Confederated Tribes of the Warm Springs
Reservation of Oregon
P. O. Box 960, Warm Springs, OR 97761

Portland General Electric
121 SW Salmon St. Portland, OR 97204

May 31st, 2019

ELECTRONICALLY FILED

Project No. 2030 – Oregon
Pelton Round Butte Hydroelectric Project

Honorable Kimberly D. Bose
Secretary
Federal Energy Regulatory Commission
888 First Street, NE
Washington, DC 20426

Re: Project No. 2030 – Pelton Round Butte Hydroelectric Project – Article 416 – 2018 Water Quality Monitoring Report

Dear Secretary Bose:

Portland General Electric Company ("PGE") and the Confederated Tribes of the Warm Springs Reservation of Oregon ("CTWS"), are the Joint Licensees for the Pelton Round Butte Hydroelectric Project (Project No. 2030). On June 21, 2005, the Commission issued an Order Approving Settlement and Issuing New License, *Portland General Electric Company & Confederated Tribes of the Warm Springs Reservation of Oregon*, 111 FERC ¶ 61,450 (2005), *order on reh'g* 117 FERC ¶ 61,112 (2006).

Article 416 of the license requires the Joint Licensees to file with the Commission a copy of their annual report of water quality monitoring pursuant to the Water Quality Management and Monitoring Plan approved by the Oregon Department of Environmental Quality ("DEQ) and the Confederated Tribes of the Warm Springs Reservation Water Control Board ("WCB") as part of the water quality certifications issued by those agencies for the Project and attached to the license as Appendices A and B, respectively. Pursuant to Article 416, this annual report is to be filed with the Commission and the Fish Committee within 30 days of its filing with DEQ and WCB. By order dated April 2, 2008, the Commission required that the report be filed by June 1 each year. *Portland General Electric Company & Confederated Tribes of the Warm Springs Reservation of Oregon*, 123 FERC ¶ 62,008 (2008),

cc: Fish Committee

Pursuant to Article 416, attached for filing with the Commission is a copy of the Joint Licensees' "2018 Water Quality Monitoring Report," which will be filed with DEQ and the WCB.

Please don't hesitate to call me (503) 464-8133 with any questions or comments regarding this filing.

Respectfully submitted,

Jessica Graeber
Environmental Compliance & Licensing

cc: Fish Committee

Pelton Round Butte Project (FERC 2030)
2018 Water Quality Monitoring Report

Prepared by:

Lori Campbell

Portland General Electric Company

On Behalf of

Portland General Electric Company

And

The Confederated Tribes of the Warms Springs Reservation of Oregon

April 2019

Campbell, L. 2019. Pelton Round Butte Project (FERC 2030) 2018 Water Quality Monitoring Report. Portland General Electric Company. Portland, Oregon.

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Introduction

This water quality monitoring report describes measures taken by Portland General Electric Company (PGE) and the Confederated Tribes of the Warm Springs Reservation of Oregon (CTWSRO) (collectively, the Licensees) in 2018 to satisfy the requirements of the 401 Water Quality Certificates for the Pelton Round Butte Project (FERC # 2030). The Project consists of a three-dam complex on the Deschutes River, west of Madras, Oregon. A complete description of the Project is available in the Settlement Agreement Concerning the Relicensing of the Pelton Round Butte Hydroelectric Project (PGE et al. 2004).

Background

The earliest water quality work on Lake Billy Chinook, the waterbody impounded by Round Butte Dam, was conducted during 1964 and 1965 (Mullarkey 1967). Later, as part of the relicensing process, PGE contracted with E&S Environmental Chemistry to conduct a limnological study of the reservoir from 1994 through 1996 (Raymond et al. 1997). This study was more extensive than the original work and included sampling sites downstream of Lake Billy Chinook in the lower river. At the completion of the Raymond et al. study, it was decided to continue monitoring water temperatures at most of the same sites to support other aquatic studies being conducted during the relicensing process (Lewis 1997); beginning in 1998, additional water quality parameters beyond temperature were also collected at these sites. During this period, Project effects on water quality in the lower Deschutes River were assessed through additional studies (Eilers et al. 2000) and by modeling of historic temperature data (Huntington et al 1999). In 2000, a subset of the water temperature recorders used for the lower river studies was replaced so that long-term monitoring could continue (Lewis 2001).

To evaluate the potential effects of surface withdrawal from Lake Billy Chinook, hydrodynamic and water quality modeling were initiated during Project relicensing (Yang et al. 2000). Modeling results indicated the potential for returning the annual temperature regime of the water released from the Project's Reregulating Dam toward pre-project patterns, and improving water quality in the project reservoirs and in the lower Deschutes River (PGE and CTWSRO 2001).

In June 2005, the Licensees were issued a new license by the Federal Energy Regulatory Commission (FERC). Terms of Clean Water Act 401 Certificates issued by the Oregon Department of Environmental Quality (ODEQ) and the CTWSRO Water Control Board were incorporated into the license by reference and specified in the Pelton Round Butte Project Water Quality Management and Monitoring Plan (PGE et al. 2004). As a condition of the new license and 401 certificates, the Licensees are required to report water quality monitoring results on an annual basis to ODEQ, the CTWSRO Water Control Board, and the Pelton Round Butte Fish Committee. Additionally, in accordance with the Water Quality Management and Monitoring Plan (WQMMP), and as specified in the Project's Section 401 certification conditions, intragravel dissolved oxygen (IGDO) has been monitored downstream of the Reregulating Dam after implementation of selective water withdrawal (SWW) in the Round Butte forebay to establish relationships between IGDO and ambient dissolved oxygen (DO) concentrations. A requirement of the WQMMP is the submittal, as part of the Annual Water Quality Monitoring Report, of an IGDO Monitoring Report.

The information summarized in this report are results of monitoring of current conditions at the Project. Selective water withdrawal was initiated late in 2009, in part to improve water quality in the lower Deschutes River and Lake Billy Chinook. The following is an annual summary of results for the water quality monitoring program for 2018. The IGDO Monitoring Report summarizing monitoring of IGDO in 2018, is included in Appendix 2.

Methods

Onset® temperature loggers (or equivalent), set at 1-h recording intervals, were installed in the project reservoirs and the lower Deschutes River (Table 1; Figure 1). There are eight loggers set in the lower river to record temperature. Site 7 in the forebay of Round Butte Dam is a continuous profile station, with 12 recorders suspended in the water column from the surface to 100 m in depth. Site 4 in the forebay of Pelton Dam is also a continuous profile, with 4 recorders from the surface to 40 m. In addition, four grab sample temperature profiles were measured monthly in Lake Billy Chinook (sites 7, 10, 13, and 16) and in the forebay of Pelton Dam (Site

4). Data summaries include the 7-day average of the daily maximum temperature for the continuous monitoring sites.

A Hydrolab® water quality multi-parameter probe was used monthly at 16 sites to collect both grab and profile samples (Table 1). Two of the 16 sites were in the lower Deschutes River. The parameters recorded included: temperature, dissolved oxygen, conductivity, turbidity, and pH. There is a continuous Hydrolab® operating in the tailrace of the Reregulating Dam, which records at 1-h intervals and is downloaded monthly. Also, as an indicator of phytoplankton productivity, Secchi visibility was sampled monthly at the forebay sites and in each arm of Lake Billy Chinook using methods described in Lind (1974).

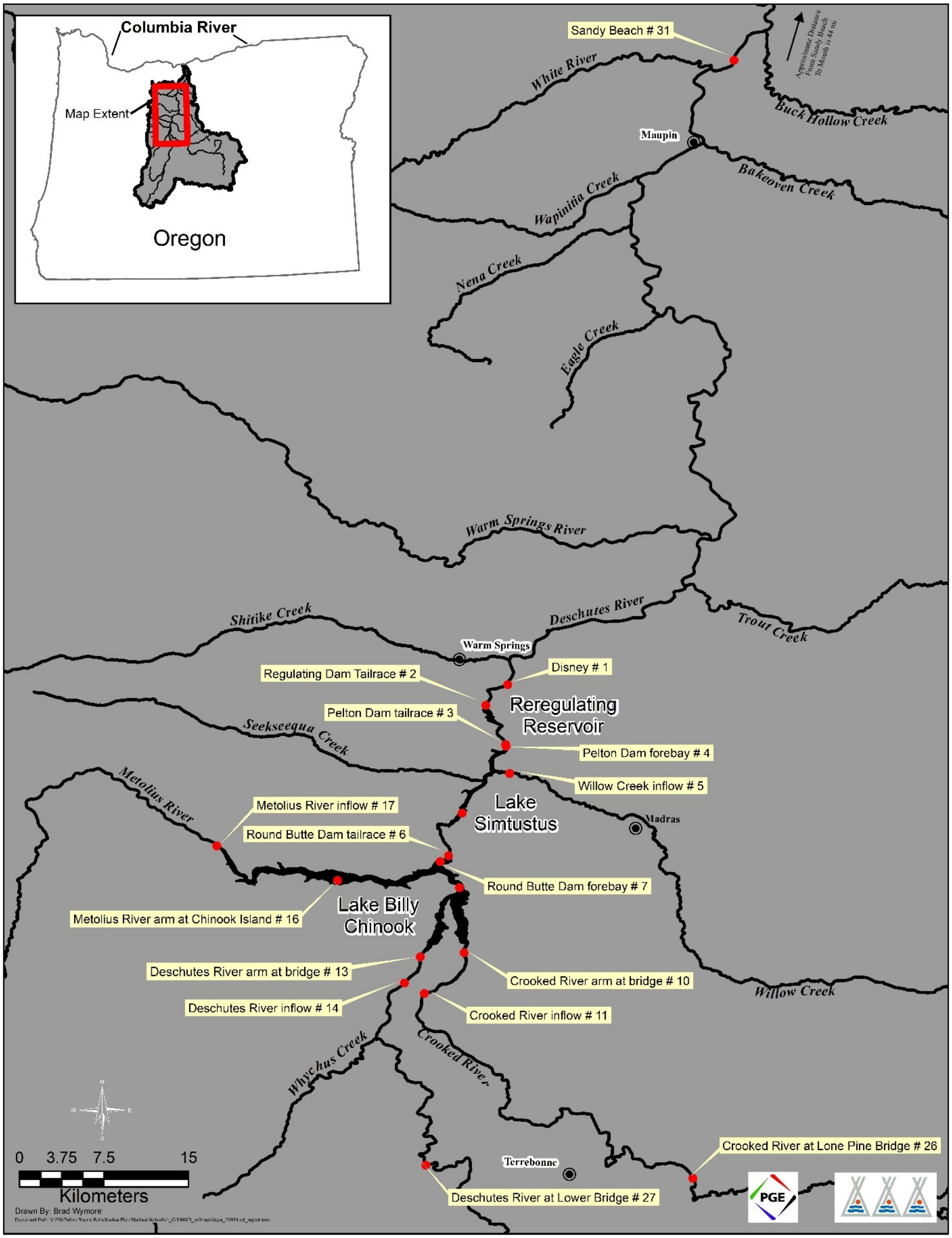

Figure 1. Water quality monthly monitoring locations.

Table 1. Water quality monitoring locations and sampling summary.

Site Number	Site Description	Site Location[a]	Method of Sampling[b]	Type of Sampling[c]	Frequency
1	Disney Riffle (**DZ**)	D 160 km	Hydrolab	Grab	Monthly
2	Reregulating Dam tailrace (**Reg TR**)	D 161 km	Temperature Hydrolab Hydrolab	Continuous Continuous Grab	1 h 1 h Monthly
3	Pelton Dam tailrace (**PEL TR**)	D 165 km	Hydrolab	Grab	Monthly
4	Pelton Dam forebay (**PELFB**)	D 166 km	Temperature Hydrolab Secchi	Continuous profile Grab profile Grab	1 h Monthly Monthly
5	Willow Creek inflow (**WC**)	W 1 km	Hydrolab	Grab	Monthly
6	Round Butte Dam tailrace (**RBTR**)	D 178 km	Temperature Hydrolab Hydrolab	Continuous Continuous Grab	1 h 1 h Monthly
7	Round Butte Dam forebay (**RBDFB**)	D 179 km	Temperature Hydrolab Secchi	Continuous profile Grab profile Grab	1 h Monthly Monthly
10	Crooked River Arm at bridge (**CRABR**)	C 5 km	Hydrolab Secchi	Grab profile Grab	Monthly Monthly
11	Crooked River inflow (**CR**)	C 10 km	Temperature Hydrolab	Continuous Grab	1 h Monthly
13	Deschutes River Arm at bridge (**DRABR**)	D 189 km	Hydrolab Secchi	Grab profile Grab	Monthly Monthly
14	Deschutes River inflow (**DR**)	D 192 km	Temperature Hydrolab	Continuous Grab	1 h Monthly

Site Number	Site Description	Site Location[a]	Method of Sampling[b]	Type of Sampling[c]	Frequency
16	Metolius River Arm at Chinook Island (**MRAIS**)	M 8 km	Hydrolab Secchi	Grab profile Grab	Monthly Monthly
17	Metolius River inflow (**MR**)	M 19 km	Temperature Hydrolab	Continuous Grab	1 h Monthly
26	Crooked River at Lone Pine Bridge (**CRALPB**)	C 48 km	Hydrolab	Grab	Monthly
27	Deschutes River at Lower Bridge (**DRALBR**)	D 216 km	Hydrolab	Grab	Monthly
28	Dry Creek	D 149 km	Temperature Hydrolab	Continuous Grab	1 h Quarterly
30	Nena	D 93 km	Temperature Hydrolab	Continuous Grab	1 h Quarterly
31	Sandy Beach (**SB**)	D 72 km	Temperature Hydrolab	Continuous Grab	1 h Monthly
32	Macks Canyon	D 39 km	Temperature Hydrolab	Continuous Grab	1 h Quarterly
33	Rockpile Campground (Moody)	D 2 km	Temperature Hydrolab	Continuous Grab	1 h Quarterly

[a] Site location is identified by the river system and kilometers from its confluence. C = Crooked River, D = Deschutes River, M = Metolius, and W = Willow Creek.

[b] Temperature data are collected with programmable recorders. Hydrolab multi-probes are used to collect other water quality measurements that include: temperature, dissolved oxygen, conductivity, and pH.

[c] Continuous sampling data are collected at the frequency indicated. Grab samples are samples collected just one time at the frequency indicated. Profile sampling data are collected at different depths: 0, 2, 4, 6, 8, 10, 20, 30, 40, 50, 75, and 100 m. If the water depth is less than 100 m, the last profile sample is taken as close the bottom as possible. The continuous temperature profile in Lake Simtustus is conducted at 0, 4, 10, and 40 m in depth.

Results of the 2018 monitoring were focused on the sites and parameters, listed in Table 1 (above). A complete list of parameters, sites and sample frequency can be found in the WQMMP.

Temperature

Temperature monitoring was conducted at selected sites identified in Table 1 and Figure 1. Hourly temperature was recorded from continuous temperature monitors installed at the Round

Butte Dam and Reregulating Dam tailraces (Sites 6 & 2). The 7-day average of the daily maximum temperature was then calculated for both sites. Continuous temperature data were recorded for the project tributary inflows and lower Deschutes River. The 7-day average of the daily maximum temperature was calculated for the tributary inflow sites (11, 14, 17), Round Butte Dam tailrace (Site 6), and lower river sites (28, 30, 31, 32, and 33). In addition, monthly grab samples using a Hydrolab® water quality multi-parameter probe were recorded for the inflow and lower river sites.

Site 7 in the forebay of Round Butte Dam has a continuous profile station with recorders suspended in the water column from the surface to 100 m in depth. Temperatures reported in this summary are from depths of 0 m (surface) to 100 m. Site 4 in the forebay of Pelton Dam also has a continuous profile station. Temperature at this site is reported at depths of 0 m to 40 m. In addition, grab profiles were collected monthly at Round Butte forebay (Site 7) and in the forebay of Pelton Dam (Site 4).

Dissolved Oxygen

Dissolved oxygen (DO) monitoring was conducted at selected sites identified in Table 1 and Figure 1. In 2018 monitoring of DO was conducted at the continuous monitoring stations in Round Butte Dam tailrace (Site 6) and in the Deschutes River immediately below the Reregulating Dam (Site 2). Monitoring for DO at tributary inflow sites (11, 14, and 17) and lower river Site 31 was conducted monthly from grab samples using the Hydrolab®. Monthly grab samples were also recorded for DO profiles at Site 7 in the Round Butte Dam forebay, Site 10 in the Crooked River Arm, Site 13 in the Deschutes River Arm, Site 16 in the Metolius River Arm, and Site 4 in the Pelton Dam forebay.

In 2018, DO/intragravel dissolved oxygen (IGDO) was monitored to validate the project's 9.0 mg/L target criterion (according to the WQMMP). The DO/IGDO was monitored downstream of the Reregulating Dam following protocols described in the 2009 IGDO Study Plan. Results from the DO/IGDO monitoring are found in Appendix 2.

pH

In 2018, monitoring of pH was conducted at the continuous monitoring station in Round Butte Dam tailrace (Site 6) and in the Deschutes River immediately below the Reregulating Dam (Site

2). Monitoring for pH at tributary inflow sites 11, 14, and 17, and lower river Site 31 was conducted monthly from grab samples using the Hydrolab®. Monthly pH grab samples were also recorded for profiles in the Round Butte Dam forebay (Site 7), the Crooked River Arm (Site 10), the Deschutes River Arm (Site 13), the Metolius River Arm (Site 16), and in the Pelton Dam forebay (Site 4).

pH was also monitored in the project tributary inflows when pH values at the Reregulating station exceeded 8.3 pH Standard Units. The weighted average of pH was calculated for the tributary inflows and compared to outflow pH values.

Results

Temperature Management Operations in 2018

In 2018, the PRB Project operated under interim agreements with ODEQ and CTWSRO-WCB for temperature and dissolved oxygen. The 2018 interim agreements allowed that project discharge waters (as the 7-d average maximum temperature) would meet or fall below the calculated temperature without the project in place once temperatures reached 13°C (the current state temperature standard), and that temperatures could be up to 0.5°C above the calculated temperature for up to three days. After that, discharge temperatures should be back down to no more than 0.3°C above calculated temperature. These interim measures reflect the emphasis on adaptive management in the WQMMP, especially with regard to temperature management.

The calculated temperature was determined using a regression equation (Huntington et al. 1999) to calculate the 7-day mean maximum temperature (7dAM) at the location of the Reregulating Dam if the Project were not in place. The 7dAM temperature derived from real time temperature at the Reregulating Dam was then used to determine compliance with the calculated temperature target (calculated temperature without the project in place).

Temperatures profiles in Round Butte Dam forebay in 2018 were similar to those recorded in 2010 through 2017 and reflected temperatures that occurred between pre-SWW conditions and the modeled temperatures described in the WQMMP. A summary of blend adjustments made for 2011 through 2018 is shown in Appendix 1-Table 1. Similar to previous years, adjustments in 2018 were intentionally made as needed in the surface/bottom withdrawal to follow changes in the calculated temperature without the project in place. Changes to the blend were as follows:

On May 22, the percentage of bottom flow from the SWW was adjusted from all surface flow to 15 percent bottom withdrawal. On May 31, the amount of bottom water was adjusted upwards to 20 percent.

The bottom flow was adjusted upward on June 11 to 25 percent, then to 30 percent on June 15, where it remained through the end of the month.

On July 23, the percentage of bottom withdrawal from the SWW was increased to 40 percent and remained there through the end of July.

On August 20 the percent bottom water was increased to 50 percent. The SWW was shut down for maintenance on September 4. Therefore, bottom flow remained at the maximum amount (approximately 60 percent) that can be released from the facility through the remainder of the temperature management season. Discharge went to 100% surface water on October 28.

Temperature Monitoring

According to the original WQMMP, once the project discharge temperature at the Reregulating Dam reaches a 7dAM of 10^{o}C, the target temperature for discharge at the Reregulating Dam becomes the calculated without-project temperature, reported as 7dAM. Under the interim agreements, the 7dAM discharge temperature threshold was adjusted to 13^{o}C, the current state temperature standard, at which point the calculated temperature was used as the temperature target for discharge at the Reregulating Dam. The calculated without-project temperatures for year 2018 are shown in Figure 2. In 2018, project discharge temperatures rose briefly above the calculated temperature in July and, then fell back below the calculated temperature. However, discharge temperatures remained within the temperature allowance according to the 2018 Interim Agreement. As inflow temperatures warmed through the spring and summer months the discharge temperatures tracked with the calculated temperature until September, at which time the calculated temperature dropped more quickly than project temperatures. In September discharge temperature dropped below the calculated temperature and simultaneously fell below the 13^{o}C criterion, thus staying within the interim agreement(s) allowance. Discharge temperatures as a 7dAM for 2010 through 2018 compared to pre SWW discharge temperatures (average 7dAM 2006-2009) are shown in Figure 3. Since selective water withdrawal was implemented, discharge temperatures have consistently reflected a shift in seasonal high temperatures 4 to 5 weeks earlier, as intended, to reflect pre-project conditions.

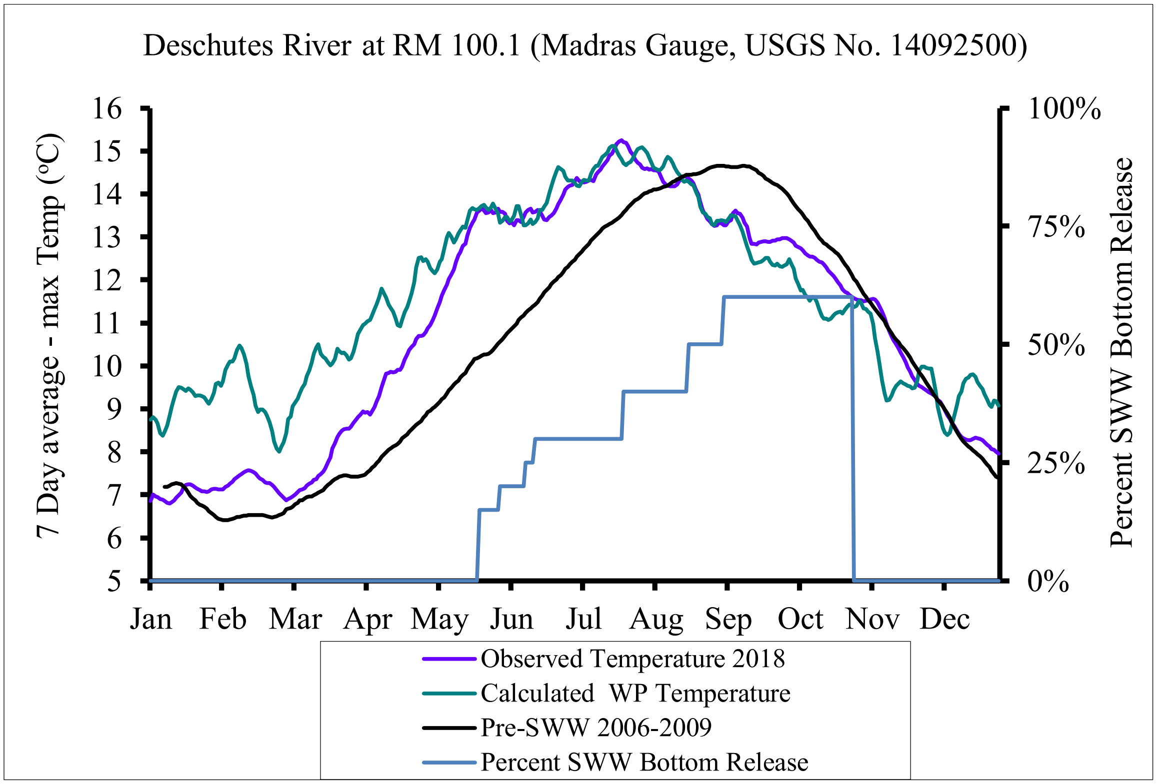

Figure 2. Calculated without project temperatures (as 7dAM) for the PRB Project compared to the pre-SWW 3-year average (2006-2009) and observed 2018 7dAM discharge temperatures. Teal line reflects the percent bottom water withdrawal.

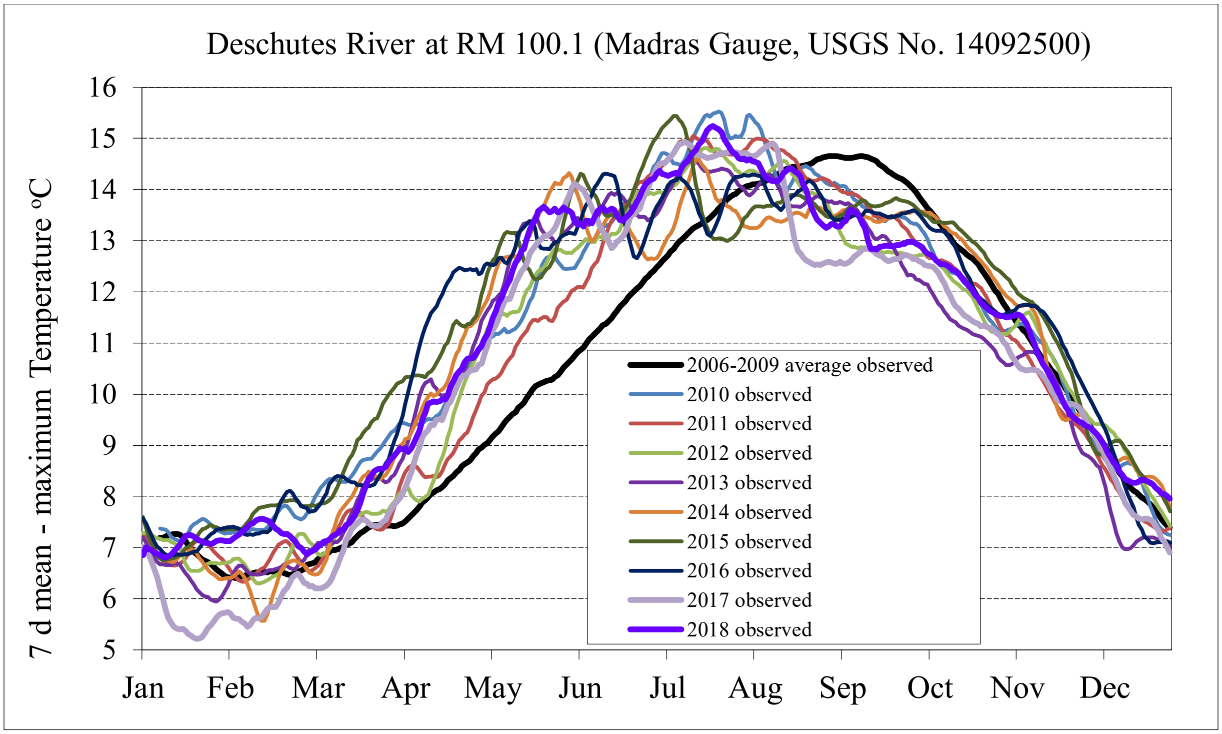

Figure 3. The pre-SWW 3-year average 7dAM (2006-2009) for the Pelton Round Butte Project compared to the observed 2010-2018 7dAM discharge temperatures.

The 7dAM temperatures for the project inflows in 2018 are shown in Figure 4; seasonal high temperatures were recorded between May and September for all tributaries. The Metolius River inflow typically remains cooler throughout the year than either the Crooked or Deschutes rivers. The maximum temperature of 11.8 ^{o}C was recorded in July, while the minimum value of 5.0 ^{o}C reported for 2018 occurred in December. The Deschutes River had the most variable temperatures of the three inflow tributaries with the highest temperature (16.5^{o}C) recorded in July and the lowest (4.7^{o}C) in February (Figure 4). Crooked River inflow temperatures periodically reached 14.1 ^{o}C in June and July. Minimum temperatures occurred in January, with a low value of 11.4 ^{o}C.

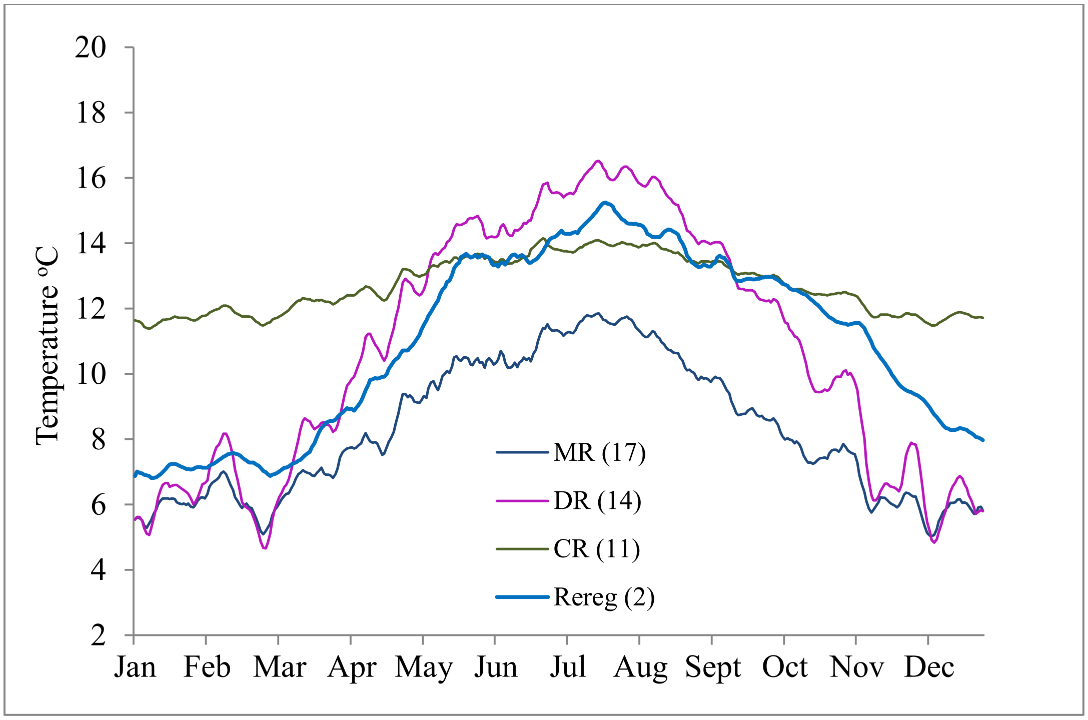

Figure 4. 7dAM inflow temperatures for the Metolius, Deschutes, Crooked rivers, and Lower Deschutes River at Madras (Sites 17, 14, 11, 2) in 2018.

The daily average temperature profiles for Round Butte forebay are shown in Figure 5. Round Butte Dam forebay showed evidence of developing thermal stratification early in the year, however, the reservoir showed the greatest degree of stratification from mid-May through October (Figure 5). In 2018, the reservoir appeared to mix and de-stratify by early December. The reported maximum temperature (7 dAM) for the epilimnion (reported at 2m depth) reached 22.8 ºC in August. The hypolimnion (20m depth) reached a maximum temperature of 14.0 ºC in September. Notably, maximum temperatures at depth occurred as the reservoir showed evidence of depleted cool water reserves. This was apparent in the discharge temperatures when they rose above the calculated temperature in early September (Figure 2). Minimum recorded temperatures in Round Butte forebay occurred in January and February for the epilimnion and hypolimnion with values of 7.0 ºC and 6.9 ºC, respectively. The 2018 profile temperatures were relatively cooler at depth in the fall (similar to years 2010 - 2013) compared to more recent years of SWW operation (years 2014-2016). In 2018 bottom water withdrawal was also initiated two weeks later in the spring than in 2016. The 2018 surface temperatures by the late summer were again warmer than recent years (Figures 5), likely due to warmer weather than seen in years prior to 2015.

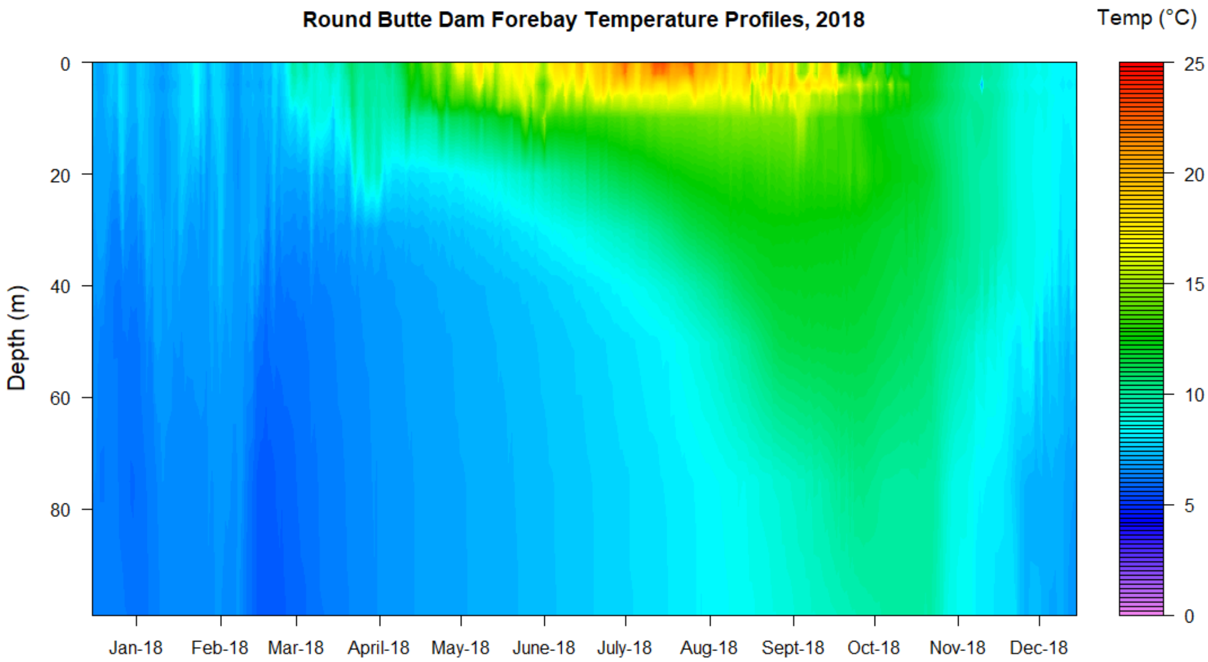

Figure 5. Round Butte Dam forebay temperature (daily average) profiles in 2018.Note that temperature data for 8m depth between November and end of year was not recorded. Temperature data for 10m depth from December was also not recorded. Temperature data was averaged for these periods since temperature profiles were consistent through upper and lower depths.

The daily average temperature profiles for the first of each month for Round Butte forebay are shown in Figure 6. Profiles from Round Butte forebay early in 2018 resulted in temperatures between pre-SWW conditions and the modeled Blend 13 condition. Blend 13 was the modeled condition based on temperatures in the 1995 water year. By late spring months in 2018, temperatures (again consistent with the previous years) had moved towards pre-SWW conditions. The second half of the year reflected a visible shift in temperatures as the reservoir became somewhat more stratified (Figure 6). The 2018 profiles, similar to conditions in years 2010 through 2017, evidenced transitional temperatures during summer and fall months (approximately 1–4 °C warmer than Blend 13 and 1–3 °C cooler than pre-SWW temperatures).

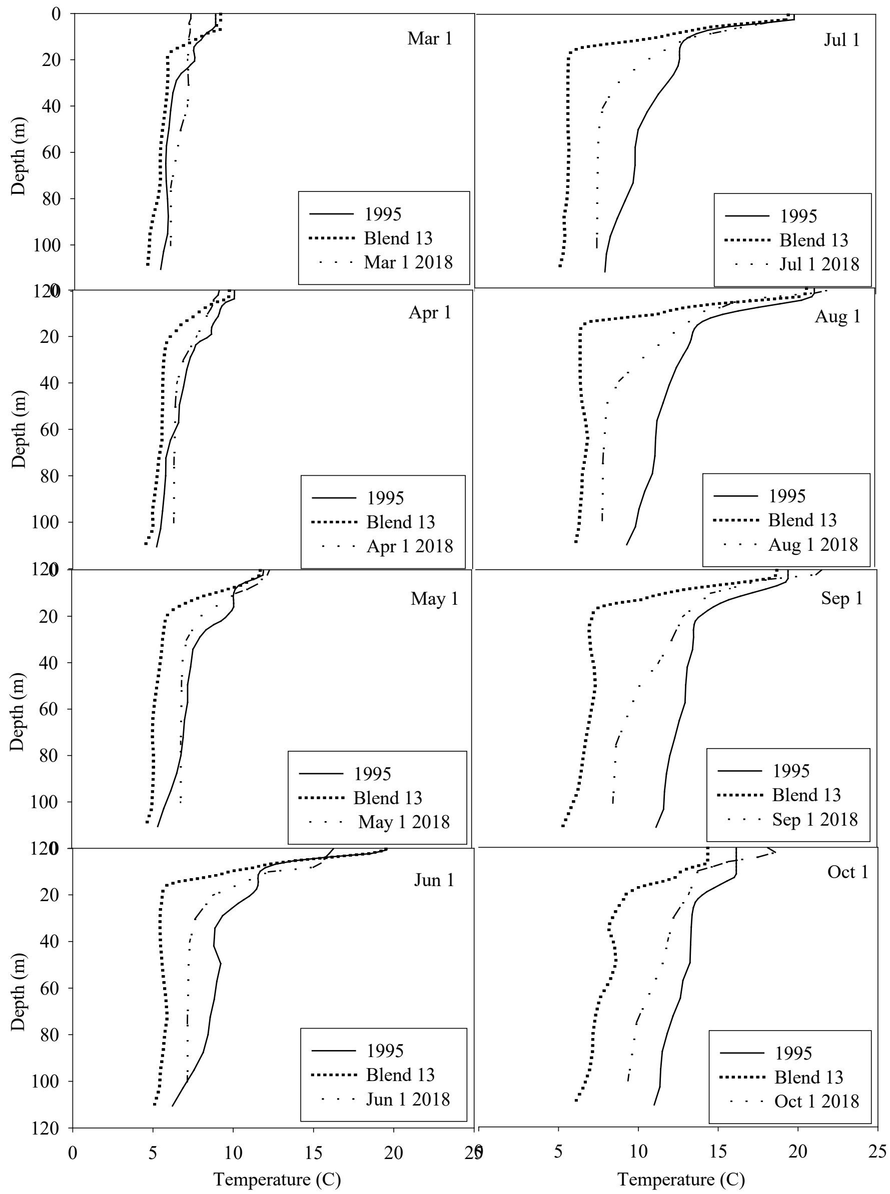

Figure 6. Round Butte Dam forebay temperature (daily average) profiles in 2018 (March-October) compared to 1995 existing conditions and Blend 13 (modeled based on 1995 water year; later iterations resulted in Blend 17).

The 7dAM temperatures for Round Butte Dam tailrace are shown in Figure 7. Temperatures in the tailrace reached a high value of 14.3 ºC in June and a low of 6.1 ºC in January. When power generation decreases or ceases altogether (typically late at night or during early morning hours), currents in the tailrace are also reduced. This results in warmer water from downstream in Lake

Simtustus moving back toward the Round Butte Dam tailrace. These fluctuations can be observed particularly in the warm summer months as peaks in the 7dAM temperatures. Therefore, temperatures recorded during non-generation hours in 2018 are not included in this report. Thus, Figure 7 reflects temperature data during the warm months that should show less temperature influence from Lake Simtustus. Blended surface and bottom withdrawal was also occurring between May and October.

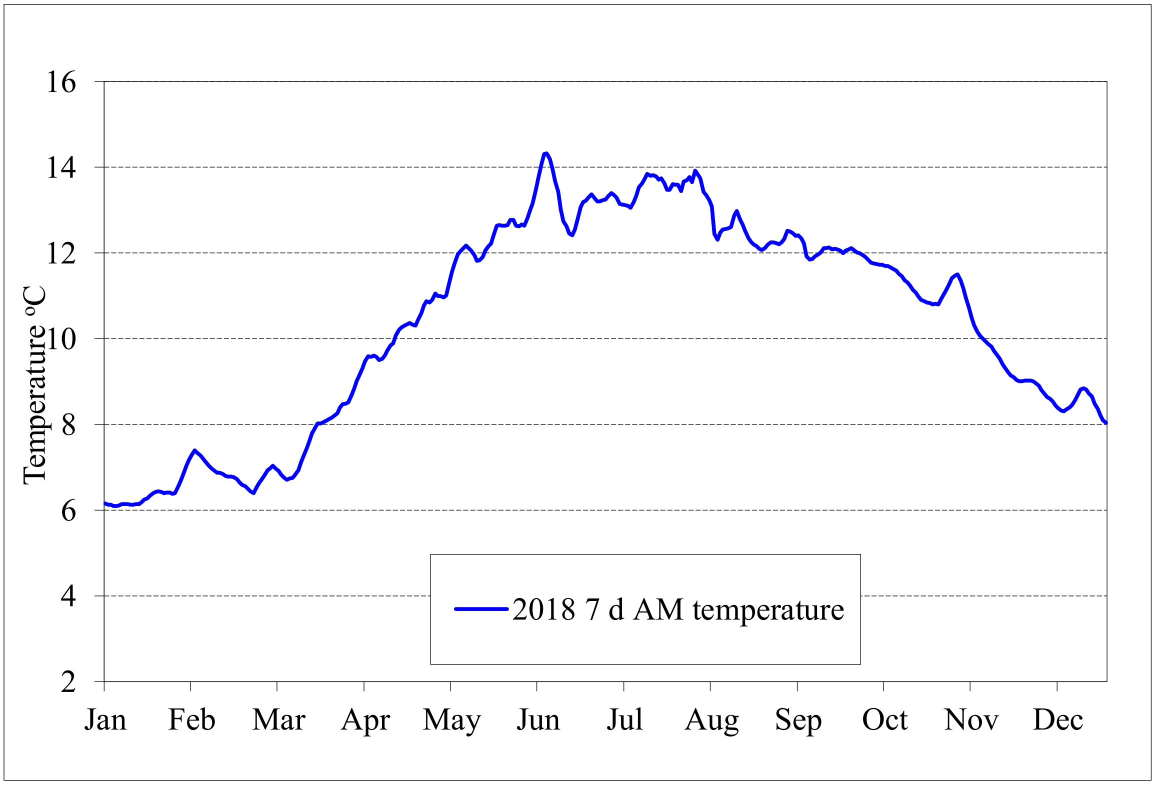

Figure 7. 7dAM temperature for Round Butte Dam tailrace (Site 6) in 2018 (does not include temperature data for non-generation hours).

The daily average temperature profiles for Pelton forebay are shown in Figure 8. During June the temperature array was lost, then replaced. In this period temperatures were not recorded, reflected by the gap shown in Figure 8. Lake Simtustus showed the greatest stratification between mid-May and September and was mixed by late-October. The maximum temperature (7 dAM) of 22.1 ºC in the epilimnion (reported at 0.5m depth) occurred in July and August. Temperatures in the hypolimnion (reported at 10m depth) reached a maximum of 1.9 ºC in

August. Seasonal low temperatures occurred in January with values of 7.1 °C and 6.9 °C at the both the surface and in the hypolimnion respectively.

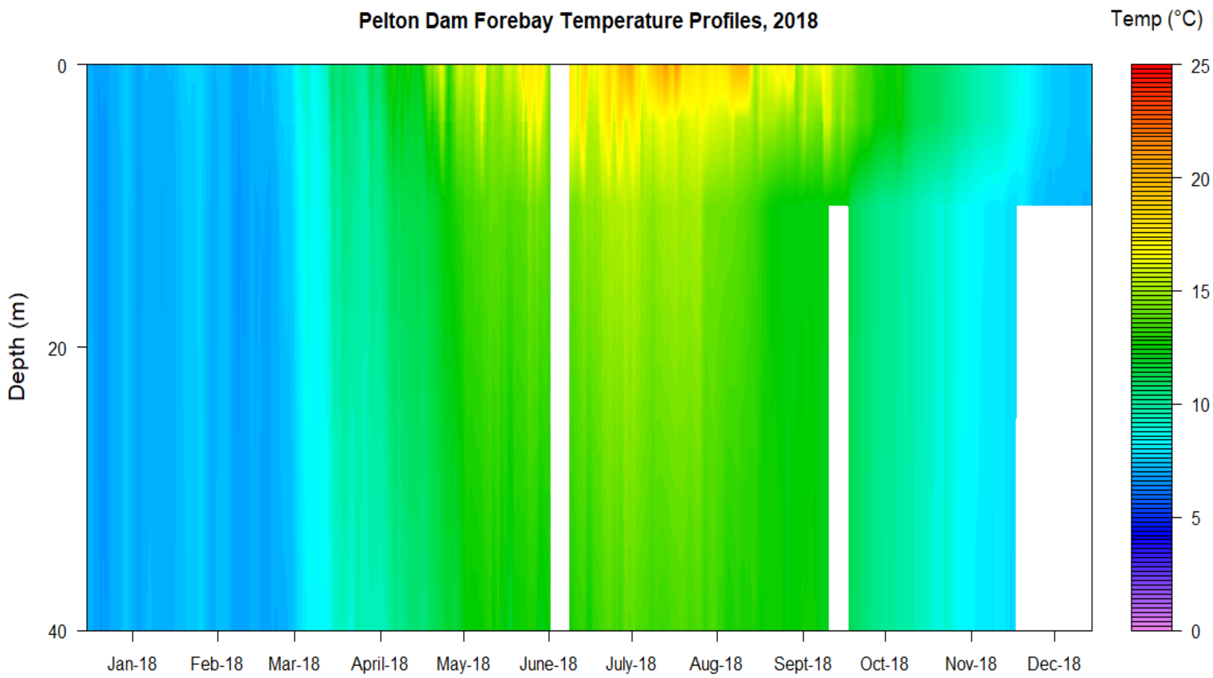

Figure 8. Pelton forebay temperature (daily average) profiles (January - December) in 2018. Gaps in color represent periods where temperature wasn't recorded.

The 7dAM temperatures for the Reregulating Dam tailrace are shown in Figure 9. Seasonal peaks in temperature occurred between May and July, with low values of 6.7 ºC (7 dAM) occurring in January. The maximum temperature of 15.0 ºC (7 dAM) was recorded in July. Daily maximum temperatures at the Reregulating Dam in 2018, similar to SWW operational years 2010 - 2017, showed an approximate 4-5 week shift of seasonal high temperatures from the end of August back to mid-July (Figures 3 and 10), mimicking pre-project conditions.

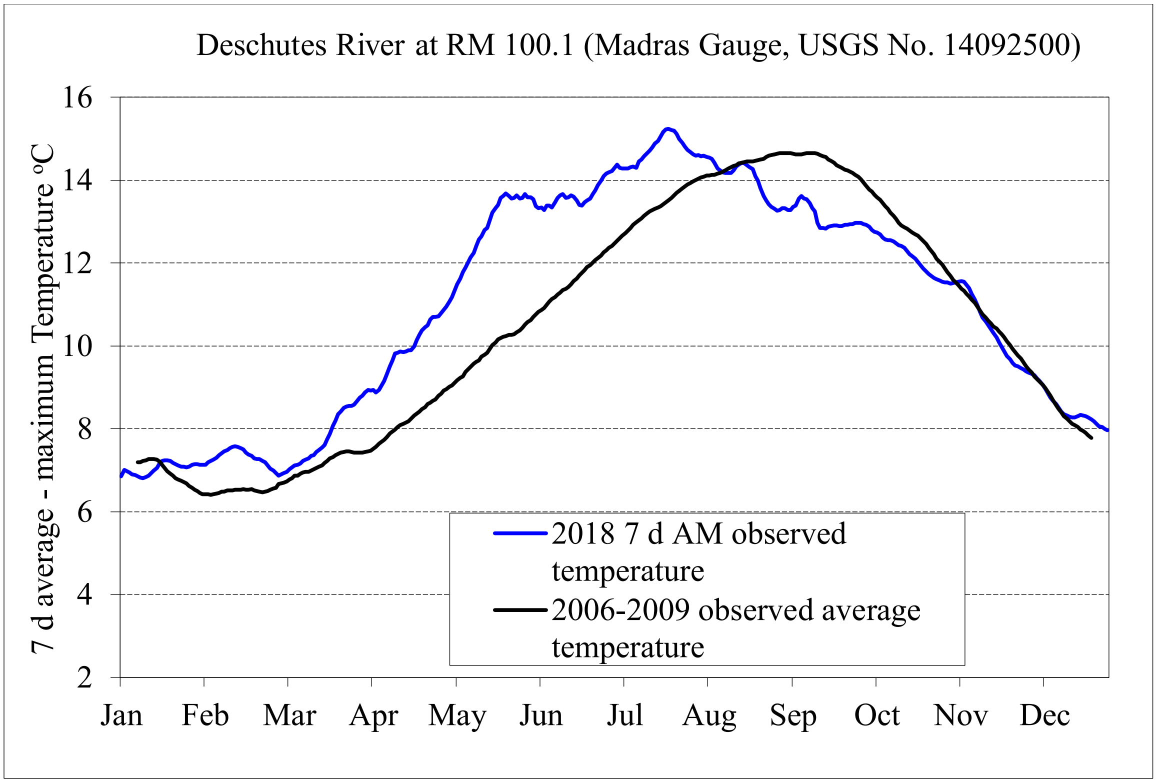

Figure 9. 7dAM temperature for Reregulating Dam tailrace (Site 2) in 2018.

The 7dAM temperatures for the months of May through October for the lower Deschutes River at Dry Creek (Site 28, rkm 149), Sandy Beach (Site 31, rkm 72), Macks Canyon (Site 32, rkm 39), and Moody (Site 33, rkm 2) are shown in Figure 10. Temperatures reported were highest in the lower river between May and October, peaking in July and August with maximum reported values of 16.6 ºC at Dry Creek, 18.7 ºC at Sandy Beach, 20.2 ºC at Macks Canyon, and 22.0 ºC at Moody.

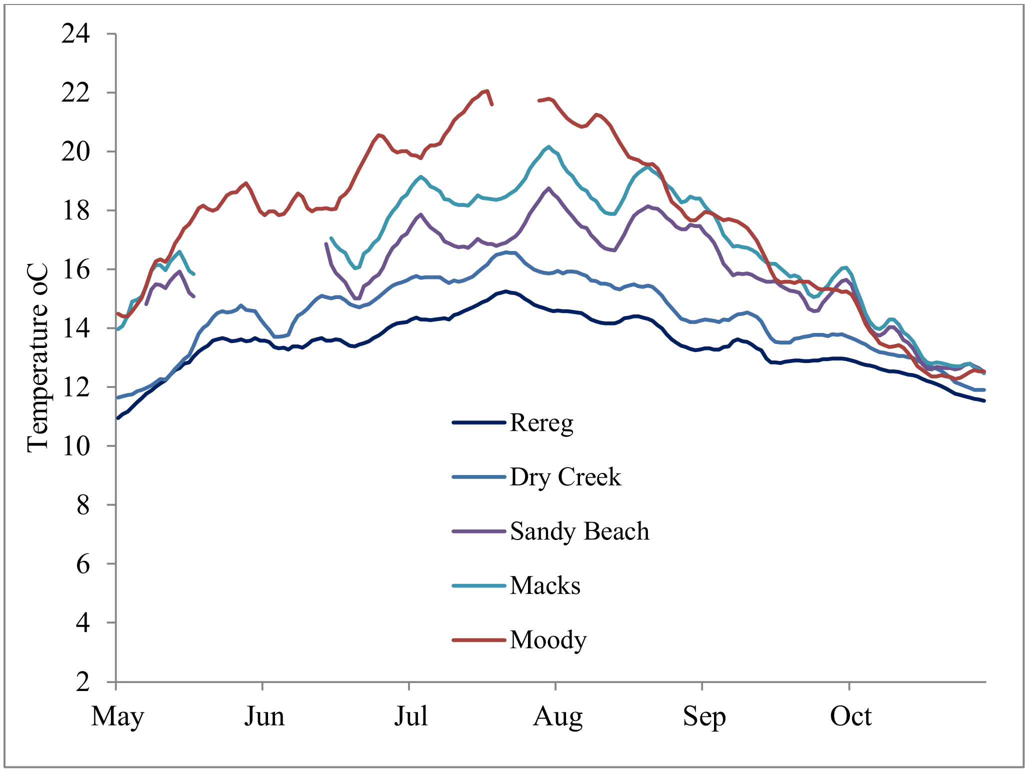

Figure 10. 7dAM temperature (May - October) for the Deschutes River at Madras (Rereg), Dry Creek (Site 28), Nena (Site 30), Sandy Beach (Site 31), Macks Canyon (Site 32), and Moody (Site 33) in 2018.

Dissolved Oxygen Management Operations in 2018

In 2018, the Project operated under interim agreements for dissolved oxygen, in addition to temperature. The 2018 interim agreement with ODEQ allowed project discharge waters to follow the current state DO criterion of 8.0 mg/L for cold-water aquatic life during the non-spawning period for salmonids, June 16 – October 14. The interim agreement with CTWSRO-WCB indicated the same, except that the non-spawning period was considered July 1 – October 14. During the salmonid spawning seasons (October 15 – July 1), the DO criterion of 9.0 mg/L (95% saturation) applied.

Spilling at the Reregulating Dam tailrace was initiated in 2018 to help boost dissolved oxygen levels. In 2018 spilling occurred between July 13 and October 29. Total dissolved gas (TDG) was periodically monitored during spill according to the WQMMP. TDG did not exceed 110% during the spill (Appendix 1, Table 2). A summary of spill events follows.

In early July DO concentrations at the Reregulating Dam tailrace began dropping and limited spills during evening hours were initiated by July 13. Full spill began by August 17 and continued through the end of the DO management season. In 2018 full spill for scheduled maintenance occurred August 27 – August 30.

Dissolved Oxygen Monitoring

The summary of results for DO recorded for inflow tributaries to Lake Billy Chinook, sites within the Project and lower river sites are shown in Table 2 and monthly values are shown in Figures 1 through 7 (Appendix 1). It must be noted that DO values reported in Tables 2 - 7 are results of one sampling event per month throughout the year, and should be interpreted within the limits of sampling frequency. The reported results do not reflect any diurnal variation that occurs. The maximum concentration of DO for Crooked River inflow, 10.7 mg/L, was recorded in February, and the minimum concentration, 9.8 mg/L, occurred in July. Deschutes River inflow had maximum DO levels of 12.5 mg/L in December and the lowest concentration of 9.8 mg/L in July. Metolius River inflow had a maximum DO value of 12.3 mg/L in December and remained well oxygenated throughout the season dropping to a minimum concentration of 10.7 mg/L in June. Dissolved oxygen values for Sandy Beach in the lower Deschutes River reached a maximum value of 12.3 mg/L in February, and a low value of 10.0 mg/L in July.

Table 2. Summary of DO (mg/L, % saturation) sampling at PRB Project reservoirs, inflows and the lower Deschutes River 2018.

	Mg/L (% saturation)			
Site[a]	**Maximum**	**Minimum**	**Median**	**Range**
CR (11)	10.7 (100.0)	9.8 (95.5)	10.24 (97.3)	0.8 (4.5)
DR (14)	12.5 (101.8)	9.8 (94.7)	11.2 (97.3)	2.7 (7.1)
MR (17)	12.3 (96.7)	10.7 (92.2)	11.5 (94.5)	1.6 (4.5)
WC (5)	10.2 (108.7)	8.7 (94.9)	9.5 (100.9)	1.5 (13.8)
PELTR (3)	12.4 (110.2)	7.7 (72.7)	10.1 (93.8)	4.7 (37.5)
DZ (1)	12.8 (115.9)	10.0 (95.6)	11.0 (105.0)	2.8 (20.3)
SB (31)	12.3 (111.6)	10.0 (98.2)	10.9 (104.8)	2.3 (13.4)

[a] CR = Crooked River, DR = Deschutes River, MR = Metolius River, WC = Willow Creek, PELTR = Pelton tailrace, DZ = Disney Riffle, SB = Sandy Beach

Dissolved oxygen values from profile sampling in each arm of Lake Billy Chinook are summarized in Tables 3 through 5. The Crooked River Arm (Table 3) had individual DO values ranging from 14.2 mg/L to 9.4 mg/L near the surface (0 m – 6 m) and 12.2 mg/L to 6.3 mg/L at depth (8 m – 30 m). Median DO values for the Crooked River Arm were somewhat lower (10.6 mg/L to 9.1 mg/L) than median DO in the both Deschutes and Metolius River Arms (11.6 mg/L to 10.2 mg/L and 11.2 mg/L to 9.6 mg/L, respectively). Deschutes River Arm (Table 4) had individual DO values ranged from 15.2 mg/L to 9.0 mg/L at the surface and from 11.9 mg/L to 4.5 mg/L at depth. The Metolius River Arm evidenced greater variability of DO concentrations through the year, individual values ranged from 15.4 mg/L to 7.4 mg/L near the surface, and between 14.0 mg/L and 4.8 mg/L at depth. Both the Crooked and Deschutes river arms experienced lower oxygen conditions below 20 m depth, while the Metolius River Arm (Table 5) reflected lower oxygen concentrations at depths of 4 m to 10 m (reported in August), as well as in the hypolimnion during late summer months.

Table 3. Summary of DO (mg/L, % saturation) sampling in Crooked River Arm, Lake Billy Chinook, 2018.

	Mg/L (% saturation)			
Depth	**Maximum**	**Minimum**	**Median**	**Range**
0m	14.2 (159.9)	9.5 (88.6)	10.6 (107.9)	4.7 (71.3)
2m	12.9 (143.0)	9.5 (88.6)	10.5 (106.8)	3.4 (54.4)
4m	12.7 (131.5)	9.5 (88.0)	10.3 (99.0)	3.2 (43.5)
6m	13.7 (118.5)	9.4 (87.0)	10.4 (94.7)	4.4 (31.5)
8m	12.2 (104.0)	9.4 (86.3)	10.1 (94.4)	2.8 (17.7)
10m	11.8 (100.4)	9.3 (85.8)	10.0 (91.5)	2.5 (14.6)
20m	10.6 (91.8)	7.0 (67.2)	9.6 (86.1)	3.5 (24.6)
30m	10.7 (87.3)	6.3 (54.6)	9.1 (83.5)	4.4 (32.7)

Table 4. Summary of DO (mg/L, % saturation) sampling in Deschutes River Arm, Lake Billy Chinook, 2018.

	Mg/L (% saturation)			
Depth	**Maximum**	**Minimum**	**Median**	**Range**
0m	15.1 (145.4)	10.6 (93.6)	11.6 (107.1)	4.5 (51.8)
2m	15.2 (146.1)	10.6 (93.9)	11.6 (106.7)	4.6 (52.2)
4m	14.0 (131.8)	9.7 (94.0)	11.4 (103.1)	4.2 (37.8)
6m	11.9 (116.7)	9.0 (88.3)	11.2 (96.5)	3.0 (28.4)
8m	11.9 (112.3)	8.6 (87.0)	10.9 (94.7)	3.3 (25.3)
10m	11.9 (107.1)	7.5 (73.6)	10.6 (94.6)	4.5 (33.5)

20m	11.9 (95.6)	4.5 (42.7)	10.3 (89.5)	7.5 (52.9)
30m	11.9 (103.0)	5.0 (46.6)	10.2 (86.0)	6.9 (56.4)

Table 5. Summary of DO (mg/L, % saturation) sampling in Metolius River Arm, Lake Billy Chinook, 2018.

	Mg/L (% saturation)			
Depth	**Maximum**	**Minimum**	**Median**	**Range**
0m	13.8 (139.9)	10.5 (88.9)	11.2 (108.2)	3.4 (51.0)
2m	15.4 (153.6)	9.9 (88.9)	11.2 (107.9)	5.5 (64.7)
4m	13.6 (141.1)	7.4 (76.6)	11.2 (104.6)	6.3 (64.5)
6m	13.6 (126.3)	8.0 (80.8)	11.1 (103.9)	5.6 (45.5)
8m	14.0 (127.4)	7.9 (79.0)	10.9 (99.2)	6.1 (48.4)
10m	13.8 (123.3)	8.8 (86.5)	10.9 (96.1)	5.0 (35.8)
20m	11.3 (96.7)	8.1 (76.0)	10.5 (96.6)	3.3 (20.6)
30m	11.4 (94.6)	8.7 (76.6)	9.8 (85.5)	2.6 (18.0)
40 m	11.4 (95.0)	7.2 (65.3)	9.6 (85.3)	4.2 (29.7)
50 m	11.4 (95.5)	6.9 (60.4)	9.9 (88.3)	4.5 (35.1)
65 m	11.6 (95.1)	4.8 (41.4)	10.3 (87.2)	6.8 (54.0)

Summaries of dissolved oxygen values (as mg/L and percent saturation) from Pelton and Round Butte forebays at all depths are shown in Tables 6 and 7. Both Pelton Dam and Round Butte Dam forebays remained well oxygenated near the surface through the year. Dissolved oxygen values in Round Butte forebay (Table 6) showed a maximum concentration in the surface (0 m to 6 m depth) during April, 16.0 mg/L, and a minimum concentration in August, 9.6 mg/L (Table 6). Maximum DO levels at depth (below 20 m) reached 11.4 mg/L in October. During September, Round Butte forebay DO values dropped to 2.9 mg/L at 75 m. Pelton Dam forebay became supersaturated during the late summer months, indicating a high level of productivity in the epilimnion. Surface concentrations of DO in Pelton Dam forebay fluctuated throughout the summer months. The Pelton Dam forebay (Table 7) had a maximum surface (0 m – 6 m) oxygen concentration of 16.8 mg/L reported in April, and a minimum value of 8.5 mg/L in August (Table 7). Dissolved oxygen concentrations below 10 m depth had high value of 13.8 mg/L in April and a low value of 7.4 mg/L in September.

Table 6. Summary of DO (mg/L, % saturation) sampling in Round Butte Dam forebay, LBC, 2018.

	Mg/L (% saturation)			
Depth	**Maximum**	**Minimum**	**Median**	**Range**
0m	15.7 (151.6)	10.7 (88.1)	11.7 (118.7)	5.1 (63.5)
2m	16.0 (152.4)	10.7 (88.0)	11.8 (121.2)	54 (64.4)
4m	15.5 (146.2)	10.4 (87.8)	11.6 (113.6)	5.0 (58.4)
6m	12.4 (132.6)	9.6 (87.6)	11.0 (104.7)	4.6 (45.0)
8m	13.1 (128.1)	8.2 (83.7)	10.8 (100.2)	4.8 (45.1)
10m	12.1 (112.1)	7.9 (79.0)	10.7 (93.1)	4.3 (33.1)
20m	11.4 (106.6)	6.9 (65.7)	10.4 (87.8)	4.6 (40.9)
30m	11.0 (92.3)	7.0 (64.2)	9.2 (78.1)	4.0 (28.1)
40 m	11.0 (91.4)	7.1 (65.0)	9.2 (78.1)	3.9 (26.4)
50 m	11.0 (89.1)	7.1 (61.7)	9.7 (81.3)	3.9 (27.4)
75 m	11.1 (93.0)	2.9 (25.4)	9.6 (80.9)	8.3 (67.6)
99 m	11.3 (92.7)	4.0 (36.6)	9.0 (74.9)	7.1 (56.1)

Table 7. Summary of DO (mg/L, % saturation) sampling in Pelton Dam forebay, LS, 2018.

	Mg/L (% saturation)			
Depth	**Maximum**	**Minimum**	**Median**	**Range**
0m	16.8 (163.2)	10.6 (89.2)	13.1 (107.3)	6.2 (74.0)
2m	16.0 (161.7)	10.4 (89.1)	12.6 (117.8)	5.6 (72.6)
4m	17.0 (176.4)	10.4 (87.2)	12.4 (114.8)	6.6 (89.2)
6m	14. (143.5)	8.5 (84.9)	11.4 (109.7)	5.9 (58.6)
8m	14.2 (131.4)	6.6 (65.4)	10.9 (100.2)	7.5 (66.0)
10m	13.8 (125.8)	7.9 (68.2)	10.8 (91.9)	6.8 (57.6)
20m	130 (118.3)	7.7 (72.9)	10.5 (90.3)	5.3 (45.4)
30m	12.5 (112.7)	7.5 (13.7)	1.2 (88.4)	4.5 (99.0)
40 m	12.2 (108.8)	7.4 (68.9)	9.9 (87.8)	4.8 (29.9)

The daily minimum concentrations of DO in the Round Butte Dam tailrace are shown in Figure 11. Dissolved oxygen values for the Round Butte Dam tailrace were lower during the late summer months, likely reflecting the influence of hypolimnetic water in the SWW surface-bottom water blend. The maximum DO (daily minimum) for Round Butte Dam tailrace occurred in April, 10.9 mg/L, and the lowest value was recorded in September, 5.8 mg/L. DO saturation levels ranged from 99.7% in May to 56.8% in September.

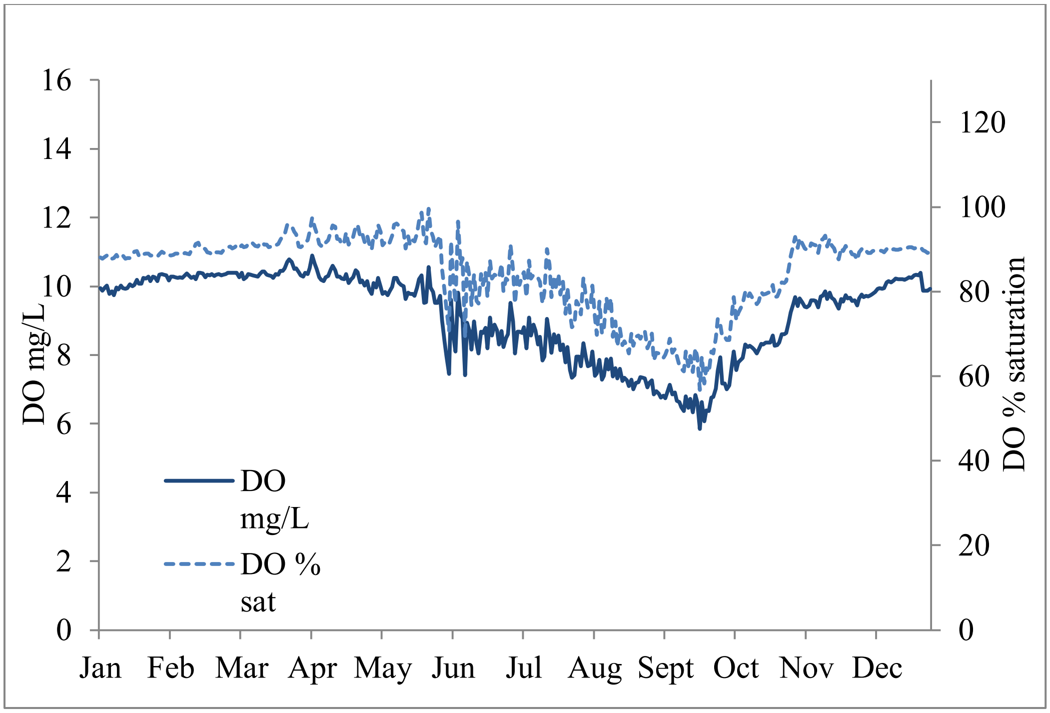

Figure 11. Daily minimum of dissolved oxygen (mg/L and percent saturation) for Round Butte Dam tailrace (Site 6), 2018.

The daily minimum concentrations of DO in the Reregulating Dam tailrace are shown in Figure 12. The 2018interim agreements allowed project discharge waters to follow the current cold water aquatic life DO criteria of 8.0 mg/L (90% saturation) during the non-spawning period (July 1 – October 14 as indicated in the CTWSRO-WCB interim agreement). The salmonid spawning criterion of 9.0 mg/L (95% saturation) applied throughout the remainder of the year.

Maximum DO values (daily minimum) at the Reregulating Dam tailrace reached 12.1 mg/L in January. Minimum DO concentrations approached the 8.0 mg/L criterion in mid-August with a low value of 7.9 mg/L occurring during one hourly reading . DO saturation levels ranged from 105.4% in January and to 76.3% in August.

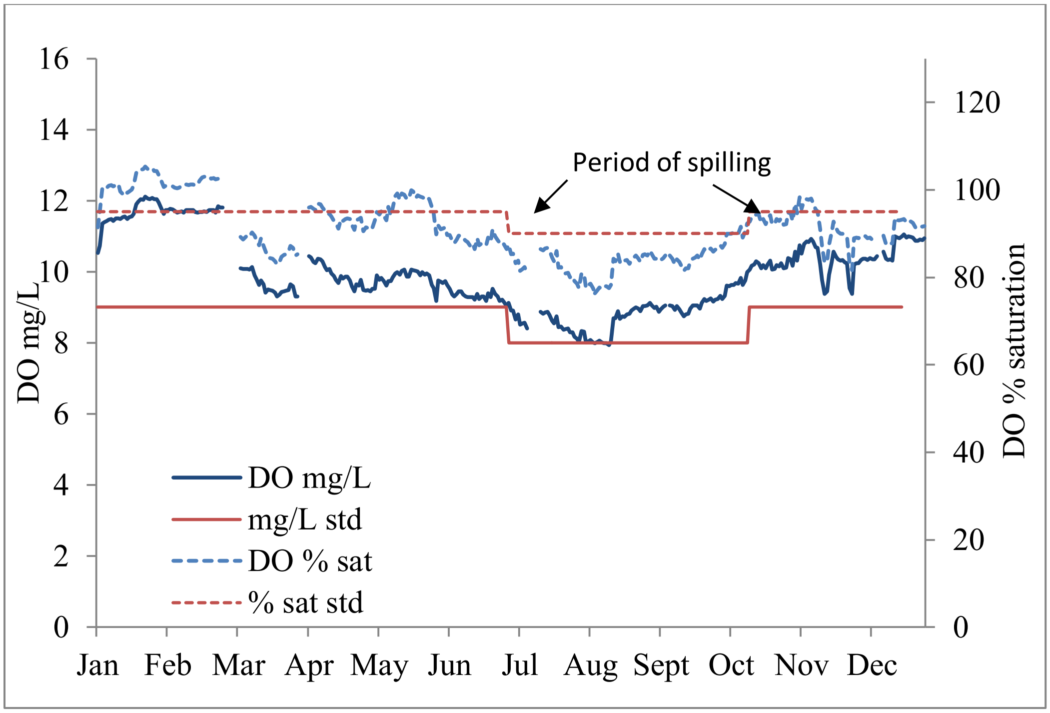

Figure 12. Daily minimum of dissolved oxygen (mg/L and percent saturation) for Reregulating Dam tailrace (Site 2) in 2018. Spill events are shown by arrows. The state and tribal standards are shown in red. The DO standard followed in 2018 was 9.0 mg/L and or 95% saturation between October 15 - June 30, and 8.0 mg/L and or 90% saturation from July 1 - October14, according to the interim agreements.

pH Management Operations in 2018

In 2018, the Project operated under interim agreements for dissolved oxygen, in addition to temperature. The pH criterion for both ODEQ and the CTWSRO-WCB was 6.5 - 8.5 standard units, applied throughout the year.

Similar to previous years, as reservoir productivity increased during spring, summer and fall months, DO values in the project reservoirs and surface/bottom water blending at the selective water withdrawal likely influenced pH values. Additional weekly monitoring of pH in the tributary inflows occurred during the time that discharge pH values exceeded 8.3 pH Units. Results of the monitoring are shown in Appendix 1, Table 3.

pH Monitoring

A summary of pH sampling for the Project tributary inflows and the lower river are shown in Table 8 and monthly pH values are shown in Appendix 1 (Figures 8 through 14). It must be noted that pH values reported in Tables 8 - 13 are results of one sampling event per month throughout the year and should be interpreted within the limits of sampling frequency. The reported results do not reflect any diurnal variation that occurs. The Crooked River had a maximum value of 8.7 in January and a low value of 8.1 in August. Values of pH for the Deschutes River reached a maximum value of 8.8 in October and a low value of 7.8 in January. The Metolius River had a maximum recorded value of 8.6 in September and October, and a minimum a value of 7.4 in January. In the lower river at Sandy Beach a maximum pH value of 8.6 was recorded in June and July and the low value of 8.0 occurred in January.

Table 8. Summary of pH (standard units) sampling at Project inflows, PRB Project and the lower Deschutes River, 2018.

	pH (standard units)			
Site[a]	**Maximum**	**Minimum**	**Median**	**Range**
CR (11)	8.7	8.1	8.4	0.6
DR (14)	8.8	7.8	8.3	1.0
MR (17)	8.6	7.4	8.0	1.3
WC (5)	9.0	8.4	8.6	0.7
PELTR (3)	8.8	8.2	8.4	0.6
DZ (1)	9.0	7.8	8.4	1.2
SB (31)	8.6	8.0	8.2	0.6

[a] CR = Crooked River, DR = Deschutes River, MR = Metolius River, WC = Willow Creek, PELTR = Pelton tailrace, DZ = Disney Riffle, SB = Sandy Beach

A summary of monthly pH profile sampling in each arm of Lake Billy Chinook is shown in Tables 9, 10, and 11. Median values in the Crooked River Arm for the year ranged from 8.7 at the surface and 2m depth to 8.0 at 30 m depth. Individual pH values ranged from 9.6 at the surface and 2m depth to 7.4 at 30 m depth. Median values from the Deschutes River Arm ranged from 9.1 from the surface up to 4 m depth to 7.8 at 30 m depth. The highest individual values of pH occurred at the surface, 9.6 (up to 2m), while low values of 7.5 were evidenced at 30 m depth. Median pH in the Metolius River Arm ranged from 8.9 at the surface and 2 m depth to 7.6 at 65 m depth. Individual values of pH in the Metolius River Arm ranged from 9.5 at 2 m depth to 7.2 at the 65 m depth.

Table 9. Summary of pH (standard units) sampling in Crooked River Arm, LBC, 2018.

	pH (standard units)			
Depth	**Maximum**	**Minimum**	**Median**	**Range**
0m	9.6	7.9	8.7	1.7
2m	9.6	7.8	8.6	1.7
4m	9.3	8.0	8.6	1.5
6m	9.0	7.7	8.6	1.3
8m	8.9	7.6	8.5	1.3
10m	8.9	7.5	8.4	1.4
20m	8.7	7.5	8.1	1.2
30m	8.6	7.4	8.0	1.2

Table 10. Summary of pH (standard units) sampling in Deschutes River Arm, LBC, 2018.

	pH (standard units)			
Depth	**Maximum**	**Minimum**	**Median**	**Range**
0m	9.6	7.7	9.1	1.9
2m	9.6	7.8	9.1	1.8
4m	9.2	7.6	9.1	1.6
6m	9.2	7.6	8.6	1.6
8m	9.1	7.6	8.5	1.5
10m	8.9	7.6	8.4	1.3
20m	8.9	7.6	8.0	1.4
30m	8.6	7.5	7.8	1.1

Table 11. Summary of pH (standard units) sampling in Metolius River Arm, LBC, 2018.

	pH (standard units)			
Depth	**Maximum**	**Minimum**	**Median**	**Range**
0m	9.4	7.5	8.9	0.0
2m	9.5	7.4	8.9	1.1
4m	9.3	7.4	8.8	1.9
6m	9.2	7.4	8.8	1.7
8m	9.0	7.4	8.6	1.6
10m	8.9	7.4	8.5	1.5
20m	8.7	7.5	8.2	1.3
30m	8.6	7.5	7.9	1.1

40 m	8.6	7.4	7.8	1.2
50 m	8.6	7.4	7.7	1.2
65 m	8.6	7.2	7.6	1.4

Summary values of pH for Pelton and Round Butte forebays are shown in Tables 12 and 13. Corresponding to higher DO levels, pH values for both reservoirs showed similar patterns. Both forebays evidenced increased pH associated with higher levels of productivity during the summer months. Compared to Pelton forebay, Round Butte Dam forebay evidenced slightly lower individual pH concentrations. However, median pH values were slightly higher in Round Butte forebay. Round Butte forebay had a maximum value of pH of 9.4 in the surface water (0m - 6m) in July and August, and a minimum value of 7.8 in January (Table 12). Below 20m depth in the Round Butte forebay, a maximum pH value of 8.8 was recorded in October, and the lowest, 7.6, was recorded in January. The Pelton Dam forebay had pH values that fluctuated at the surface, again reflecting patterns observed in DO. Pelton forebay had pH levels that were highest in the surface water (0m - 6m) in July reaching 9.7 up to 4m depth (Table 13), while the lowest value at the surface (7.0) was recorded in February. Maximum pH levels of 9.1 below 10m depth were reported in April, and a minimum value of 7.7 occurred in January.

Table 12. Summary of pH (standard units) sampling in Round Butte Dam forebay, LBC, 2018.

	pH (standard units)			
Depth	**Maximum**	**Minimum**	**Median**	**Range**
0m	9.4	7.9	9.2	1.6
2m	9.4	7.9	9.2	1.6
4m	9.4	7.9	9.2	1.5
6m	9.2	7.8	9.0	1.4
8m	9.1	7.8	8.7	1.3
10m	9.1	7.8	8.6	1.3
20m	8.8	7.8	8.3	1.0
30m	8.5	7.8	8.1	0.7
40 m	8.4	7.8	7.9	0.6
50 m	8.4	7.8	7.9	0.7
75 m	8.4	7.6	7.8	0.8
99 m	8.4	7.6	7.7	0.8

Table 13. Summary of pH (standard units) sampling in Pelton Dam forebay, LS, 2018.

	pH (standard units)			
Depth	**Maximum**	**Minimum**	**Median**	**Range**
0m	9.7	8.1	9.0	1.6
2m	9.7	8.1	9.0	1.7
4m	9.7	8.0	9.0	1.7
6m	9.5	8.0	8.9	1.5
8m	9.2	8.0	8.7	1.2
10m	9.1	8.0	8.6	1.1
20m	9.0	8.0	8.5	1.0
30m	8.9	7.8	8.3	1.1
40 m	8.8	7.7	8.3	1.1

Daily maximum and minimum of pH for the Round Butte Dam and Reregulating Dam tailraces are shown in Figures 13 and 14. The daily values of pH in Round Butte Dam tailrace ranged from a maximum of 9.2 in August and a minimum of 7.2 in August. The Reregulating tailrace had a high pH of 9.3 in May, and a low value of 7.7 in September.

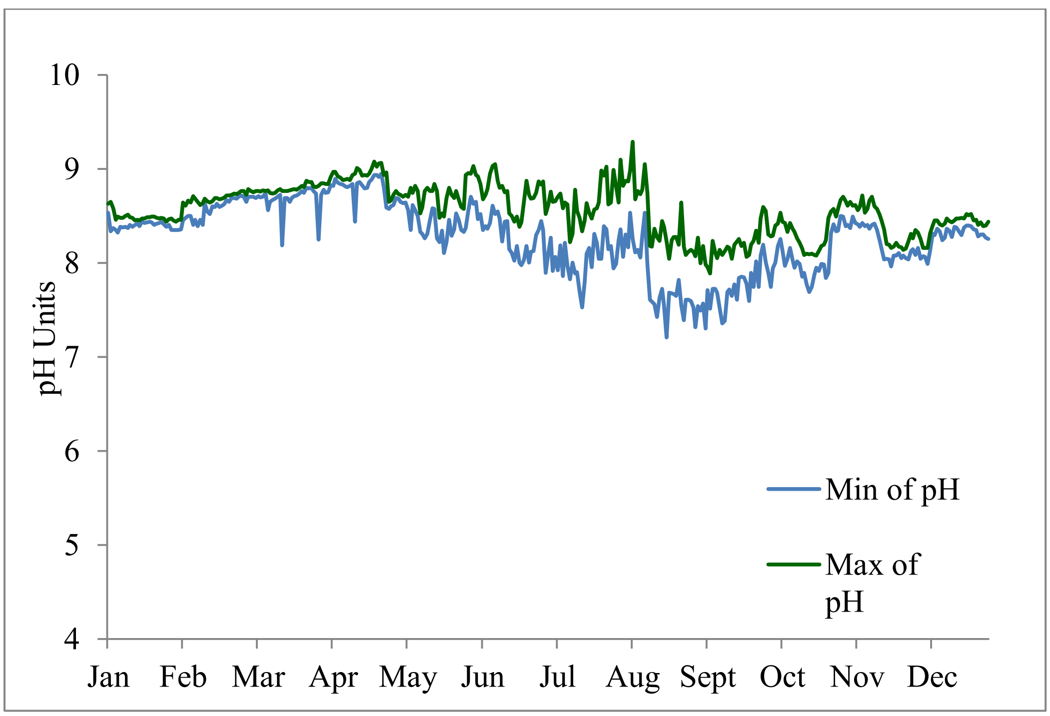

Figure 13. Daily maximum and minimum of pH for Round Butte Dam tailrace (Site 6), 2018.

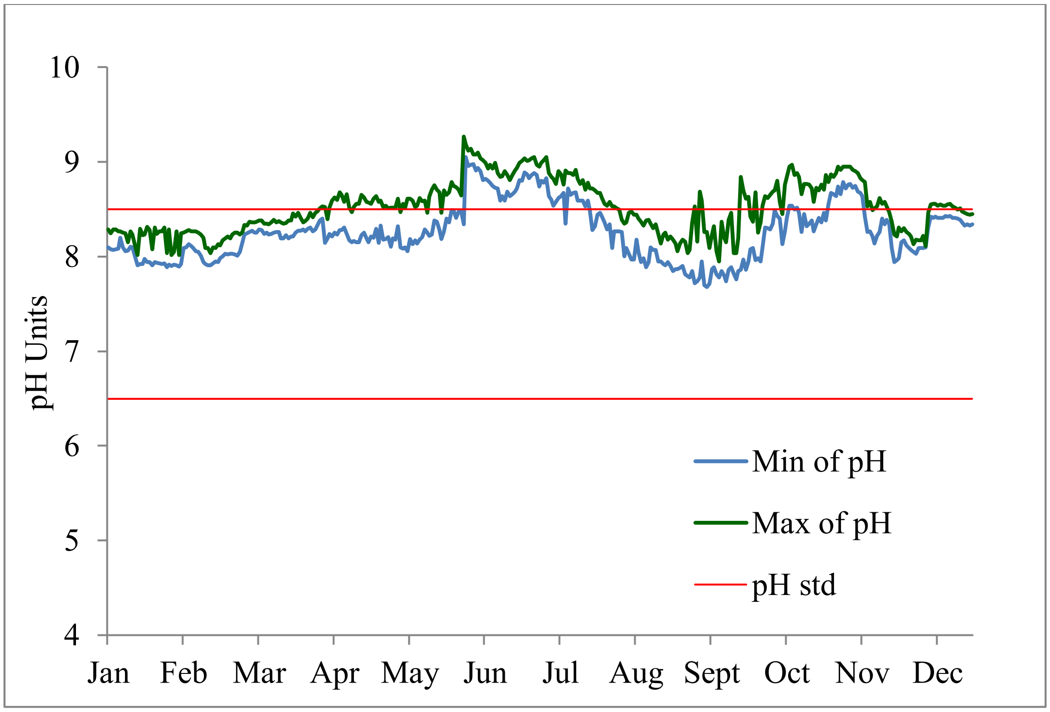

Figure 14. Daily maximum and minimum of pH for Reregulating Dam tailrace (Site 2), 2018. The state and tribal standard for pH occurs in red.

Discussion

Temperature

In 2018, as has been the case in previous years, the Metolius River provided colder water to Lake Billy Chinook than did the Deschutes and Crooked Rivers. The Deschutes and Metolius rivers demonstrated more seasonal variation in temperature than the Crooked River. The Crooked River, near the confluence with Lake Billy Chinook receives much of its water from Opal Springs which moderates seasonal temperature variation. The Metolius receives much of its water from relatively cold groundwater (Raymond et al. 1997) farther upstream.

Temperatures through the Project in 2018 were similar to 2010 through 2017, again reflecting values between historical conditions and the projected temperatures described in the WQMMP. The 2018 temperatures in Round Butte forebay were mostly consistent with 2010-2017 temperatures, and were not as cool as the modeled blends had predicted. Surface water/bottom water blend occurred following intentional adjustments made during the spring and summer months to meet the calculated temperature.

Temperatures profiles in Round Butte forebay throughout the year, compared to 1995 existing and modeled temperatures, shifted towards the modeled condition, however were not as cold as the earlier modelling suggested. The 2018 profiles during late summer months reflected transitional temperatures and offer some insight as to why discharge temperatures were frequently closer to the calculated without project target than indicated by the model. The reservoir since SWW operation was implemented has experienced warmer water than the temperature modeling predicted, and thus has had less cold water in the blend to help meet calculated discharge target temperatures.

Typically, the thermocline in the Pelton Dam forebay occurs at a depth of less than 10 m depth. Lake Simtustus becomes well stratified by June and exhibits thermal stratification through mid-October, becoming homothermic by November. Prior to SWW, Lake Billy Chinook was reported to be stratified between June and October (Raymond et al. 1997).

In 2018, Pelton Dam and Round Butte Dam forebays both developed a thermocline, although the thermocline was less defined in Lake Billy Chinook. Lake Simtustus was stratified in May. Although some thermal stratification was evident during early spring, Lake Billy Chinook showed the degree of stratification from May through October. Mixing in Lake Billy Chinook normally occurs by early November. In 2018 Lake Simtustus de-stratified in late October, as evidenced by similar temperatures among depths. Although Lake Billy Chinook never developed a well-defined thermocline during spring and summer, the reservoir did evidence similar temperatures through depth by late October.

Temperatures in the lower Deschutes River immediately downstream of the Reregulating Dam varied seasonally, with lower temperatures observed between November and April. Historically (pre-SWW), maximum temperatures at the Reregulating Dam tailrace occurred in August and September, whereas the maximum temperature for the lower river site at Sandy Beach occurred in July. In 2018, with the beginning of operation of the SWW, maximum temperatures at the Reregulating Dam shifted 4-5 weeks compared to previous years (through 2009), with seasonal high temperatures occurring in mid-July rather than the end of August.

Dissolved Oxygen

Changes in dissolved oxygen and pH through the Project resulting from surface withdrawal were less obvious than those observed with temperatures. Project inflows and the lower Deschutes River remained relatively well oxygenated through the year. The Metolius River consistently maintained higher DO concentrations than other tributaries. During late summer and fall months, DO levels at the Round Butte Dam tailrace dropped below that of the inflow and lower river sites reflecting the increased percentage of less-oxygenated hypolimnetic water in the SWW surface water/bottom water blend. During 2018 the Reregulating Dam tailrace had lower DO concentrations particularly during the late summer and early fall months. However, discharge DO concentrations remained above the cold water criterion during this time, and remained above the salmonid spawning criterion during the spawning season. Sandy Beach had DO concentrations that were at levels similar to the inflow sites. Raymond et al. (1997) reported similar results for the lower river from earlier studies.

Pelton Dam and Round Butte Dam forebays were similar in their seasonal DO patterns. Both forebays were well oxygenated at the surface. The epilimnion in the Pelton Dam forebay remained supersaturated during much of the growing season, whereas the DO concentrations in Lake Billy Chinook remained at somewhat lower levels in the summer and continued this way through early fall. The hypolimnion in both reservoirs had lower DO concentrations during middle and late summer. Dissolved oxygen reduction in hypolimnetic waters through the summer months is a common phenomenon in stratified lakes or reservoirs. It occurs when increased photosynthesis takes place in the epilimnion as phytoplankton take advantage of warm temperatures and available nutrients. Phytoplankton eventually senesce and sink to the bottom, which leads to bacterial decomposition that uses up available oxygen at deeper depths. Both reservoirs exhibited noticeable decreases in DO at depth during the summer, particularly Round Butte forebay at depths below 50 m. Lake Billy Chinook was previously described as having generally lower DO values than Lake Simtustus in summer months (Raymond et al 1997). In 2018 this pattern was still evident.

pH

Raymond et al. (1997) described the tributary inflows as differing slightly in pH. In 2018, the Metolius River typically had a lower pH, and the Crooked and Deschutes rivers had similar somewhat higher pH levels. Of the latter two, pH in the Deschutes River was more variable than in the Crooked River. Values of pH in the inflows were lower than those observed in the reservoirs through most of the year.

Round Butte Dam and Pelton Dam forebays both had seasonal pH patterns that were similar to those of DO and temperature. High photosynthetic activity in the epilimnion depletes carbon dioxide, which increases pH. In the hypolimnion, low concentrations of DO lead to decreases in pH. Pelton Dam forebay showed greater fluctuations in pH levels through the summer than did the Round Butte Dam forebay. Similar to previous years, Lake Simtustus maintained a higher level of productivity relative to Lake Billy Chinook in 2018. The Reregulating Dam tailrace had pH levels that varied similarly to those recorded at the Round Butte tailrace and were higher than inflow tributary values during spring through early fall months.

Management of pH is a challenge compared to managing temperature and dissolved oxygen in the Project. Finding feasible, effective solutions to reduce elevated pH levels through the Projects reservoirs while minimizing negative effects to other water quality criteria and fish passage continues to be formidable task.

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Appendix 1

Inflow, Reservoir and Lower River pH, DO

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Portland General Electric Company

And

The Confederated Tribes of the Warms Springs Reservation of Oregon

April 2019

Inflow, Reservoir, Lower River DO, pH

DO

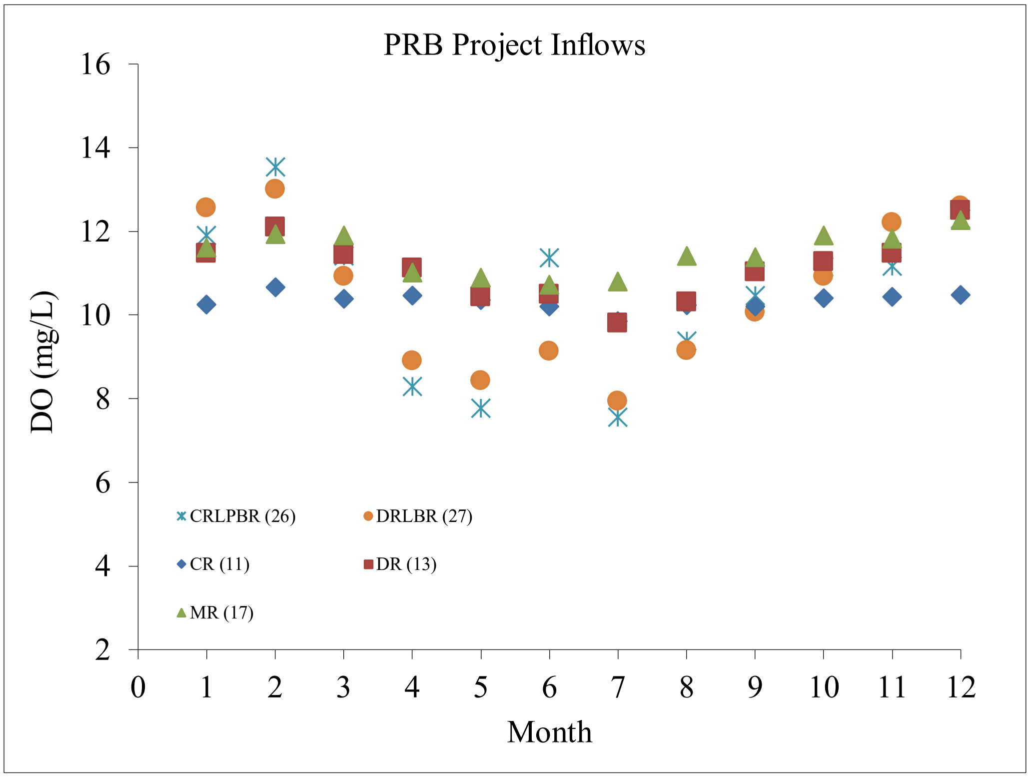

Figure 1. Monthly dissolved oxygen values (individual readings) for PRB Project inflows (Sites 11, 13, 17, 26, 27), 2018.

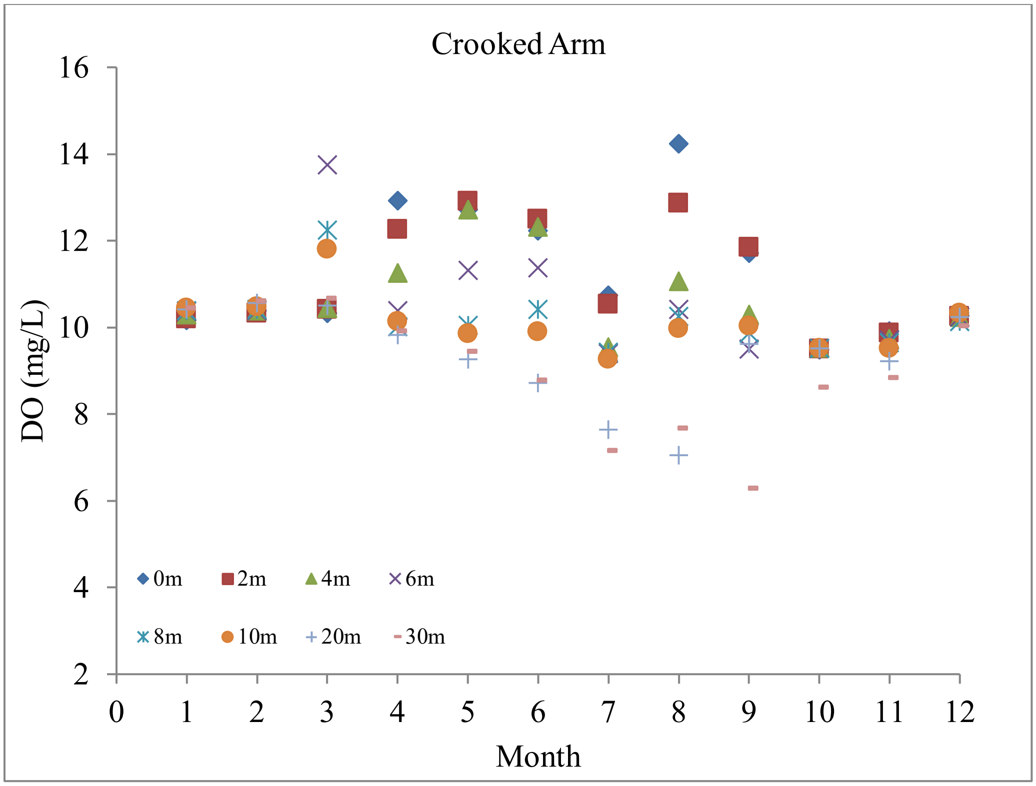

Figure 2. Monthly dissolved oxygen values at depth for LBC at Crooked River Arm, 2018.

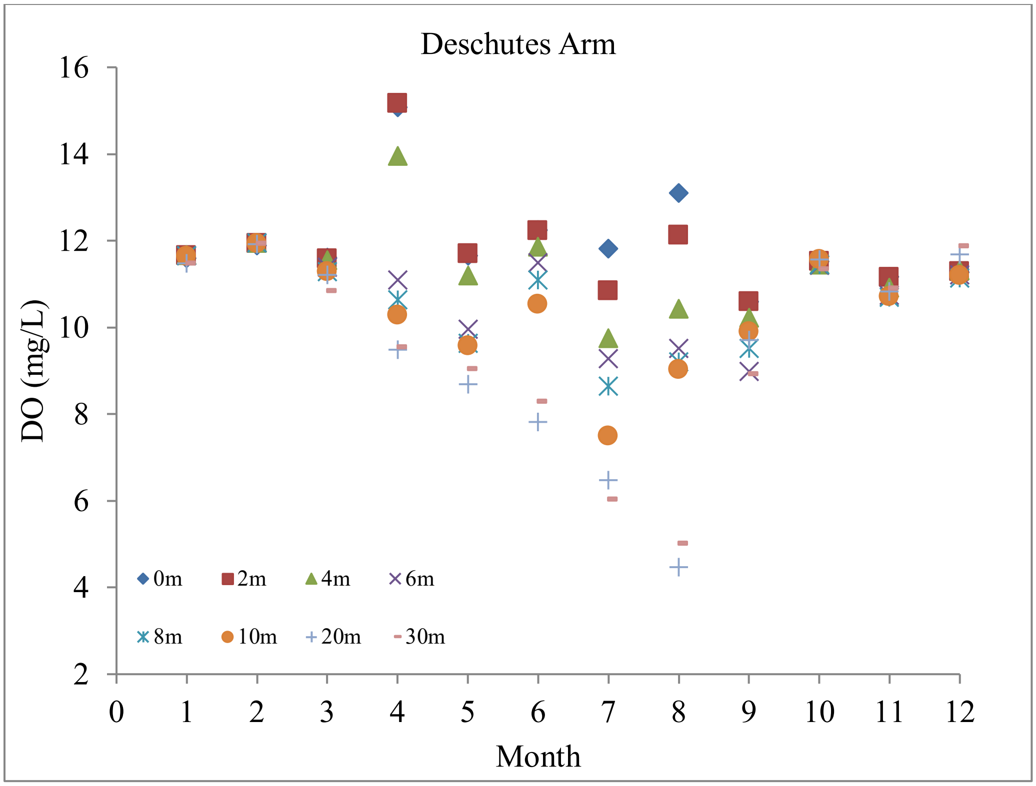

Figure 3. Monthly dissolved oxygen values at depth for LBC at Deschutes River Arm, 2018.

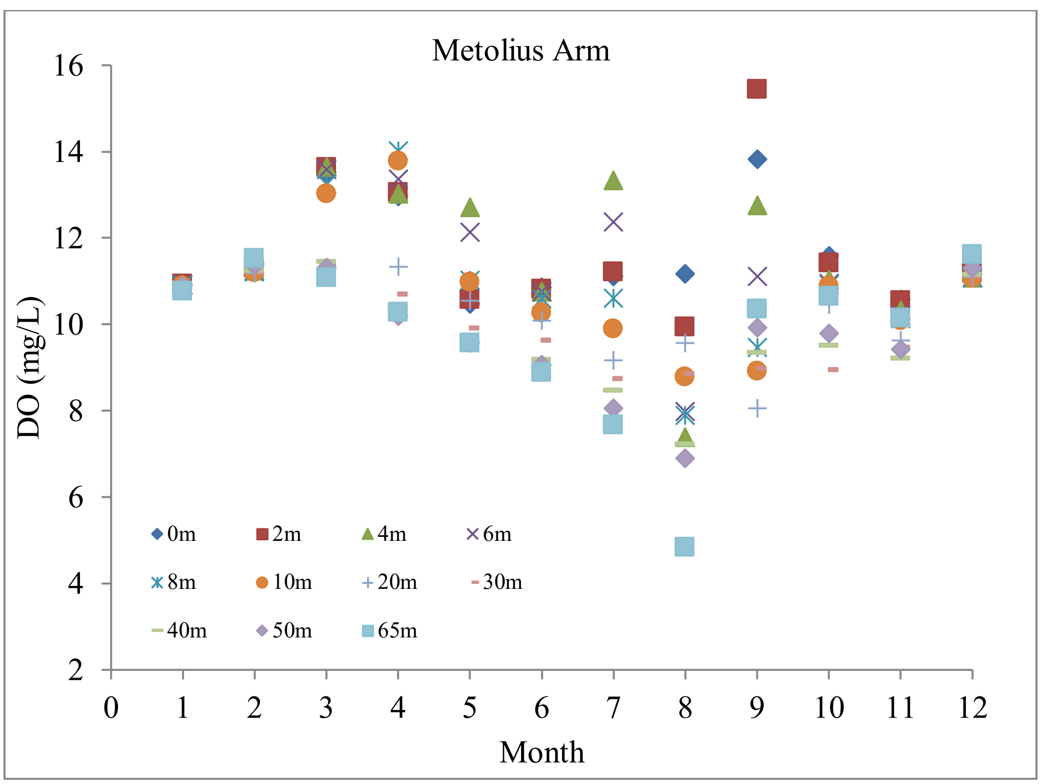

Figure 4. Monthly dissolved oxygen values at depth for LBC at Metolius River Arm, 2018.

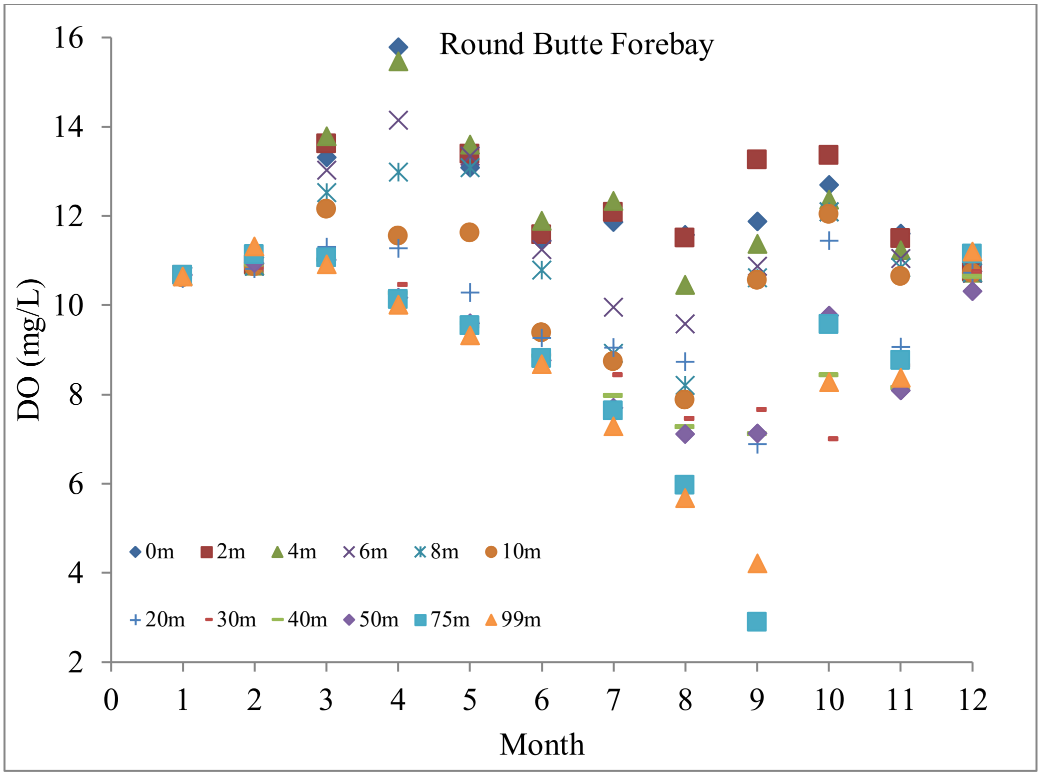

Figure 5. Monthly dissolved oxygen values at depth for Round Butte forebay, LBC, 2018.

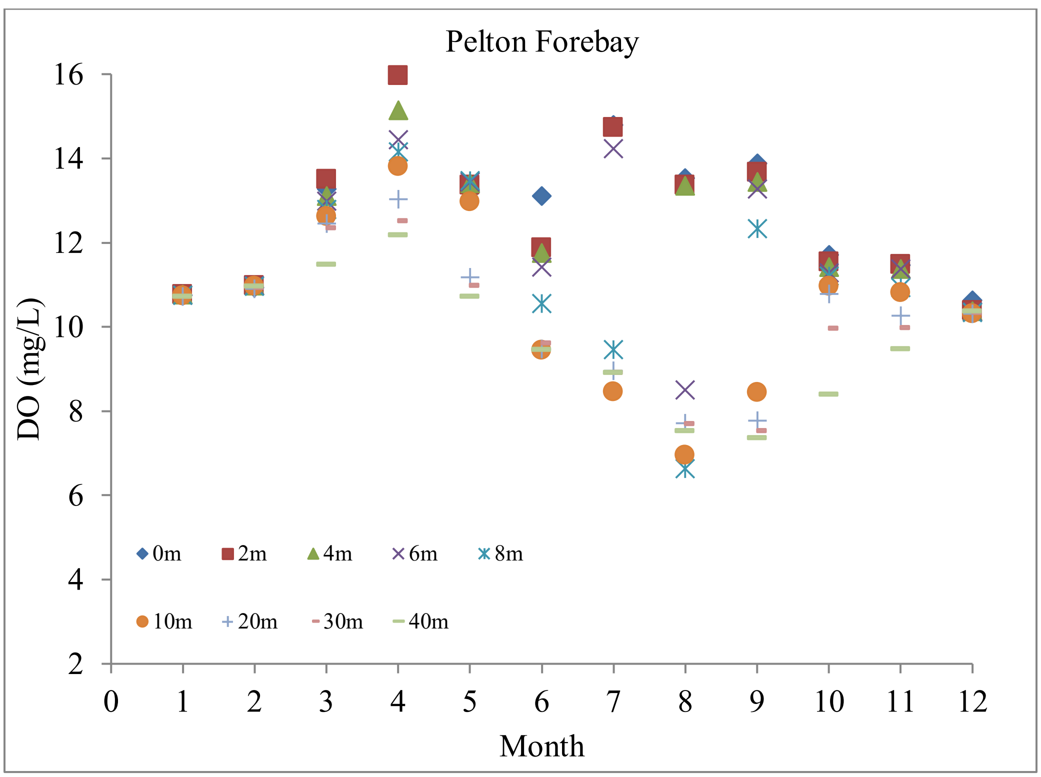

Figure 6. Monthly dissolved oxygen values at depth for Pelton forebay, LS, 2018.

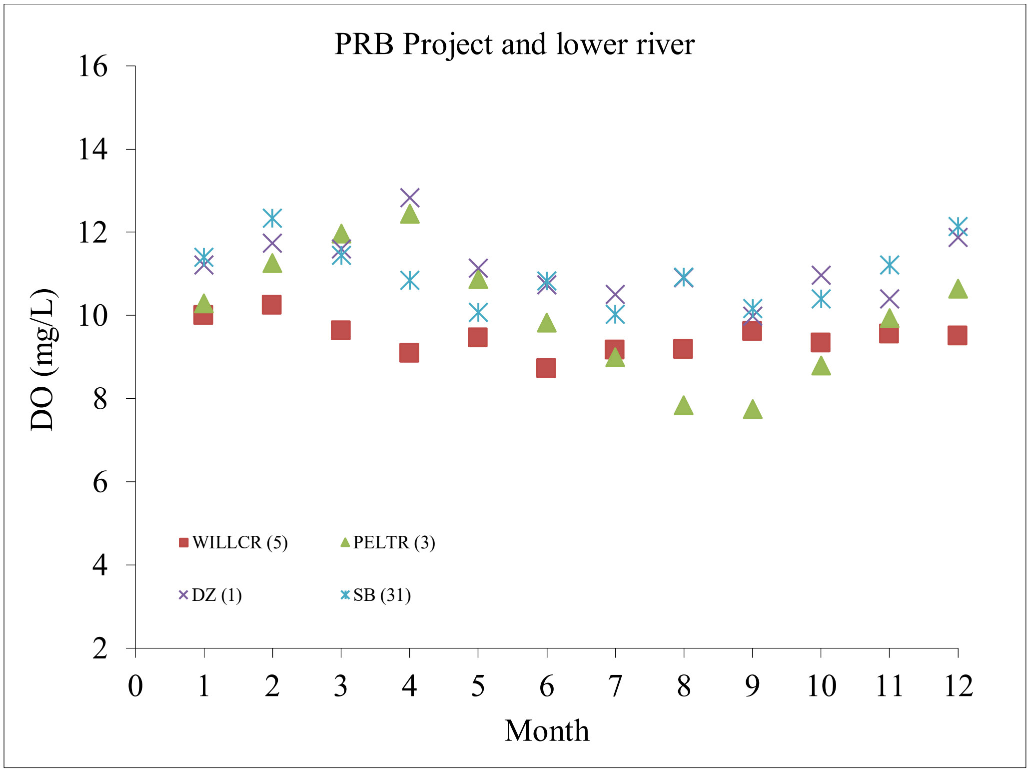

Figure 7. Monthly dissolved oxygen values (individual readings) for PRB Project and lower river (Sites 1, 3, 5, 31) 2018.

pH

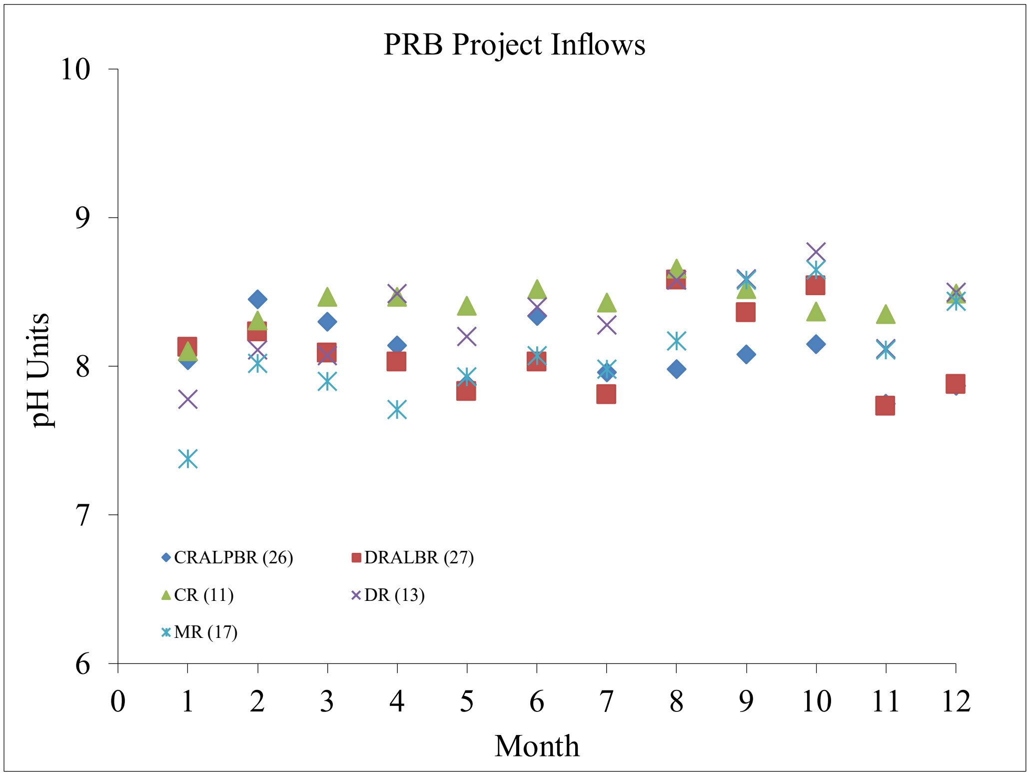

Figure 8. Monthly pH values (individual readings) for PRB Project inflows and (Sites 11, 13, 17, 26, 27), 2018.

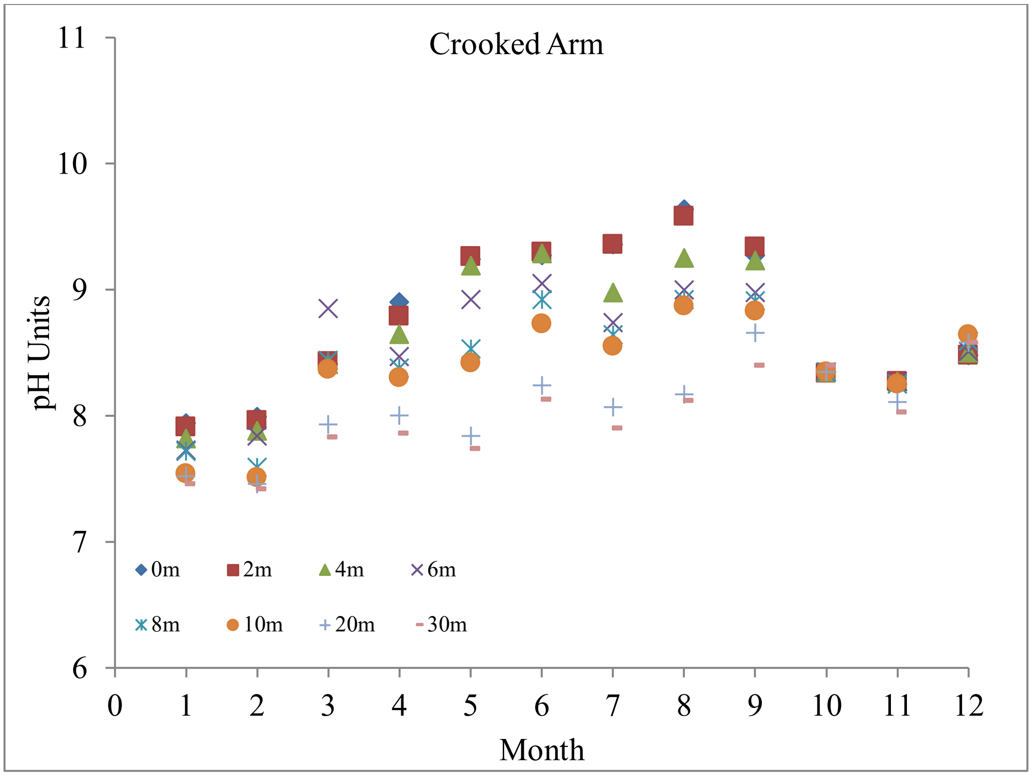

Figure 9. Monthly pH values at depth for LBC at Crooked River Arm, 2018.

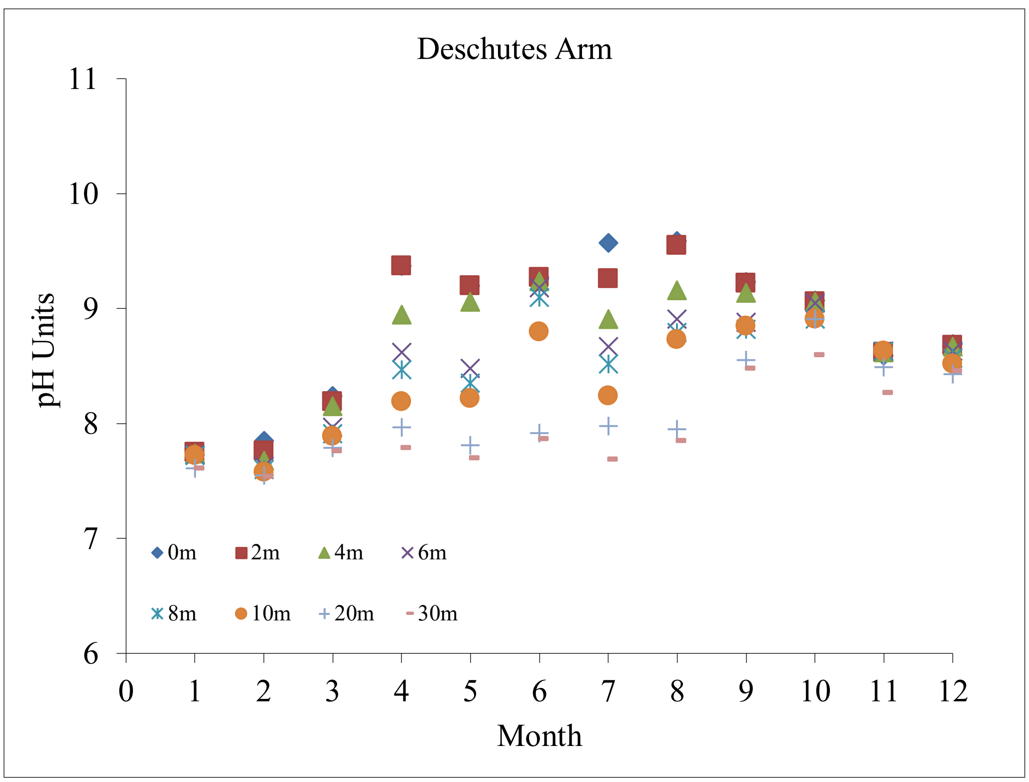

Figure 10. Monthly pH values at depth for LBC at Deschutes River Arm, 2018.

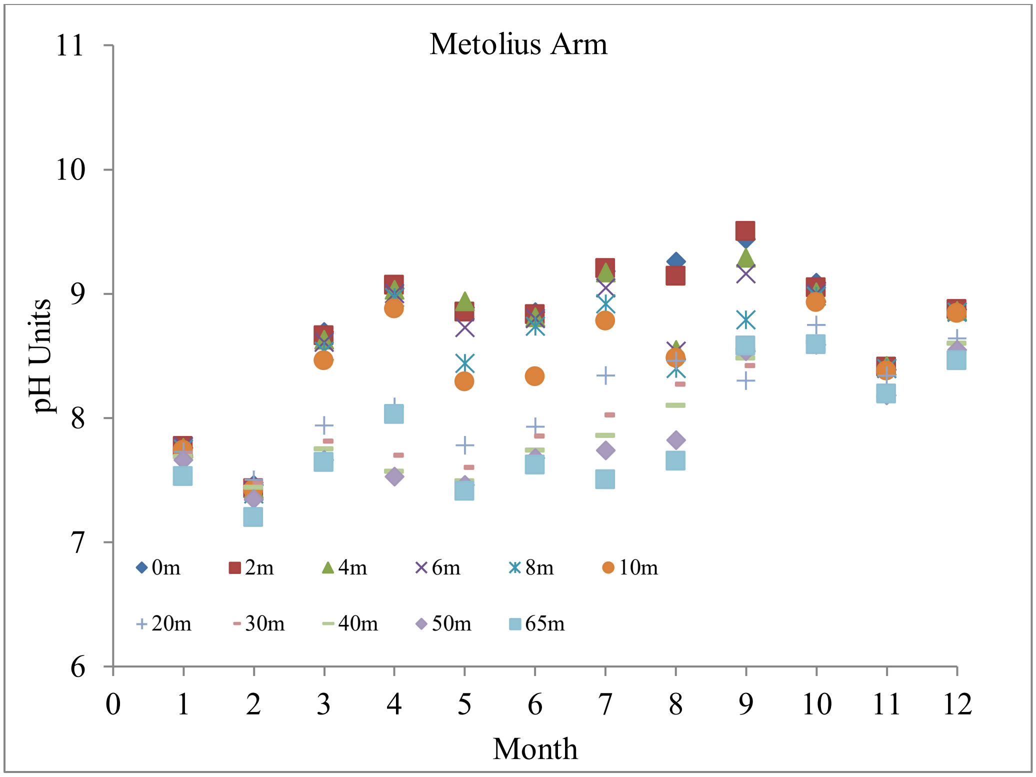

Figure 11. Monthly pH values at depth for LBC at Metolius River Arm, 2018.

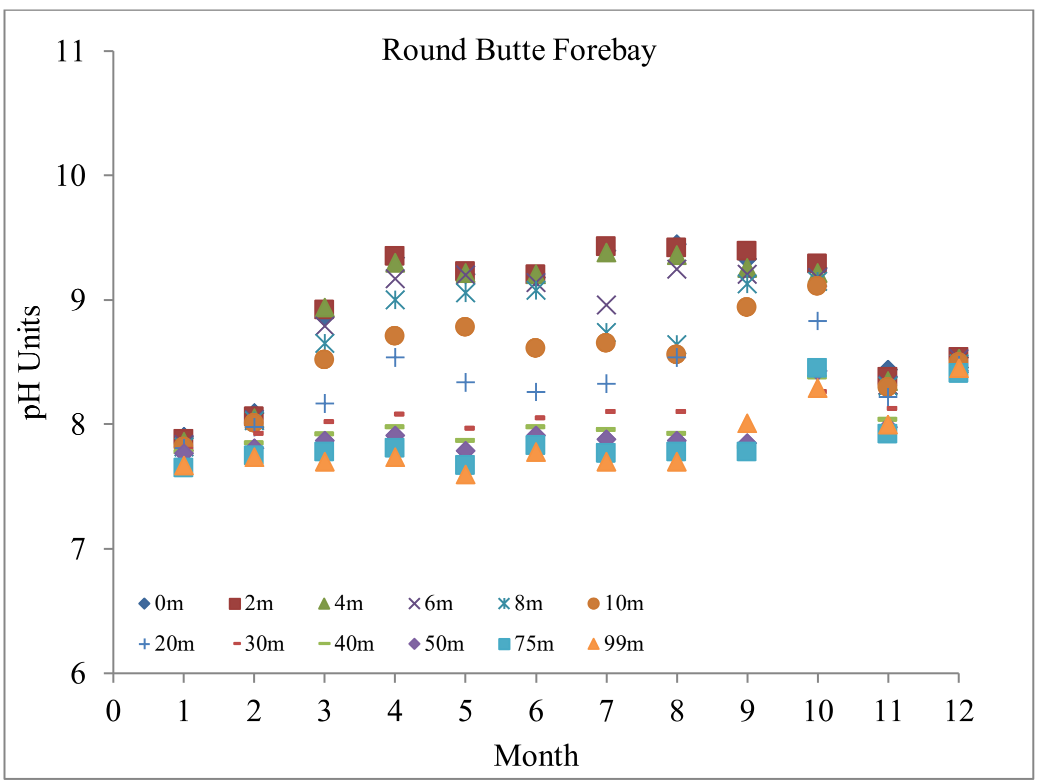

Figure 12. Monthly pH values at depth for Round Butte forebay, LBC, 2018.

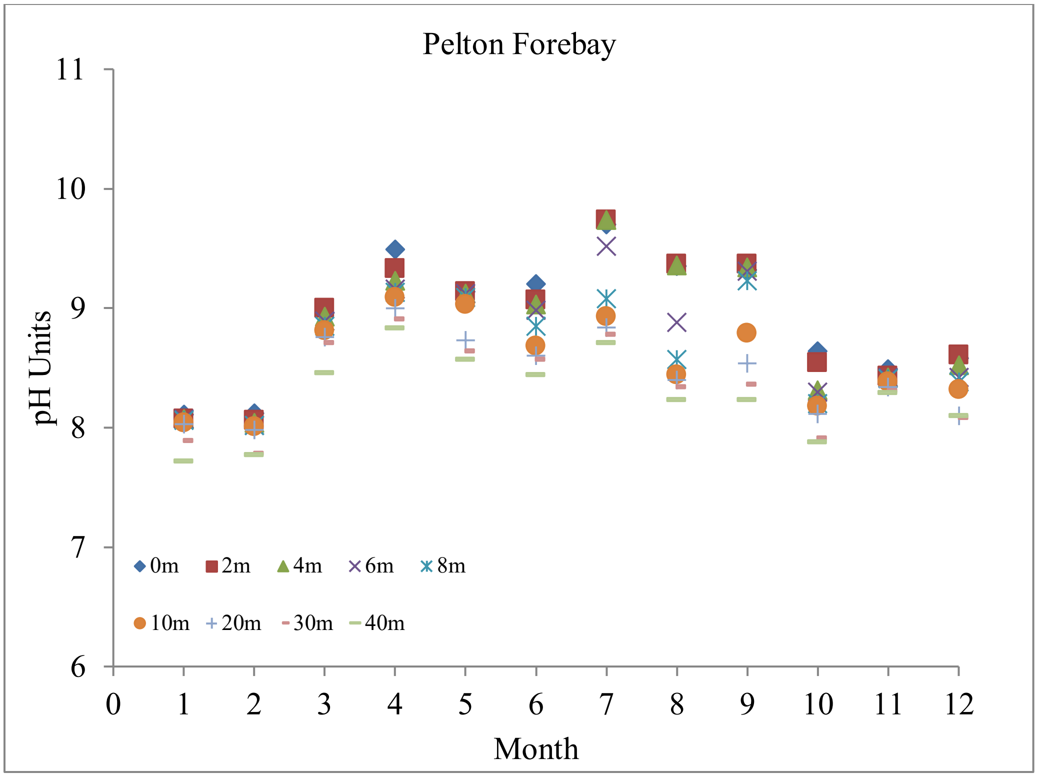

Figure 13. Monthly pH values at depth for Pelton forebay, LS, 2018.

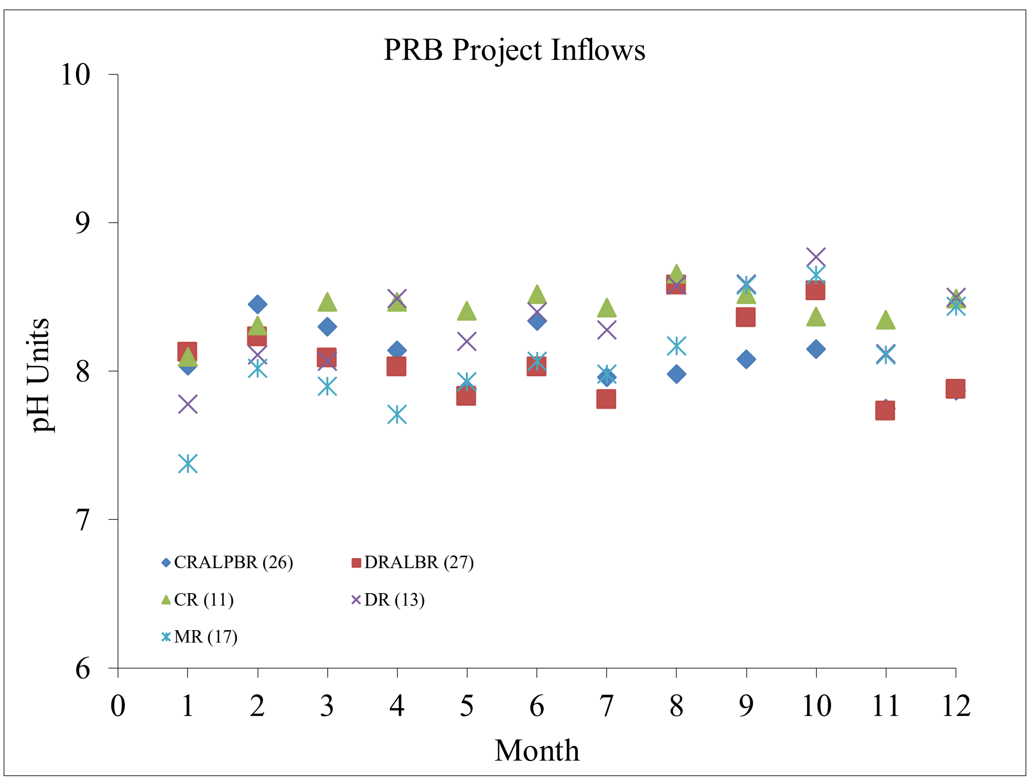

Figure 14. Monthly pH values (individual readings) for PRB Project and lower river (Sites 1, 3, 5, 31), 2018.

Table 1. Summary of blend adjustments made relative to changes in the calculated temperature without the project in place in 2013 – 2018 at the SWW.

	2013		2014		2015		2016		20167		2018	
	% water withdrawal		% water withdrawal		% water withdrawal		% water withdrawal		% water withdrawal		% water withdrawal	
Month	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom	Surface	Bottom
January 1	100	0	100	0	100	0	100	0	100	0	100	0
February 1	100	0	100	0	100	0	100	0	100	0	100	0
March 1	100	0	100	0	100	0	100	0	100	0	100	0
April	100	0	100	0	100	0	100	0	100	0	100	0
May 1	100	0	100	0	100	0	100	0	100	0	100	0
May 5			90	10								
May 7			85	15								
May 9					90	10						
May 11					80	20						
May 12					75	25						

May 13							85	15				
May 14	95	5										
May 16			80	20			80	20				
May 17	90	10										
May 19									85	15		
May 20	85	15										
May 22											85	15
May 23			75	25								
May 25							75	25				
May 26			70	30					90	10		
May 27	80	20										
May 29			65	35								
May 31									85	15	80	20
June 1	80	20	60	40			80	20				
June 3							85	15	80	20		

June 4			70	30								
June 5					65	35						
June 6					60	40						
June 7	85	15										
June 8									75	25		
June 9									70	30		
June 10							75	25				
June 11											75	25
June 13							70	30				
June 14	80	20					65	35				
June 15							60	40	65	35	70	30
June 16			60	40			55	45				
June 17					65	35	50	50				
June 18	75	25										
June 19					70	30						

June 20									75	25		
June 22							60	40				
June 23, 24, 29, 30	70	30	50	50	75	25			80	20	60	
June 25												
June 27			55	45								
June 29							70	30				
July 1	75	25										
July 3	80	20	60	40								
July 7			65	35	65	35						
July 8							60	40	70	30		
July 9					50	50						
July 10	75	25										
July 11	70	30					45	55				
July 12							35	65				

July 13					40	60						
July 15			55	45								
July 17												
July 18							50	50				
July 20					45	55	55	45				
July 23											60	40
July 24			50	50								
July 25	65	35										
July 27					50	50						
Aug 1	50	50										
Aug 2	65	35										
Aug 6							40	60				
Aug 8							45	55				
Aug 9	55	45										
Aug 11									60	40		

Aug 12									35	65		
Aug 15												
Aug 16			45	55			55	45				
Aug 18	60	40										
Aug 20											50	50
Aug 22							45	55				
Aug 23					40	60						
Aug 26	55	45										
Aug 28												
Aug 30			40	60								
Aug 31							35	65				
Sep 1	55	45										
Sep 3					35	65						
Sep 4											40	60
Sep 6			35	65								

Sep 9	50	50										
Sep 20	40	60										
Sep 30	35	65										
Oct 1	35	65	-	-								
Oct 3												
Oct 8												
Oct 10												
Oct 28							100	0				
Oct 30											100	0
Nov 1, 3	100	0	100	0	100	0	100	0	100	0	100	0
Dec 1	100	0	100	0	100	0	100	0	100	0	100	0

Table 2. Total dissolved gas monitoring at the Reregulating Dam tailrace, 2018.

Date	Total dissolved gas
August 9	102
September 26	100
October 8	106

Table 3. Tributary flow weighted pH compared to pH at the Reregulating Dam tailrace, 2018.

Date	Tributary flow weighted pH	Daily minimum of pH at the Rereg Dam	Daily maximum of pH at the Rereg Dam
March 5	8.36	8.25	8.37
March 15	8.26	8.26	8.38
March 22	8.32	8.25	8.42
March 28	8.36	8.31	8.46
April 2	8.47	8.40	8.53
April 9	8.38	8.28	8.68
April 19	8.38	8.25	8.63
April 26	8.38	8.33	8.60
May 3	8.38	8.32	8.61
May 10	7.77	8.18	8.53
May 16	8.01	8.22	8.64
May 22	8.11	8.27	8.70
June 1	8.01	8.96	9.12
June 8	8.03	8.82	8.99
June 14	8.26	8.59	8.84
June 22	8.17	8.81	8.99
June 28	8.02	8.88	9.05
July 6	8.02	8.54	8.82
July 17	8.16	8.65	8.88
July 26	8.13	8.28	8.72
August 2	8.02	8.34	8.58
August 9	8.07	8.09	8.36
August 15	8.37	7.94	8.37
September 6	8.31	7.72	8.53
September 17	8.39	7.85	8.37
September 26	8.55	7.97	8.70
October 3	8.44	7.95	8.36
October 8	8.42	8.35	8.69

October 18	8.42	8.52	8.88
October 30	8.54	8.38	8.86
November 6	8.37	8.79	8.95
November 15	8.31	8.42	8.70

Appendix 2
Lower Deschutes River Intergravel Dissolved Oxygen 2018 Monitoring Report

Introduction

The Selective Water Withdrawal (SWW) intake facility at Round Butte Dam became operational in late 2009. In accordance with the Water Quality Management and Monitoring Plan, or WQMMP (Appendix A of the Settlement Agreement), and as specified in the Project's Oregon Department of Environmental Quality (ODEQ) and Confederated Tribes of the Warm Springs Reservation of Oregon (CTWSRO) Water Control Board Clean Water Act (CWA) Section 401 certification conditions, intergravel dissolved oxygen (IGDO) is monitored downstream of the Reregulating Dam after implementation of SWW to establish relationships between IGDO and ambient dissolved oxygen (DO) concentrations. A requirement of the WQMMP is the submittal, as part of the Annual Water Quality Monitoring Report, of an IGDO Monitoring Report.

This report summarizes results of the 2018 IGDO monitoring to verify the relationship between intergravel and ambient dissolved oxygen following implementation of SWW operations.

Methods

IGDO Downstream of the Reregulating Dam after SWW

In accordance with the WQMMP, the methodology described below is consistent with current ODEQ and CTWSRO Water Control Board (WCB) protocols. To provide a continuous record of water column DO, a real-time ambient DO monitoring station was installed at the USGS gaging station, near the entrance to the old Pelton Fish Ladder a short distance below the Reregulating Dam. In order to develop relationships between water column DO measured at this site and IGDO, a combination of grab sampling and diel sampling using water quality Sondes (e.g., Hydrolab, YSI) and Winkler titrations (APHA 1998) were employed. Diel DO and IGDO records were used to help determine the maximum potential IGDO depression between the grab sample results collected at other locations as well as relationships with the existing Sonde installed at the USGS gage house. For IGDO sampling downstream of the Reregulating Dam, the measurement methods were as follows:

IGDO Sampling Sites

In 2018 a total of four fixed sampling sites were constructed within existing gravel patches just downstream of the ambient DO monitoring station. The sampling sites were located within the first 0.3 miles downstream of the Reregulating Dam near "Jackson's spawning site" (Figure 1). At each sample site, perforated standpipes were placed vertically at a depth of 20-30 cm into artificial redds constructed in a manner similar to previous IGDO studies (Lewis and Raymond 2000). The standpipes were placed on the downstream face of the mound to provide local velocity conditions sufficient to ensure upwelling of interstitial water from within the gravel bed.

IGDO Grab Sites

At three of the four IGDO sampling sites, standpipes were constructed of 30-cm lengths of 3/4-inch ID PVC pipe. The standpipes were provided with threaded protective end caps and with 20 perforations of 3/16-inch diameter drilled along the lowermost 10 cm. The standpipes were buried vertically to a depth of 25 cm, and fitted with a 25-cm diameter neoprene disk at a depth of approximately 5 cm. This left approximately 5 cm of the standpipe protruding from the gravel surface.

Diel IGDO Site

The remaining IGDO sampling site was used for installation of a continuous recording water quality Sonde. A single standpipe was constructed of a 125-cm length of 3-inch ID PVC pipe. The standpipe was provided with threaded end caps and 20 perforations of 3/16-inch diameter along the lowermost 10 cm. The standpipe was buried vertically with perforations at a depth of 20–30 cm (Lewis and Raymond 2000).

IGDO Sampling

Prior to IGDO sampling, the water quality Sonde was calibrated by either the air saturation method or applicable manufacturer's instructions. The DO calibration was accepted when it was within 0.5 mg/L of DO determined by Winkler titration. Time of day, ambient water temperature, and local absolute barometric pressure were recorded at the time of sampling to allow for potential data adjustments and comparisons of relative DO levels between one sampling event and another.

Figure 1. Approximate location of Lower Deschutes River IGDO sampling sites.

IGDO Grab Sites

Water samples were withdrawn from within vertical standpipes after removal of protective end caps. Sampling was conducted using a low flow (0–500 mL/min) peristaltic pump assembly fitted with 3/8-inch flexible tubing and rigid sipping tube as used for permeability sampling. Discharge from the pump was directed to a flow-through cell mounted to a calibrated water quality Sonde. DO was recorded either after the minimum DO value was reached or after 50–60 seconds of sampling time, whichever occurred first. For use in data quality validation, triplicate water column DO readings were collected with the sampling device, with the pump discharge collected in three corresponding 300-mL BOD bottles for use in Winkler titrations. Preserved Winkler samples were analyzed within 8 hours of collection (APHA 1998).

Diel IGDO Site

A calibrated multi-parameter water quality Sonde was set up for recording IGDO at 30-minute intervals for 2–3 days. After removal of the protective end cap, the Sonde was placed with the probes adjacent to the standpipe perforations. For use in data quality validation, triplicate 300-mL water samples were withdrawn using the peristaltic pump assembly described above and preserved for Winkler titration. Three additional 300-mL Winkler samples were collected once per day for the duration of the diel sampling event and at the time of Sonde retrieval.

Sampling Schedule

The frequency of IGDO sampling in 2018 was determined following discussion and recommendations in 2014 by the ODEQ and CTWSRO. The 2018 IGDO sampling was intended to coincide with the beginning and end of the spawning season. IGDO was measured at all sampling sites in late June/early July and mid-November. Diel IGDO sampling was conducted coincident with IGDO grab samples at the location described above.

Results and Discussion

Steelhead redds in the Lower Deschutes typically have eggs and/or newly hatched fry through June (Zimmerman and Reeves, 1996). In 2018 standpipes were installed in fresh artificial redds in June prior to sampling and checked for any scouring during sample events.

Daily values for ambient and intergravel dissolved oxygen grab sampling for 2018 are shown in Figure 2. Diel IGDO sample results for June and November are shown in Figures 3 and 4.

The 2018 daily minimum for ambient DO was 10.3 mg/L in June and 11.5 mg/L in November. The daily median for IGDO was 10.4 mg/L in June and 11.7 mg/L in November. Daily median values of IGDO from both grab and diel samples in 2018 remained above the ODEQ criteria of 8.0 mg/L for sample dates. Ambient dissolved oxygen values remained above the state's 9.0 mg/L level required for salmonid spawning. In 2018 the project operators, according to an interim agreement with ODEQ and the CTWSR WCB, operated to meet the current ambient DO standard (8.0 mg/L) for that section of the lower river during the non-spawning season (July 1 - October 14), and the 9.0 mg/L criteria for the remainder of the year.

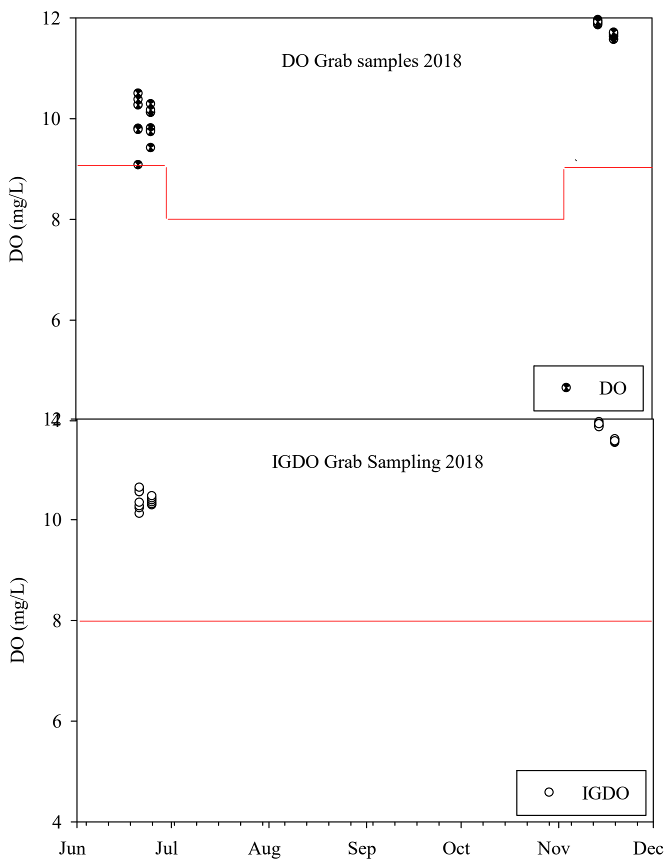

Figure 2. Ambient and intergravel dissolved oxygen values from grab samples from 2018. Red line indicates ODEQ ambient dissolved oxygen and intergravel dissolved oxygen criteria.

Diel IGDO was compared to ambient DO values recorded from the fixed station immediately downstream of the Reregulating Dam (Figures 3 and 4). The daily median IGDO, and individual readings, remained above the ODEQ 8.0 mg/L standard throughout sampling events. Paired t tests were performed comparing the DO and IGDO diel sample results for sample dates. There were statistically significant differences between IGDO and DO for all dates (P = < 0.001).

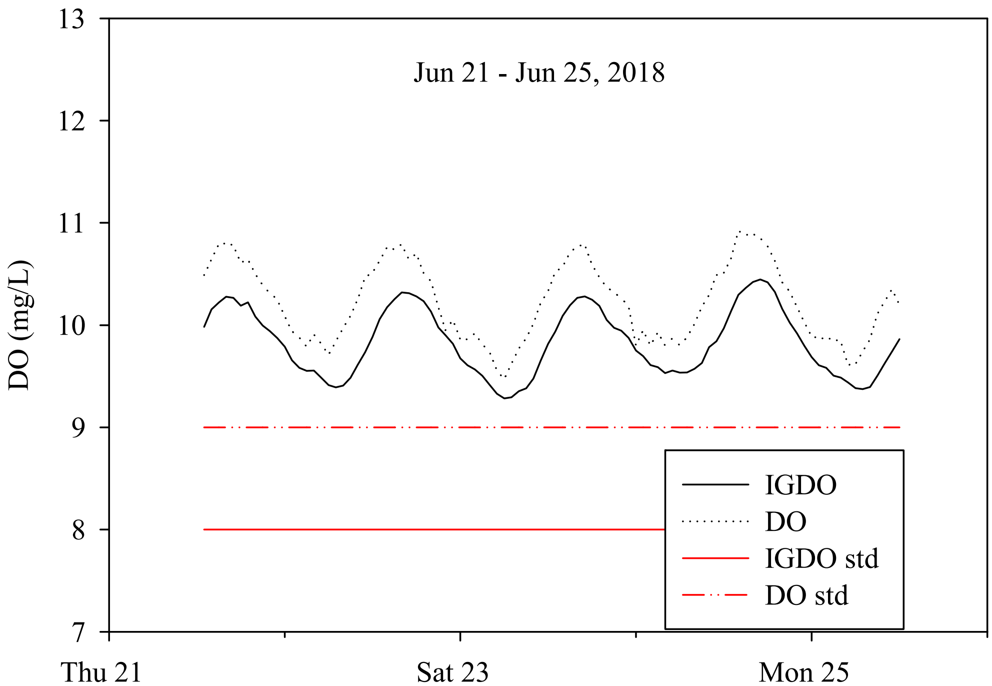

Figure 3. Diel IGDO values compared to ambient DO from June 21 through June 25, 2018.

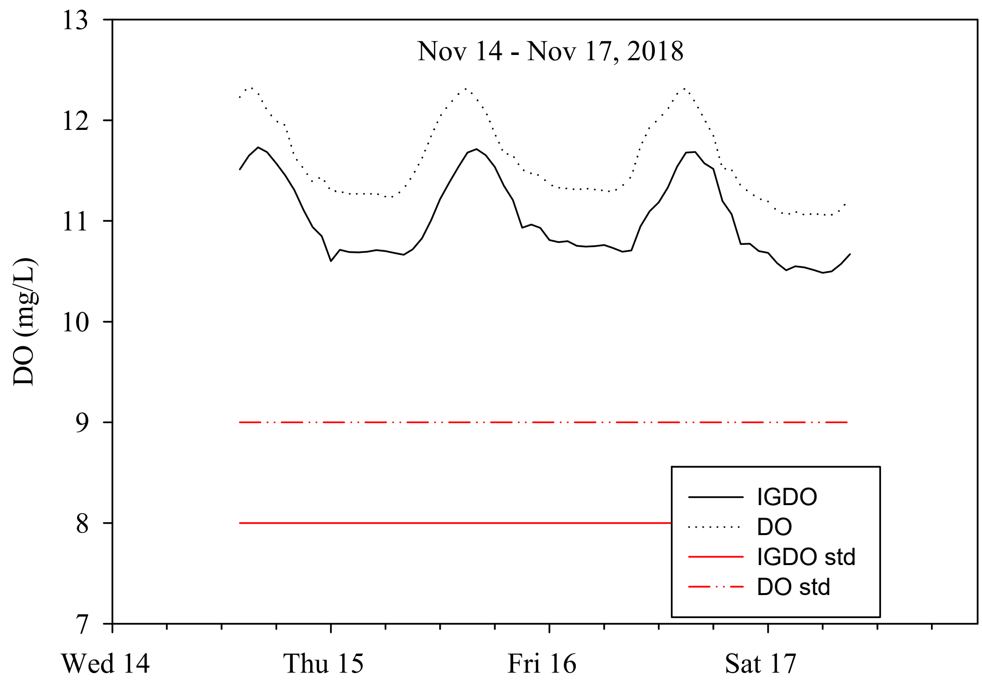

Figure 4. Diel IGDO values compared to ambient DO from November 14 through November 17, 2018.

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