–	10.8	–	5.5	8.7	10.8	5.5	2.3
Bear River at Summit Creek	7.5	9.4	–	8.1	–	11.0	8.8	11.0	7.5	1.4
Cutler Reservoir at Highway 23	8.6	10.1	–	10.9	–	–	9.9	10.9	8.6	1.2
Bear River below dam	8.3	10.3	–	10.5	–	12.8	10.5	12.8	8.3	1.8
2013										
Logan River	8.5	7.0	*	8.1	7.5	10.5	8.3	10.5	7.0	1.4
Little Bear River	9.1	6.1	*	8.1	8.2	10.7	8.4	10.7	6.1	1.7
Spring Creek	9.5	6.3	*	7.9	7.4	9.8	8.2	9.8	6.3	1.5
Cutler Reservoir south of Swift Slough	7.7	5.6	*	9.6	–	8.0	7.7	9.6	5.6	1.6
Cutler Reservoir at Benson Marina	9.7	6.0	*	8.4	7.6	11.0	8.5	11.0	6.0	1.9
Bear River at Summit Creek	8.9	7.3	*	8.4	7.6	9.8	8.4	9.8	7.3	1.0
Cutler Reservoir at Highway 23	10.0	7.2	*	8.8	7.0	10.4	8.7	10.4	7.0	1.6
Bear River below dam	11.5	8.3	*	9.2	7.0	10.9	9.4	11.5	7.0	1.9
2018										
Logan River	9.6	7.9	6.2	9.4	7.2	17.4*	8.1	9.6	6.2	1.4
Little Bear River	9.3	7.0	6.3	10.5	5.5	13.6*	7.7	10.5	5.5	2.1
Spring Creek	7.6	7.7	6.5	7.7	6.7	12.2*	7.2	7.7	6.5	0.6
Cutler Reservoir south of Swift Slough	8.6	7.4	6.7	14.4	8.1	14.8*	9.0	14.4	6.7	3.1
Cutler Reservoir at Benson Marina	8.8	9.0	4.9	12.8	7.4	19.4*	8.6	12.8	4.9	2.9
Bear River at Summit Creek	9.6	7.6	6.8	11.2	7.4	16.8*	8.5	11.2	6.8	1.8
Cutler Reservoir at Highway 23	9.2	7.9	7.0	14.0	8.2	18.1*	9.3	14.0	7.0	2.8
Bear River below dam	9.3	7.9	8.1	15.2	8.9	9.8*	9.9	15.2	7.9	3.0

* Indicates potential equipment failure – data not used for analysis; – indicates samples not taken

Turbidity and Sediment

Turbidity is a measurement of the visible clarity of water. Turbidity can be caused by both inorganic particles and suspended algae. Turbidity from inorganic particles can limit algal growth because it limits light, even if there are sufficient nutrients for algal blooms. In Cutler Reservoir, large populations of carp contribute to turbid conditions by stirring up bottom sediments, which may confound efforts to measure sediment inputs into the system. Light limitation from large amounts of suspended inorganic particles can limit algal growth; however, turbidity can also be correlated with phytoplankton density in very productive aquatic systems (Wetzel 2001). In that situation, high turbidity is not caused by sediment input but rather the sheer density of phytoplankton. Turbidity is often reported in nephelometric turbidity units (NTUs) or formazin nephelometric units (FNUs), which represent the degree to which light is scattered in water. Prior to 2013, the field meters used to measure turbidity recorded values as NTUs, which changed to FNUs in 2013 and 2018 with the use of a new meter. Although no conversion exists between these units, they are directly comparable (personal communication, telephone conversation with Pat Noteboom, senior chemist, American West Analytical Laboratories, with Andrew Myers, SWCA, February 7, 2014).

Sediment is the most visible pollutant in fresh waters and leads to increased turbidity in water. It is usually reflected in measurements of TSS in mg/L. Erosion of upland soils and stream banks is the primary cause of elevated sediment levels in rivers and reservoirs, and reflects land management practices in the watershed. Excessive sediment loading in receiving waters can lead to the alteration of aquatic habitat, reduced reservoir storage capacity from sedimentation, and reduced aesthetic value of waters. Accumulation of sediments can directly harm fish and aquatic wildlife, or indirectly impact the functioning of aquatic systems by contributing to nutrient loading and eutrophication (algal overgrowth) (Novotny and Olem 1994).

Turbidity and Sediment Differences between Monitoring Hydroperiods

Turbidity at monitoring sites was measured during all hydroperiods in 2013 and in 2018. A comparison of turbidity results during baseflow, runoff, and storm conditions in 2013 and 2018 is presented in Figure 9. The data show that, in general and as expected, runoff conditions resulted in the highest turbidity at the Cutler Reservoir sites compared to tributary sites. The highest values occurred during the 2018 runoff at Bear River at Summit Creek, with a turbidity value of 185.2 NTUs. This high reading was most likely because of erosion during the runoff. In comparison to other monitoring hydroperiods, runoff conditions are expected to create high turbidity due to the magnitude of terrestrial, streambed, and bank disturbance and erosion related to these disturbances. Spikes in turbidity can also be related to specific areas of ground disturbance (i.e., from a construction or agricultural project or other large ground-disturbing event), or the growth of suspended algae rather than increases in suspended sediment loads in streams.

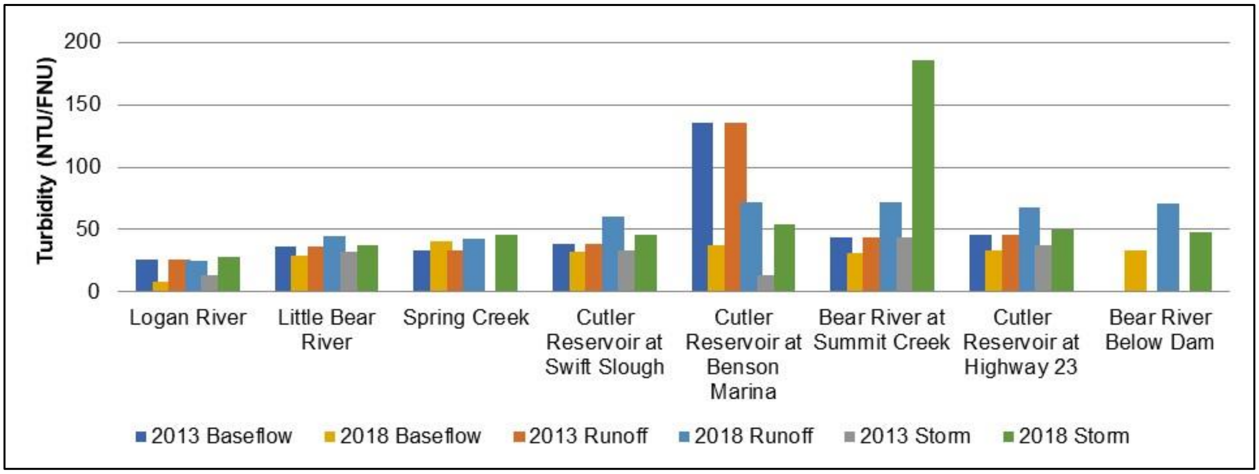

Figure 9. Average turbidity for monitoring sites by 2013 and 2018 hydroperiod.

Total suspended solids (TSS) samples were also collected during all monitoring hydroperiods in 2013 and in 2018. A comparison of TSS results during baseflow, runoff, and storm conditions in 2013 and 2018 is presented in Figure 10. In general, TSS follows a similar seasonal trend as turbidity, with the highest values collected during runoff or storm conditions. These results also suggest that storms have the potential to increase TSS more than turbidity in this system, which can result in higher nutrient inputs. Results from the two graphs also show that turbidity and TSS are closely correlated at most sites as would be expected.

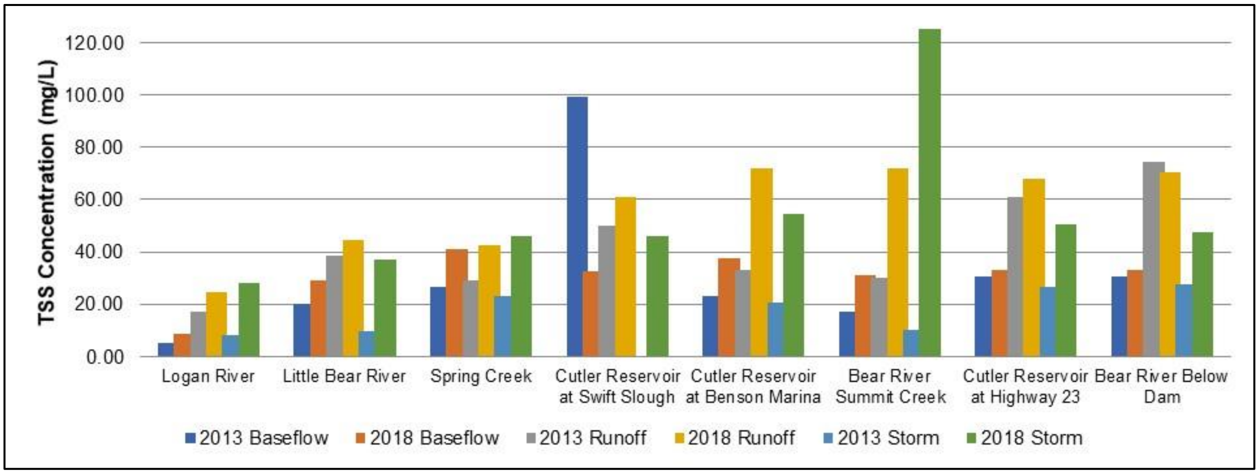

Figure 10. Average total suspended solids for monitoring sites by 2013 and 2018 monitoring hydroperiods.

Trophic State Index

Waterbodies with high nutrient concentrations (that could lead to a high level of algal growth) are said to be eutrophic. The health and support status of a waterbody can be assessed using a trophic state index (TSI), which is a measurement of the biological productivity or growth potential of a body of water. The basis for TSI classification is algal biomass (an estimation of how much algae is present in the waterbody). The calculation of a TSI generally includes the relationship between chlorophyll (the green pigment in algae measured as *chlorophyll a*), transparency using Secchi depth measurements, total phosphorus, and total nitrogen (Carlson and Simpson 1996). *Chlorophyll a* samples and Secchi depths were collected for calculating TSI; however, the data are not presented in this report in keeping with previous 5-year report standards.

The TSI analysis presented here is limited to trophic state predictions related to total phosphorus and is calculated using the following equation:

$$\text{TSI TP} = 14.42 \ \text{Ln}\ (\text{TP}) + 4.15$$

Table 12 identifies generally accepted TSI values derived from this relationship. In most cases, the greater the TSI value a waterbody has (based on collected data), the more eutrophic the waterbody is considered to be.

Table 12. Trophic State Index Values and Status Indicators

TSI	Trophic Status and Water Quality Indicators
<30	Highly oligotrophic, clear water, and high DO throughout the year in the entire hypolimnion
30–40	Oligotrophic, clear water, and possible periods of limited hypolimnetic anoxia (DO = 0)

TSI	Trophic Status and Water Quality Indicators
40–50	Mesotrophic, moderately clear water, increased chance of hypolimnetic anoxia in summer, cold-water fisheries threatened, and supportive of warm-water fisheries
50–60	Mildly eutrophic, decreased transparency, anoxic hypolimnion, macrophyte problems, and generally supportive of warm-water fisheries only
60–70	Eutrophic, blue-green algae dominance, scums possible, and extensive macrophyte problems
70–80	Hypereutrophic, heavy algal blooms possible throughout summer, and dense macrophyte beds
>80	Algal scums, summer fish kills, few macrophytes due to algal shading, and "rough fish" dominance

Source: Carlson and Simpson (1996)

The trophic scale illustrates these general classifications, as well as the midrange conditions that occur between each major category. However, each waterbody is unique and will exhibit site-specific characteristics based on the water quality conditions identified in the lake or reservoir, and over specific time periods, seasons, or water-flow conditions. The identification of TSI values for a specific waterbody allows a general classification and provides insight into overall water quality trends and seasonality. Figure 11 illustrates a decrease in TSI values over time at three sites from a eutrophic state in 1996–1998, 2000–2003, and 2008 to borderline mesotrophic conditions in 2013. The TSI again increased for all three indicator sites to a hypereutrophic state in 2018. The 2013 trophic index is probably not a reliable measure because the total phosphorus measurements seem to be anomalous and off-scale from the rest of the monitoring hydroperiods. This analysis is similar to findings by Budy et al. (2011) where the authors termed Cutler Reservoir as in the state of high eutrophy.

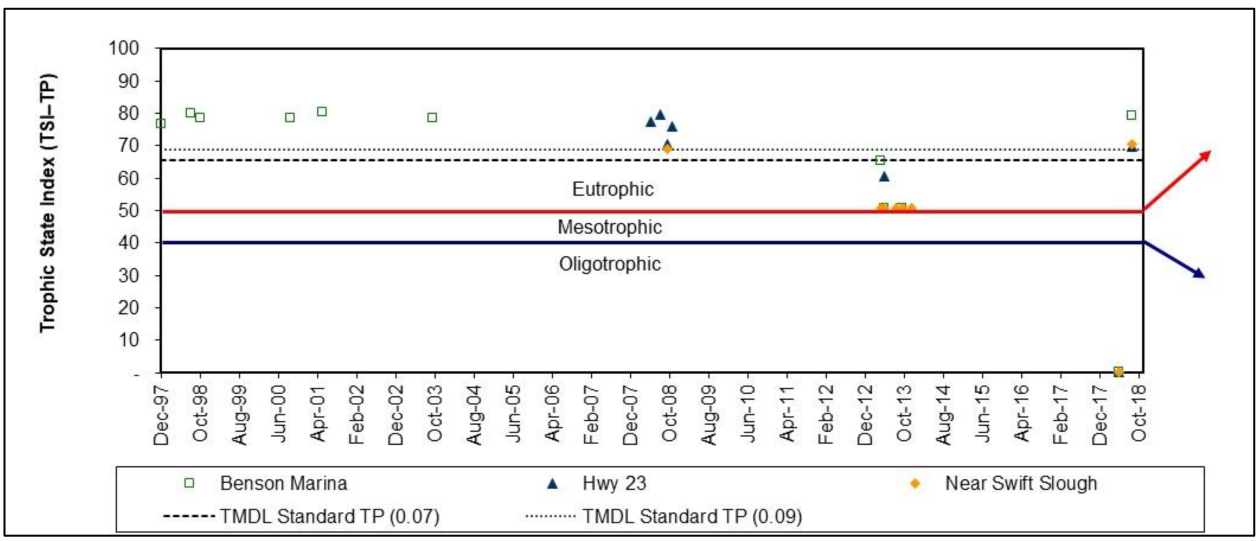

Figure 11. TSI predicted based on total phosphorus concentrations in Cutler Reservoir.

Summary of Spatial Data

Consistent with previous water quality results, data collected in 2018 indicate that water quality in the southern tributaries, specifically Spring Creek, Swift Slough, and the Little Bear River, have considerable influence on water quality throughout Cutler Reservoir. These tributaries continue to have elevated nutrient and bacteria concentrations compared to the other sampling locations in the watershed. *E. coli*, phosphorus, and nitrogen concentrations continue to be highest in the southern tributaries (Figures 12 and 14). This is partially explained by the shallow nature of the southern reservoir and the limited flow-through that occurs, as well as land and water use practices in the area. Total phosphorus concentrations were also high in the northern end of Cutler Reservoir, which could be attributable to much lower inflows especially in the summer and fall periods.

Figure 12. ***E. coli*** **concentrations in the Cutler Reservoir system for 2018 baseflow samples.**

Figure 13. Total phosphorus concentrations in the Cutler Reservoir system for 2018 baseflow samples.

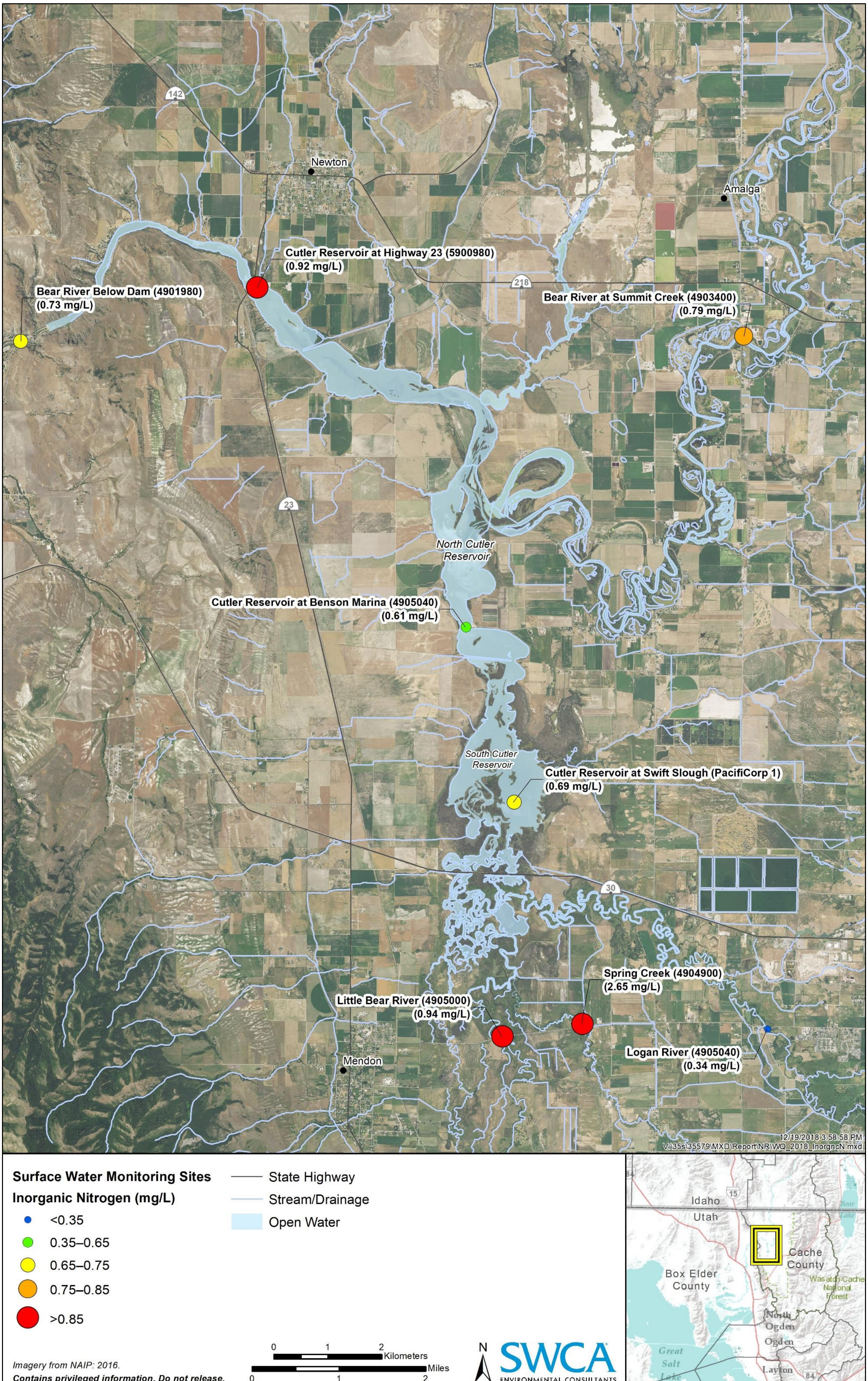

Figure 14. Inorganic nitrogen concentrations in the Cutler Reservoir system for 2018 baseflow samples.

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CUTLER RESERVOIR RESTORATION PROJECTS

PacifiCorp has numerous mitigation projects planned or constructed within the Project watershed, as outlined in the Cutler RMP and elsewhere (PacifiCorp 2002, 2008, 2013, 2018). Included in the implemented Cutler RMP are shoreline buffers, bank stabilization, woodland plantings, fencing for livestock restrictions, grazing management practices, and fish habitat enhancement. Initial monitoring results for the Cutler RMP implementation efforts have rated most of the mitigation/restoration work as good to excellent on most of the implementation sites. Limited sites were rated as poor or destroyed or had failed to establish per the standards detailed in the Cutler RMP. Most of the work around Cutler Reservoir has taken place along the southern tributaries and the reservoir unit and has therefore addressed water quality issues in the Little Bear River, Spring Creek, the Logan River, and the main reservoir section of Cutler Reservoir.

RECOMMENDATIONS

To improve comparability across hydroperiods, future monitoring (the final monitoring sequence for the current Cutler license is scheduled for 2023) should occur at the same monitoring sites and follow the same seasonal distribution as the samples collected in 2008, 2013, and 2018. In addition, samples should be analyzed with the same methods as those used in 2018. This would help exclude any potential data discrepancies in future analyses. Continued collection of chlorophyll *a* data would help identify the level of algal production that, with the climate changes observed in 2018 and potential for the trend to continue, could lead to unwanted algal communities. The addition of storm samples to the monitoring regime have also been difficult to plan for and sample but ensuring the collection of both spring and fall samples will continue to aid in understanding water quality patterns throughout the system. Additionally, more frequent and spatially diverse (e.g., northern end of Cutler Reservoir between Benson Marina and Highway 23) sampling would aid in understanding the sources of water quality issues (e.g., *E. coli*) throughout the Cutler Reservoir system. Total phosphorus and nitrogen in 2013 raised some concerns in part because of results below laboratory detection limits but were determined to be anomalous through the analysis of the 2018 data. Continued sampling would help clarify spatial and temporal changes in water quality. Finally, load analyses from each of the tributaries would aid in the understanding of their relative contributions, and how they affect the conditions throughout Cutler Reservoir.

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APPENDIX A

Comparison Charts

COMPARISON CHARTS

Tables A-1 and A-2 compare 2018 winter baseflow samples with other 2018 baseflow samples and winter baseflow samples from previous hydroperiods.

Table A-1. Hydroperiod Comparison (2018)

***E. coli* (organisms/100 mL)**							
Monitoring Site	**Fall Baseflow**	**Spring Baseflow**	**Summer Baseflow**	**Winter Baseflow**	**STDEV All**	**STDEV No Winter**	**Difference**
Cutler Reservoir south of Swift Slough	12.1	3.9	164.3	16	77.0	90.3	13.4
Cutler Reservoir at Benson Marina	2	98.4	13.5	0.05	47.0	52.7	5.7
Cutler Reservoir at Highway 23	0.05	65	18.3	3.1	30.0	33.5	3.5
Total Phosphorus (mg/L)							
Monitoring Site	**Fall Baseflow**	**Spring Baseflow**	**Summer Baseflow**	**Winter Baseflow**	**STDEV All**	**STDEV No Winter**	**Difference**
Cutler Reservoir south of Swift Slough	0.050	0.137	0.080	0.110	0.038	0.044	0.007
Cutler Reservoir at Benson Marina	0.134	0.251	0.223	0.050	0.091	0.061	-0.030
Cutler Reservoir at Highway 23	0.060	0.158	0.090	0.080	0.043	0.050	0.008
Orthophosphate as P							
Monitoring Site	**Fall Baseflow**	**Spring Baseflow**	**Summer Baseflow**	**Winter Baseflow**	**STDEV All**	**STDEV No Winter**	**Difference**
Cutler Reservoir south of Swift Slough	0.030	0.060	0.025	0.030	0.016	0.019	0.003
Cutler Reservoir at Benson Marina	0.134	0.204	0.222	0.030	0.087	0.046	-0.041
Cutler Reservoir at Highway 23	0.030	0.117	0.005	0.030	0.049	0.059	0.010
Nitrate Nitrogen (mg/L)							
Monitoring Site	**Fall Baseflow**	**Spring Baseflow**	**Summer Baseflow**	**Winter Baseflow**	**STDEV All**	**STDEV No Winter**	**Difference**
Cutler Reservoir south of Swift Slough	0.836	0.802	0.180	0.860	0.327	0.369	0.042
Cutler Reservoir at Benson Marina	0.368	0.557	0.005	0.690	0.298	0.281	-0.017
Cutler Reservoir at Highway 23	0.669	0.825	0.005	0.680	0.367	0.435	0.069

E. coli (organisms/100 mL)							
Total Nitrogen (mg/L)							
Monitoring Site	**Fall Baseflow**	**Spring Baseflow**	**Summer Baseflow**	**Winter Baseflow**	**STDEV All**	**STDEV No Winter**	**Difference**
Cutler Reservoir south of Swift Slough	0.250	0.690	1.170	0.520	0.387	0.460	0.073
Cutler Reservoir at Benson Marina	0.250	1.070	1.540	0.660	0.553	0.653	0.100
Cutler Reservoir at Highway 23	0.250	1.020	0.980	0.600	0.362	0.433	0.072

Table A-2. Winter Baseflow Compared to Previous Winter Hydroperiods (1996–2018)

E. coli (organisms/100 mL)								
Monitoring Site	**1996–1998 Winter**	**2000–2003 Winter**	**2008 Winter**	**2013 Winter**	**2018 Winter**	**STDEV All**	**STDEV No 2018**	**Difference**
Cutler Reservoir south of Swift Slough	N/A	N/A	10	25.44	16	7.8	10.9	3.1
Cutler Reservoir at Benson Marina	123.69	5.09	20.29	30.21	0.05	50.5	53.6	3.0
Cutler Reservoir at Highway 23	N/A	N/A	33.25	9.54	3.1	15.9	16.8	0.9
Total Phosphorus (mg/L)								
Monitoring Site	**1996–1998 Winter**	**2000–2003 Winter**	**2008 Winter**	**2013 Winter**	**2018 Winter**	**STDEV All**	**STDEV No 2018**	**Difference**
Cutler Reservoir south of Swift Slough	N/A	N/A	0.09	0.03	0.11	0.0	0.0	0.0
Cutler Reservoir at Benson Marina	0.23	0.43	0.27	0.27	0.05	0.1	0.0	-0.1
Cutler Reservoir at Highway 23	N/A	N/A	0.17	0.03	0.08	0.1	0.1	0.0
Orthophosphate as P								
Monitoring Site	**1996–1998 Winter**	**2000–2003 Winter**	**2008 Winter**	**2013 Winter**	**2018 Winter**	**STDEV All**	**STDEV No 2018**	**Difference**
Cutler Reservoir south of Swift Slough	N/A	N/A	0.06	0.03	0.03	0.0	0.0	0.0
Cutler Reservoir at Benson Marina	0.13	0.23	0.16	0.27	0.03	0.1	0.1	0.0
Cutler Reservoir at Highway 23	N/A	N/A	0.05	0.03	0.03	0.0	0.0	0.0

***E. coli* (organisms/100 mL)**

Nitrate Nitrogen (mg/L)

Monitoring Site	1996–1998 Winter	2000–2003 Winter	2008 Winter	2013 Winter	2018 Winter	STDEV All	STDEV No 2018	Difference
Cutler Reservoir south of Swift Slough	N/A	N/A	0.33	1.28	0.86	0.5	0.7	0.2
Cutler Reservoir at Benson Marina	0.76	1.14	0.66	1.35	0.69	0.4	0.5	0.1
Cutler Reservoir at Highway 23	N/A	N/A	0.55	1.11	0.68	0.3	0.4	0.1

Total Nitrogen (mg/L)

Monitoring Site	1996–1998 Winter	2000–2003 Winter	2008 Winter	2013 Winter	2018 Winter	STDEV All	STDEV No 2018	Difference
Cutler Reservoir south of Swift Slough	N/A	N/A	0.025	0.472	0.52	0.3	0.3	0.0
Cutler Reservoir at Benson Marina	N/A	N/A	0.461	0.666	0.66	0.1	0.1	0.0
Cutler Reservoir at Highway 23	N/A	N/A	0.651	0.708	0.6	0.1	0.0	0.0

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