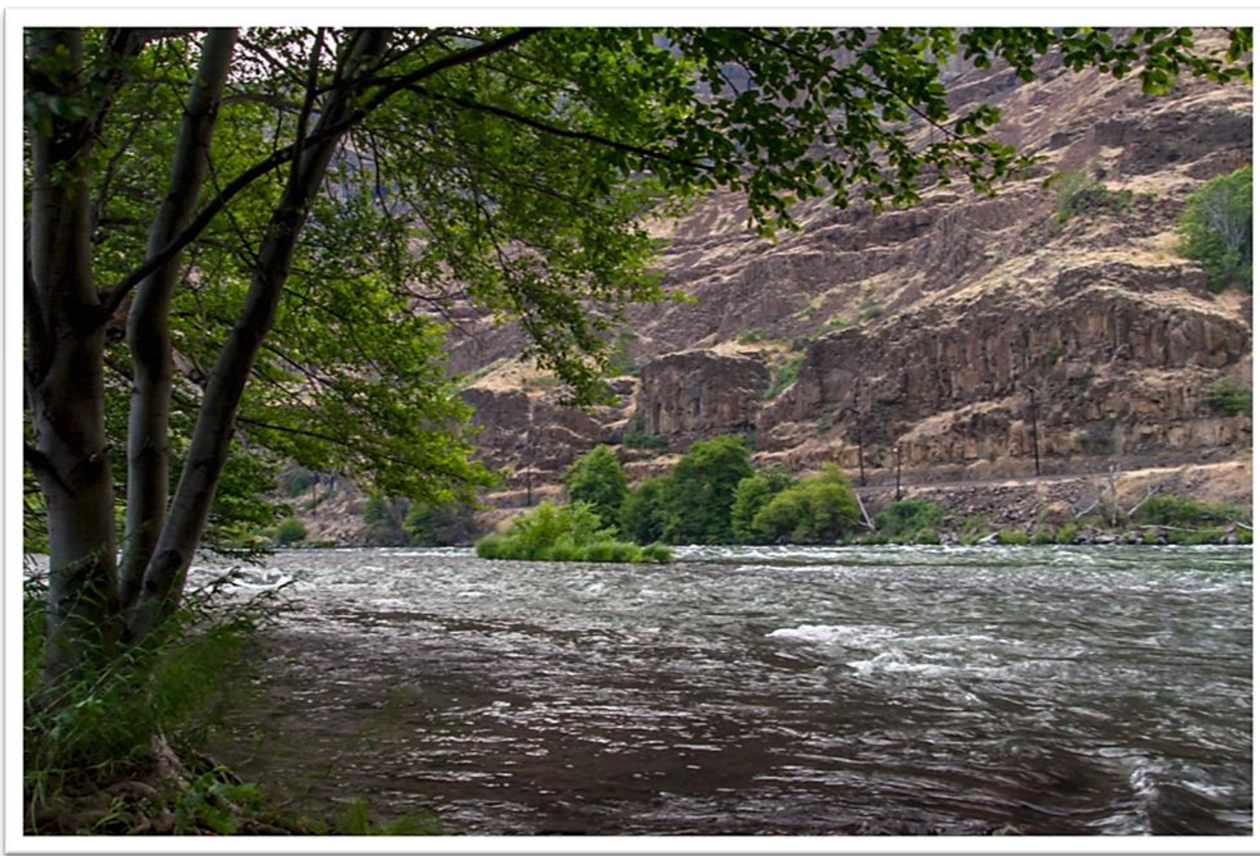
2022 LOWER DESCHUTES RIVER WATER QUALITY REPORT



Deschutes River Alliance
March, 2023

Purpose:

This report is a continuation of the Deschutes River Alliance's (DRA) annual water quality monitoring of the lower Deschutes River. It presents the known issues concerning unforeseen consequences affecting the lower Deschutes River following the installation and operation of the Selective Water Withdrawal (SWW) Tower at the Pelton-Round Butte Hydroelectric Project. Since the SWW Tower started operating late 2009, the lower Deschutes has experienced an increase in water quality violations.

In this report, the DRA presents results from ongoing annual water quality monitoring and explores how flows from the Crooked River affect water quality in the lower Deschutes River. This report also emphasizes how changes in operation practices at the SWW Tower could mitigate known factors negatively influencing the lower Deschutes River's water quality and ecology.

Objectives

The monitoring objectives of this ongoing study are:

1. To determine how SWW Tower operations affect the lower Deschutes River.
2. To determine how the water quality parameters of temperature, pH, and DO change on an hourly, seasonal, and annual basis in the lower Deschutes River.
3. To determine if any of these parameters violate Oregon's water quality standards for the Deschutes Basin and, if so, how frequently.
4. To explore plausible alternatives to the current operation practices of the SWW Tower and the Project.

Key Findings

- SWW Tower operations intentionally warm the lower Deschutes River during critical spawning and incubation periods for resident trout, spring Chinook, bull trout, and steelhead.
- Relative to pre-SWW Tower operations, the cooling during the fall caused by the current operations is disproportionate to the warming that occurs during the rest of the year, most of which falls during the designated salmon and steelhead spawning and incubation period.
- Excess nutrients in surface water released from Lake Billy Chinook continues to be the primary contributor to the declining health of the lower Deschutes River and is largely influenced by high nitrogen inputs from the Crooked River.
- Similar to previous years monitored by the DRA, large diel swings in pH and dissolved oxygen indicate excess nutrients from the Crooked River contribute to the well-documented nuisance algal growth and aquatic plant biomass accumulation in lower Deschutes River.
- High pH levels continued to exceed Oregon water quality standards throughout the monitoring period in 2022 but showed an immediate improvement with increased %bottom-draw.
- The current operating permit requires salmonid spawning standards for DO to apply year-round. Dissolved oxygen concentration does not meet state standards set to protect incubating trout eggs and fry for a large portion of observed spawning and incubation periods.

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Acknowledgments

Thank you to Rick Hafele, Steve Pribyl, and Larry Marxer for their continued support with this year's data acquisition and analysis.

In addition, thank you to the organizations that have provided critical funding needed for this ongoing monitoring project: Clabough Foundation, Maybelle Clark Macdonald Fund, the Tualatin Valley Chapter of Trout Unlimited, Washington County Fly Fishers, and The Burning Foundation. As well as those not specifically listed.

Last, thanks to all those not mentioned here who care about the Deschutes River and have contributed hours of their time and money to better understand the river's changing ecology and protect its health. Many hundreds of people and numerous companies and foundations have made it possible to keep this work moving forward - THANK YOU.

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List of Abbreviations

CFS - Cubic Feet per Second

CTWSRO - Confederated Tribes of the Warm Springs Reservation of Oregon

DO - Dissolved Oxygen

DRA - Deschutes River Alliance

IGDO - Intergravel Dissolved Oxygen

NOAA -National Oceanic and Atmospheric Administration

OAR - Oregon Administrative Rules

ODEQ - Oregon Department of Environmental Quality

ODFW - Oregon Department of Fish and Wildlife

PGE – Portland General Electric

Project - Pelton Round Butte Hydroelectric Project

RM - River Mile

SWW Tower - Selective Water Withdrawal Tower / Tower

USBR - United States Bureau of Reclamation

USDA -United States Department of Agriculture

USGS - United States Geological Survey

WQMMP - Water Quality Management and Monitoring Plan

7-DADM - 7-Day Average Daily Maximum

Background:

The lower Deschutes River, Pelton-Round Butte Hydroelectric Project, Licensees, and the Selective Water Withdrawal Tower:

The 252-mile-long Deschutes River runs south to north and is broken into three segments: the upper, middle, and lower Deschutes (see figure 20 in Appendix C). The lower Deschutes River (LDR) begins at the tailrace of the downstream most dam of the Pelton-Round Butte Hydroelectric Project (Project), a three-dam complex (Figure 1) jointly owned by licensees Portland General Electric (PGE) and the Confederated Tribes of the Warm Springs Reservation of Oregon (CTWSRO). The LDR runs 100 miles north to where it converges with the Columbia River (River Mile 0).

Start of lower Deschutes River (River Mile 100)

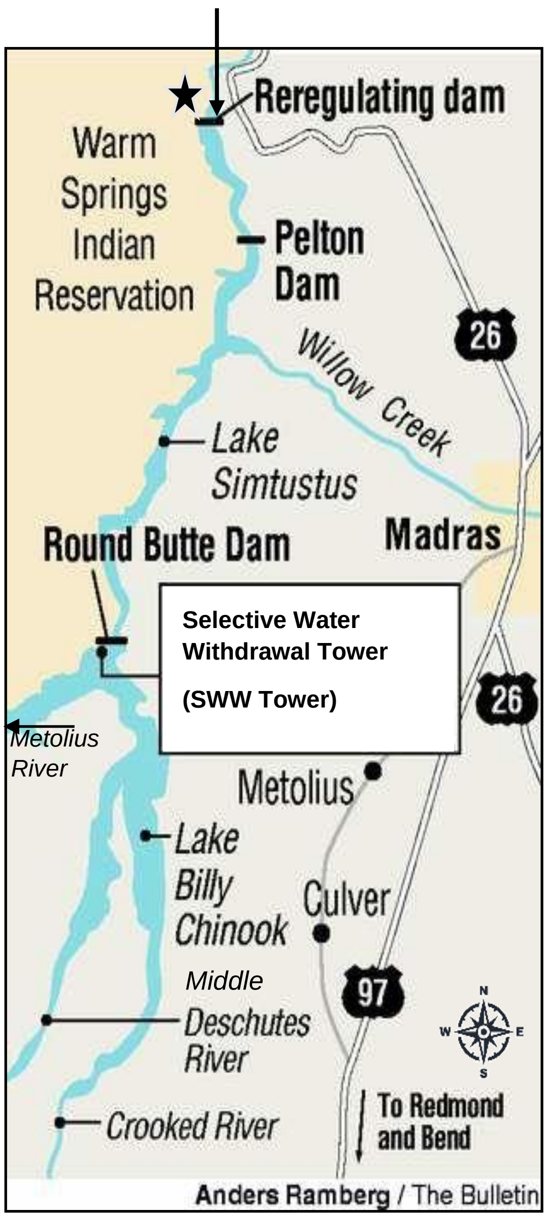

Figure 1. The Pelton-Round Butte Hydroelectric Project and Selective Water Withdrawal Tower owned by Portland General Electric and the Confederated Tribes of Warm Springs, Oregon. Round Butte Dam (creates Lake Billy Chinook reservoir), Pelton Dam (creates Lake Simtustus reservoir), and the Reregulating Dam (creates the Reregulating reservoir). The lower Deschutes River originates from the tailrace of the Reregulating Dam. Map adapted from original source.

In 2004, licensees PGE and the CTWSRO received a new operating license from the Federal Energy Regulatory Commission (FERC) allowing the generation of hydropower until 2054. Under the new FERC license, licensees were required, among other things to 1) reestablish both upstream and downstream passage of anadromous fish through the 3-dam Project, 2) improve water quality in both Lake Billy Chinook (LBC) and in the lower Deschutes River and 3) monitor and report a variety of water quality parameters on an annual basis to FERC, the Oregon Department of Environmental Quality (ODEQ), the Oregon Department of Fish and Wildlife (ODFW), the CTWSRO Water Control Board, and the Pelton-Round Butte Fish Committee (PGE & CTWSRO 2002). These relicensing Requirements are thoroughly discussed in the DRA's 2021 water quality report (DRA 2022).

To meet these requirements, PGE and the CTWSRO constructed the Selective Water Withdrawal (SWW) Tower in 2009. A thorough discussion of the Tower's construction and operation is covered in the Deschutes River Alliance's 2016 water quality report (DRA 2017).

Established Findings

The following is a brief summary of established findings consistent among three independent monitoring entities: 1) PGE's annual Water Quality Monitoring and Management Plan's (WQMMP's) data & reports, 2) conclusions from Max Depth Aquatics Inc.'s report (Eilers & Vache 2021 [from here forward referenced as the PGE water quality study]), and 3) the ongoing Deschutes River Alliance's annual water quality monitoring program:

1. Water released from the SWW Tower discharges 100% surface water from Lake Billy Chinook starting around early November through early summer compared to 100% bottom water year-round prior to Tower construction and operation. This has resulted in a disproportionate release of water derived from the Crooked River for most of the year.

2. Current operation of the SWW Tower intentionally warms the lower Deschutes River January through August compared to pre-SWW Tower temperatures.[1] This warming is disproportionate to the intentional cooling that occurs in the fall.

3. Surface water in Lake Billy Chinook is comprised primarily of lower quality water due to high nutrient loads from the Crooked River.[2] Water entering Lake Billy Chinook from the Crooked River has very high nitrate (NO3) concentrations compared to the nitrate contributions from the Metolius and Deschutes rivers.[3] Agricultural pollutants, including the pesticide chlorpyrifos, have been reported in the lower Deschutes River by ODEQ at levels that exceed the toxicity limits for fish, other aquatic life forms, and humans set by the Environmental Protection Agency.[4] The contribution of toxics from the Crooked River is currently unknown.

4. After construction of the dams and before SWW Tower installation, water released from LBC was 100% bottom water, which is comprised almost entirely of the colder, cleaner Metolius River water. Prior to dam construction in 1964, the lower Deschutes River was a blend of nearly equal amounts of Crooked River water and Metolius River water (the middle Deschutes River contributed a minor amount of water).

5. High daytime pH and large diel swings in both pH and dissolved oxygen (DO) concentrations indicate that the lower Deschutes River has become eutrophic.[5]

[1] See Figure 16a

[2] DRA Water Quality and Land Use Report (DRA 2019a), Lower Crooked River Water Quality Monitoring Project (MHE & CRWC 2022)

[3] DRA Lake Billy Chinook Water Quality Study Results (DRA 2016); PGE Water Quality Study (Eilers & Vache 2021)

[4] 2022 Integrated Report (ODEQ 2022)

[5] DRA Lower Deschutes River Water Quality Reports (DRA 2015, 2017, 2018, 2019b, 2022)

6. Operations at the SWW Tower release planktonic, free-floating algae and cyanobacteria (not commonly found in natural, free-flowing streams) from the surface of Lake Billy Chinook into the lower Deschutes River; causing, among other things, further nutrient transfer and a murky appearance in the lower Deschutes River.[6]

7. Both increased water temperature and nutrient pollution from Lake Billy Chinook cause excessive algal growth including both green algae (mainly *Cladophora*) and nuisance diatom species forming felt-like mats of algae on stream substrate in the lower Deschutes River.[7]

[6] PGE Water Quality Study (Eilers & Vache 2021)

[7] Lower Deschutes River Macroinvertebrate Hatch Activity Survey Results (Hafele 2014); Spring peak flows and Cladophora Study (Eilers et al. 2022)

Executive Summary

DRA Position statement:

The DRA advocates for returning to the release of the maximum amount of bottom water from Lake Billy Chinook into the lower Deschutes River while still providing surface withdrawal during peak smolt migration. As demonstrated below and in the DRA's other annual water quality reports, releasing a higher percentage of bottom water for a longer duration could provide immediate relief to the declining water quality in the lower Deschutes River. The DRA also supports changes to anadromous fish capture-and-release practices at the Project to maximize the possible success of anadromous fish reintroduction above the Project. A complete position statement is available here on our website.

Based on the data presented in the PGE Water Quality Study, results from PGE's annual water quality monitoring reports, and annual water quality monitoring by the DRA, we believe that the installation and operation of the SWW Tower, and the ensuing release of warmer, nutrient laden water from the surface of Lake Billy Chinook, has resulted in numerous unintended consequences that negatively impact the lower Deschutes River. These consequences include but are not limited to degraded water quality, increase in fish pathogens affecting resident and anadromous fish, a decline in pollution sensitive aquatic insects, as well as negative effects on terrestrial animals such as insect-feeding birds.

DRA has implemented several studies independent of those by PGE to assess the impact of the Tower on aquatic life and water quality. The results of these studies are published in annual reports and are available to the public on our website. This report presents the results from our continued water quality monitoring of the lower Deschutes River for the 2022 monitoring season and continues to advocate for changes in SWW Tower operations that could immediately benefit the lower Deschutes River. The subsections below outline the major issues surrounding the SWW tower and the LDR.

SWW Tower:

The DRA believes that construction and operation of the SWW Tower in 2009 is arguably the greatest anthropogenic change imposed on the lower Deschutes River since the initial completion of the Pelton Round Butte Hydroelectric Project in 1964. The SWW Tower allows operators to release up to 100% surface water from Lake Billy Chinook at any time and duration. Water (surface or a blend of surface and bottom water) is only released from LBC via Round Butte Dam during periods of power production. When the turbines in the dam are not running, water is not released from Lake Billy Chinook. The Project is managed to reflect a run-of-the-river system, which in the case of the LDR means that the flows exiting the Project must equal the flows entering Lake Billy Chinook within 10% (PGE &CTWSRO 2022). Constant streamflow in the lower Deschutes River is maintained by the continued release of water from the Reregulation Dam (the third and most downstream dam of the three-dam complex) (Figure 1).

Prior to the construction of the SWW Tower in Lake Billy Chinook, all water released from Round Butte Dam was 100% bottom-draw. Upon installation of the SWW Tower, all water released from Lake Billy Chinook passes through the SWW Tower (unless it is spilled for flood control or maintenance). Current tower operations release 100% surface water for about nine months of the year (September-May) and a blend of surface and bottom water the other three months (June-August). Original license documents indicated the Tower would be able to release up to 100% bottom water (PGE & CTWSRO 2002). However, the Tower now appears to have constraints that restrict it from releasing more than 60-to-65% bottom-draw as no more than 65% bottom draw has been reported by PGE since Tower operations began. Reasons for these constraints have not been publicized and no explanation has been given. This constraint appears to be the result of some unforeseen engineering or construction failure.

Operational changes at the Tower have occurred, with the primary change being the release of surface water at night starting in 2017 (PGE: Our Story…). These "Night Blend[8]" operations occur from March-June (during the downstream migration of juvenile fish) in an attempt to increase capture rates for out-migrating juvenile salmonids at the Tower; a primary objective of the SWW Tower (PGE & CTWSRO 2022b). The modeling from the PGE Water Quality Study indicates that the "Night Blend" provides slight improvements to multiple water quality parameters in the lower Deschutes in addition to the enhanced capture rate of out-migrating juvenile anadromous fish (Eilers & Vache 2021), two things we support. However, outside of the peak juvenile migration period, modeling from the PGE Water Quality Study (Eilers & Vache 2021) and the available record (including DRA 2015-2022; Edwards 2018; MHC &CRWC 2022) shows that releasing maximal bottom draw is best for both the water quality and ecosystem in the LDR. See 2019 and 2020 DRA Water Quality Report Discussion sections for additional details about the "Night Blend" in relation to current Tower operations (DRA 2020; DRA 2021).

Lake Billy Chinook:

Temperature stratification of Lake Billy Chinook occurs each year and generally follows the same pattern demonstrated at other lakes at similar latitudes. In the case of Lake Billy Chinook, recently (2016-2020) this has occurred from March/April through October/November (PGE & CTWSRO 2017-2021; PGE & CTWSRO 2022a). Based on

[8] To attract smolts to the Tower's fish trap 100% surface water is released from the Tower to create attractive surface currents. However, water is only released from LBC when water is run through the dam's turbines to produce electricity, and power production only occurs during part of the day. The use of the "night blend" approach means all of the surface water released from the Tower takes place at night, and that power production also occurs at night

typical tower operations and stratification dynamics in LBC, 100% surface draw during lake stratification (when the surface water quality is at its poorest) occurs for a little less than half of the year: late March – May and September – November. From June – August, even though some bottom draw occurs, there is always at least 40% surface water released into the LDR.

During stratification, surface water is composed primarily of warmer, nutrient-laden water from the Crooked River, which carries a higher concentration of nutrients and other pollutants (ODEQ 2012, Eilers & Vache 2021). By contrast, the reservoir geology and stratification dynamics cause the bottom water to be comprised primarily of the cooler and denser water sourced from Metolius River. The surface nutrients are in a dynamic relationship with algal growth and density. When algal blooms occur during the spring and summer, most of the nutrients are consumed resulting in dense populations of algae. Yet, with SWW Tower operation, these algae are now released downstream (as seston) into the lower Deschutes where their cells breakdown either naturally or by being mechanically damaged in the power production turbines through which they must pass and release their nutrients back into the water. Prior to the release of surface water from the SWW Tower, release of 100% bottom water from Round Butte Dam during lake stratification had fewer negative effects on the lower Deschutes River relative to post-Tower operations since the bottom water, primarily sourced from the Metolius River, is colder and contains fewer nutrients.

Crooked River Water Quality:

Because the Deschutes Basin is nitrogen-limited, including the lower Deschutes River, nitrogen is the most important nutrient when considering the recent changes in water quality and periphyton growth (Eilers & Vache 2021; Eilers et al. 2022). The DRA believes that the available records show that for the long-term health of the entire basin, the water quality from the lower Crooked River ultimately needs improvement. By virtue of the location of the Crooked River as it enters Lake Billy Chinook and thermal stratification from late March to late November most of the surface water in Lake Billy Chinook is comprised of the nitrogen-rich Crooked River and is subsequently released directly into the lower Deschutes River through the SWW Tower. Nutrient loads from the Crooked River are a key component that needs to be managed for long-term improvement.

A recent study published in September 2022 by Mount Hood Environmental in collaboration with the Crooked River Watershed Council (MHE & CWRC 2022) found that the source of the majority of the Crooked River's total daily nitrogen load comes from spring inputs downstream of Smith Rock State Park. This high-volume of groundwater is the most significant source of nutrients entering Lake Billy Chinook.

For restoration and water quality improvement purposes, determining the proportion of nitrogen from these springs that is anthropogenically/naturally sourced is important.

However, further research needs to be performed to determine this. A previous study of carbon and hydrogen isotopes at Opal and surrounding smaller springs found differing residence times (time as groundwater) of the water released by these springs into the lower Crooked River (Caldwell 1998). The greatest residence time found from Opal Springs water was over 40 years old, which suggests that some of the nitrate is naturally sourced. However, other spring water located near Opal Springs was dated young enough to potentially have anthropogenically sourced nutrients (Caldwell 1998). Additionally, a crude evaluation of nutrients entering LBC estimated that only 12% of the nitrate entering LBC was naturally sourced, assuming that the Metolius River water chemistry (largely undeveloped) roughly represents the natural chemistry of the basin (Eilers & Vache 2021). Regardless of the source, the long residence times of the Crooked River spring water clearly shows that even under the most optimistic scenarios, large-scale stream restoration to the Crooked River watershed will likely take decades to significantly improve water quality.

The DRA's monitoring work in the lower Crooked River is presented in a separate report found here: 2020 Crooked River Water Quality Report. See also DRA's Crooked River Basin GIS water quality report: Mapping Water Quality and Land Use in the Crooked River Basin). Altogether, the current record suggests that the simplest solution to the problems facing the LDR now and in the coming decades is more bottom draw from the SWW Tower.

Sampling Methods and Procedures

Annual Water Quality Monitoring

One multi-parameter YSI EXO2 data sonde was deployed with the YSI EXO Handheld Display (Figure 2) at the DRA monitoring site (Figure 3) approximately 0.3 miles below the Reregulating Dam tailrace at around river mile (RM) 99.7 of the lower Deschutes River from mid-spring through late fall 2022. The monitoring site is the same location the DRA has sampled in 2021 and is close enough to the Reregulating Dam tailrace to eliminate external influences on water quality, yet far enough downstream to allow the river to stabilize after its release from the Project. The current monitoring site is located 0.6 miles upriver from the site monitored during the 2016-2020 seasons.

Before deployment, the YSI EXO2 was tested and calibrated to lab standards and programmed to record hourly readings of the following water quality parameters: temperature, DO, pH, conductivity, and turbidity. Each sensor was cleaned by an automatic central wiper to eliminate inaccurate results caused by biofouling.

Figure 2. YSI 6600 V2 multi-parameter data sonde (left) and YSI 650 MDS Handheld (right). Source: YSI.

The data sonde was deployed from 4/4/2022, 0900 hours through 11/23/2022, 1100 hours. Data audits of the sonde sensors were conducted at the time of initial deployment and repeated during monthly field audits. Field probes independent of the data sonde were used to compare precision of deployed sonde sensors throughout the season (Appendix A). Data downloads were made during the field audits and batteries were replaced as needed. The final field audit and data downloads were completed when the sonde was removed from the river on 11/23/2022. Quality control and assurance procedures were followed throughout the study (Appendix B).

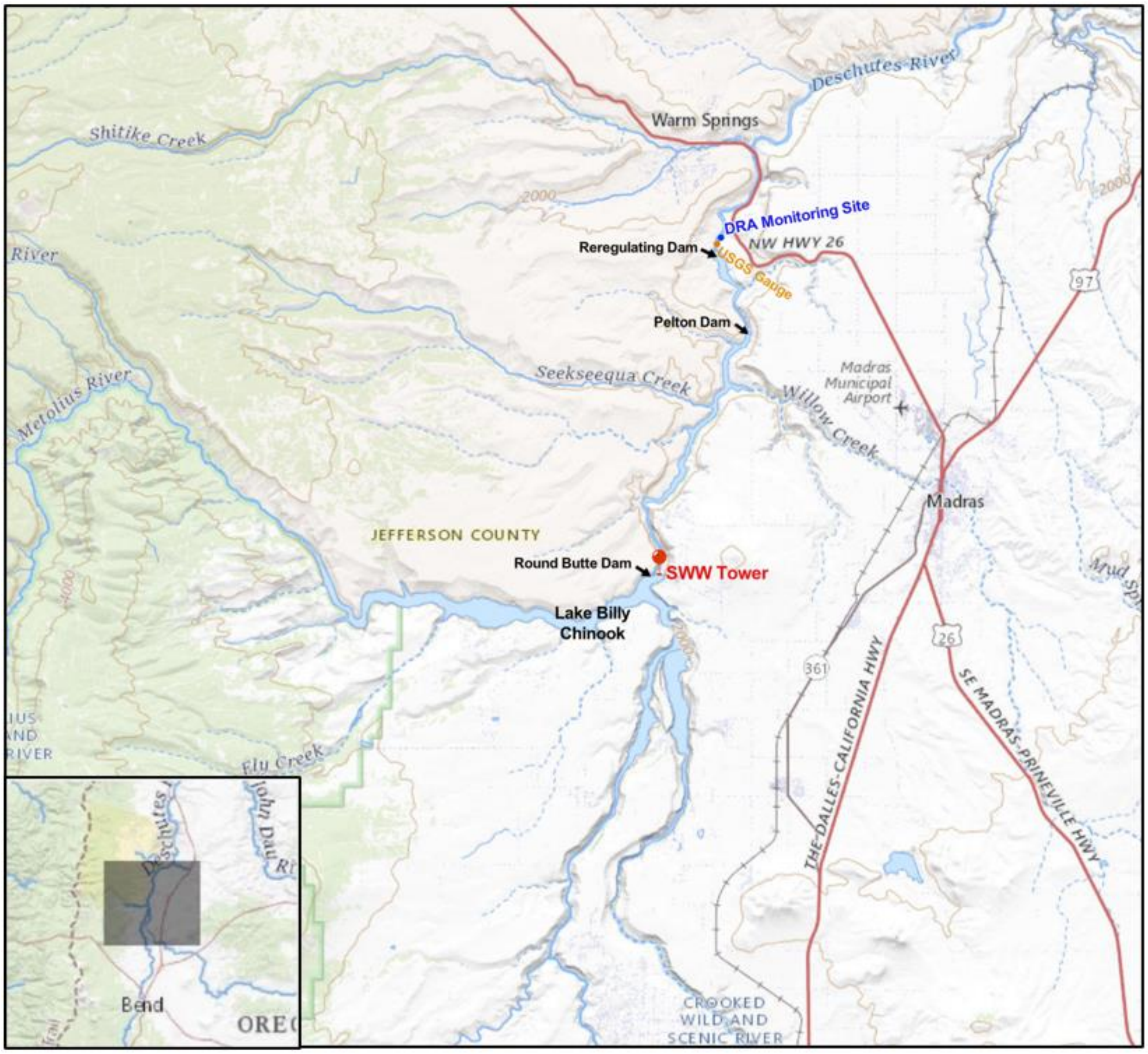

Figure 3. Topographical view of the Project with approximate placements of USGS Madras gauging station and DRA monitoring site located downstream of the Reregulating Dam near RM 100. Generated with Esri ArcGIS Online utilizing USGS Topographic base map.

In addition to the collection of water quality, the DRA reviewed river data collected by USGS National Water Information System at sites in the LDR and its tributaries to assess annual flow rates and water temperature changes. The DRA also collected weather data from the NOAA Climate Data Online, NOAA National Weather Service, USDA Snow & Climate Monitoring database, and University of Nebraska-Lincoln-USDA US Drought Monitoring database to determine differences in annual drought, precipitation, and air temperature in the Deschutes Basin. Lastly, the DRA monitored SWW Tower operation data submitted by licensees to DEQ as required by the Project's Clean Water Act Section 401 permit through public records requests. These data were reviewed and compared to DRA data, where applicable.

Results

Hourly Temperature:

Hourly temperature measurements from 4/4/2022 to 11/23/2022, are shown in Figure 4. The graph shows the seasonal changes and daily ranges (diel range). The average difference between the daily minimum (occurs just before sunrise) and daily maximum (typically around 3pm) was 0.66°C (~1.2°F). The maximum diel range was 1.60°C (2.88°F) on May 16 and the minimum diel range was 0.154°C (0.28°F) on November 12. The maximum daily recorded temperature reached 15.455°C (59.82 °F) on August 02.

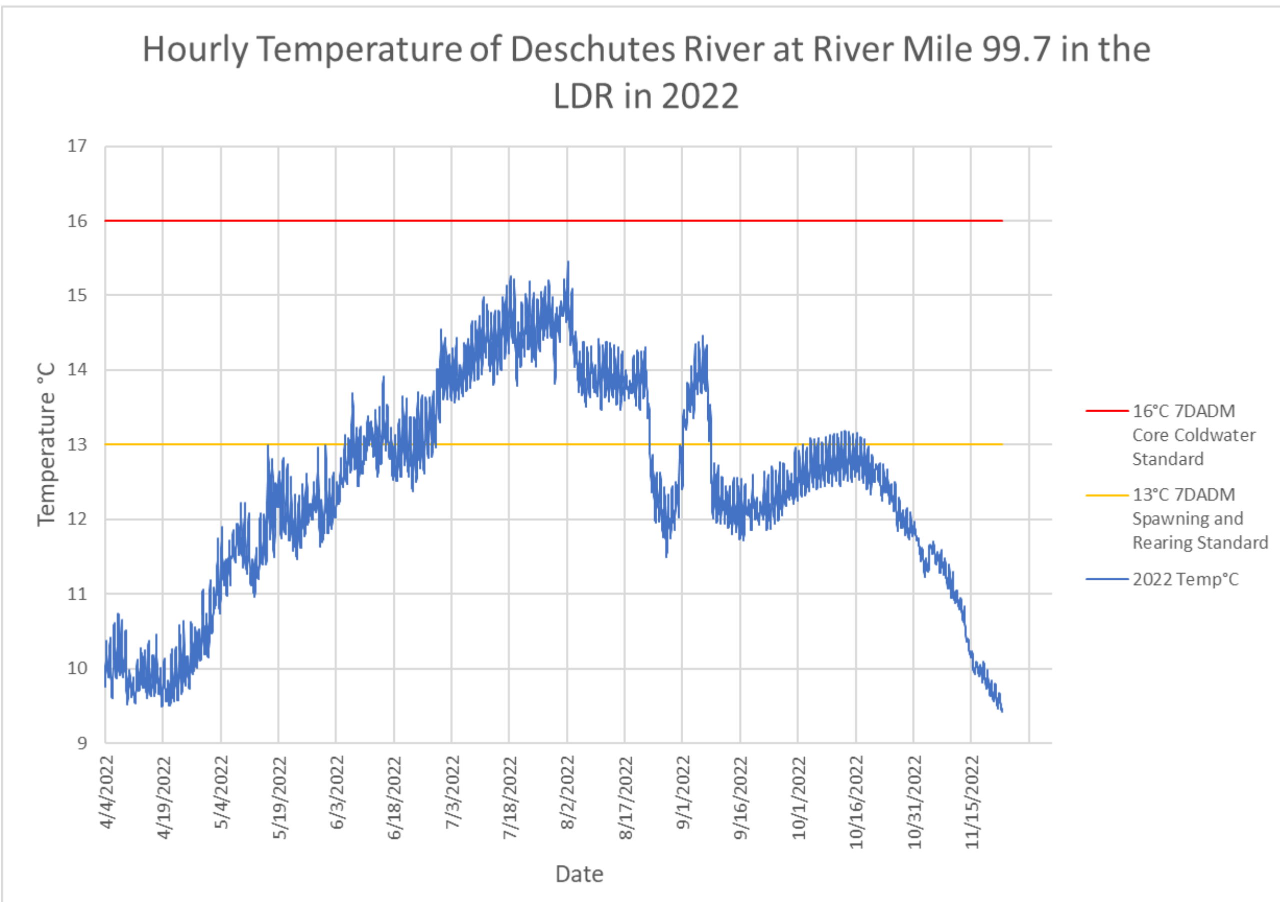

Figure 4. 2022 Hourly water temperature at River Mile 99.7 of the lower Deschutes River with the basin core-cold water habitat 7-Day Average Daily Maximum (7DADM) temperature standard (16°C) shown with a red line. 7-Day Average Daily Maximum Temperature during spawning periods (October 15 – June 15 for salmon and steelhead), is shown with a yellow line. See 7-Day Average Daily Maximum Temperature below for an explanation of this standard.

7-Day Average Daily Maximum Temperature:

Oregon's maximum water temperature standard is based on a 7-day moving average of the daily maximum water temperatures or "7-DADM" (OAR 340-041-0028[9]). The

[9] https://secure.sos.state.or.us/oard/viewSingleRule.action?ruleVrsnRsn=244176

standard applied in the lower Deschutes River from below the Project downstream to the confluence with the Warm Springs River is 16°C (60.8°F) for core cold-water habitat use (see red line in Figure 4; For Oregon's cold-water maps and criteria, see Appendix D). A lower water temperature standard (13°C; 55.4°F) is applied during periods identified as having salmon and steelhead spawning use.

Figure 5 below shows the 7-day average daily maximum temperature (7-DADM) at the DRA monitoring site in 2022. The orange highlighted area shows date range designated as salmon and steelhead spawning/incubation. The 13°C maximum temperature standard applies from October 15 until the end of the salmon and steelhead spawning/incubation period on June 15 (OAR 340-041-0130[10] – Figure 130B; see Appendix D).

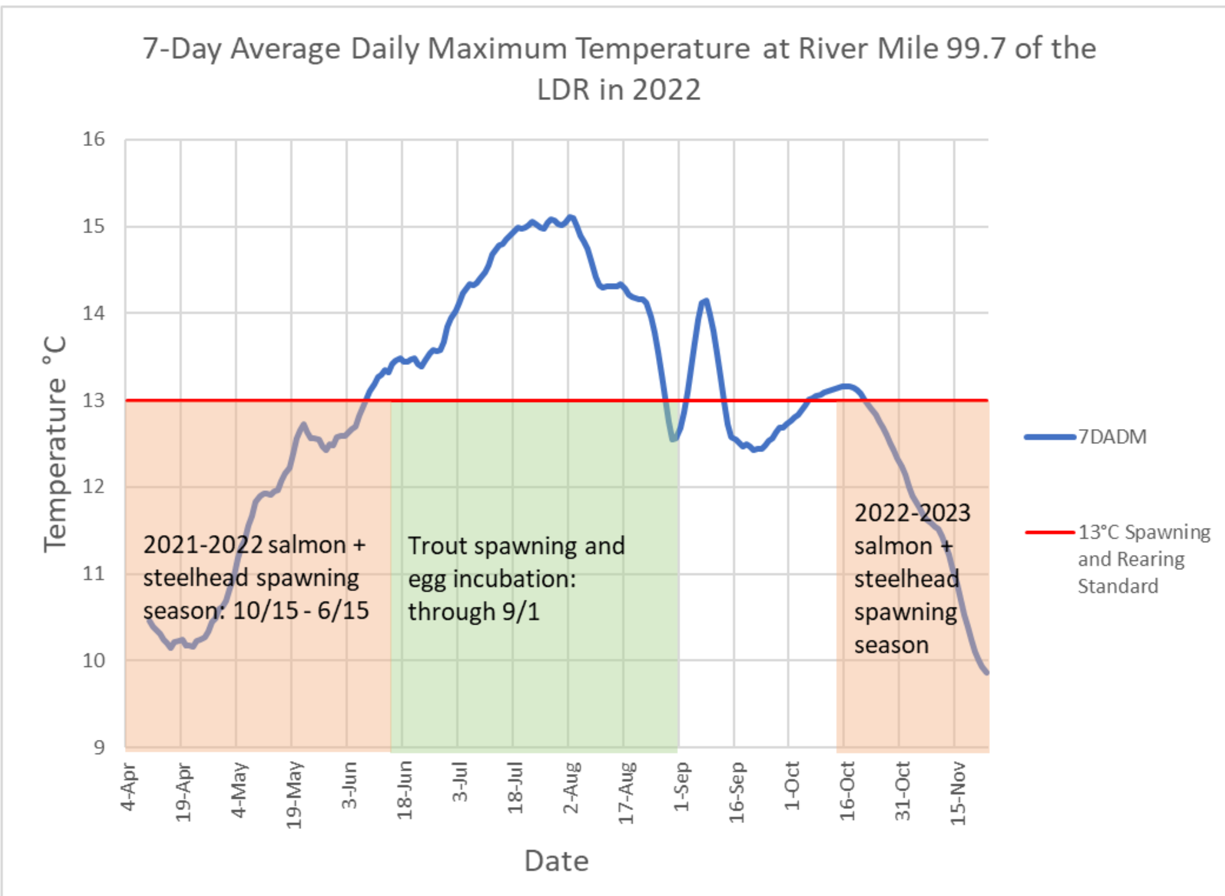

Figure 5. 2022 7-DADM water temperature at River Mile 99.7 of the lower Deschutes River with the maximum temperature standard during spawning and rearing times (October 15 – June 15 for salmon and steelhead, shaded in orange) show with a red line (13°C). The green highlighted area shows the resident trout spawning/incubation period continuing until at least the end of August (Zimmerman & Reeves 2000).

Licensees are required to increase bottom draw when temperatures in the Deschutes at the Reregulating dam approaches 13°C (PGE & CTWSRO 2002). In 2022, temperature

[10] https://secure.sos.state.or.us/oard/viewAttachment.action?ruleVrsnRsn=256033

exceeded the 13°C maximum temperature during the last seven days of the spawning-egg incubation period in the spring and the first seven days of the spawning and egg incubation period in the fall: 6/8/22 to 6/15/22 and 10/15/22 to 10/21/22, respectively. While Oregon's 13°C maximum temperature standard does not currently apply to resident trout spawning/incubation, it is widely documented that cooler water temperatures during this period provide better survival of resident trout eggs and fry. Throughout the monitoring period, the 7-DADM exceeded 13°C from 6/8/22 to 8/28/22, 9/3/22 to 9/12/22, and 10/6/22 to 10/21/22.

Dissolved Oxygen:

Dissolved oxygen (DO) is measured in two ways: 1) the concentration in milligrams per liter (mg/L), and 2) the percent of oxygen dissolved in the water (% saturation) based on where the sample was collected (i.e., temperature, elevation, and barometric pressure). In most cases it is the concentration (mg/L) of DO that is applied to water quality standards.

Figures 6 and 7 show the daily DO levels as % saturation and mg/L, respectively, during the monitoring period from 04/04/22 to 11/23/22. The daily minimum DO % saturation was at or above 100% until early July, after which it stayed below 100% until August 25, when saturation quickly shot back up from 71% at 2300 on August 24 to 100% 0000 (midnight) August 25. This rapid change is discussed further below. The largest diel swings (daily range ~30%) for both DO concentration and % saturation occurred during the summer from early July until August 25. From August 25 until the end of the sampling period in November, the daily diel range was noticeably smaller (10% or less) with the exception of September 14-23, when diel swings increased.

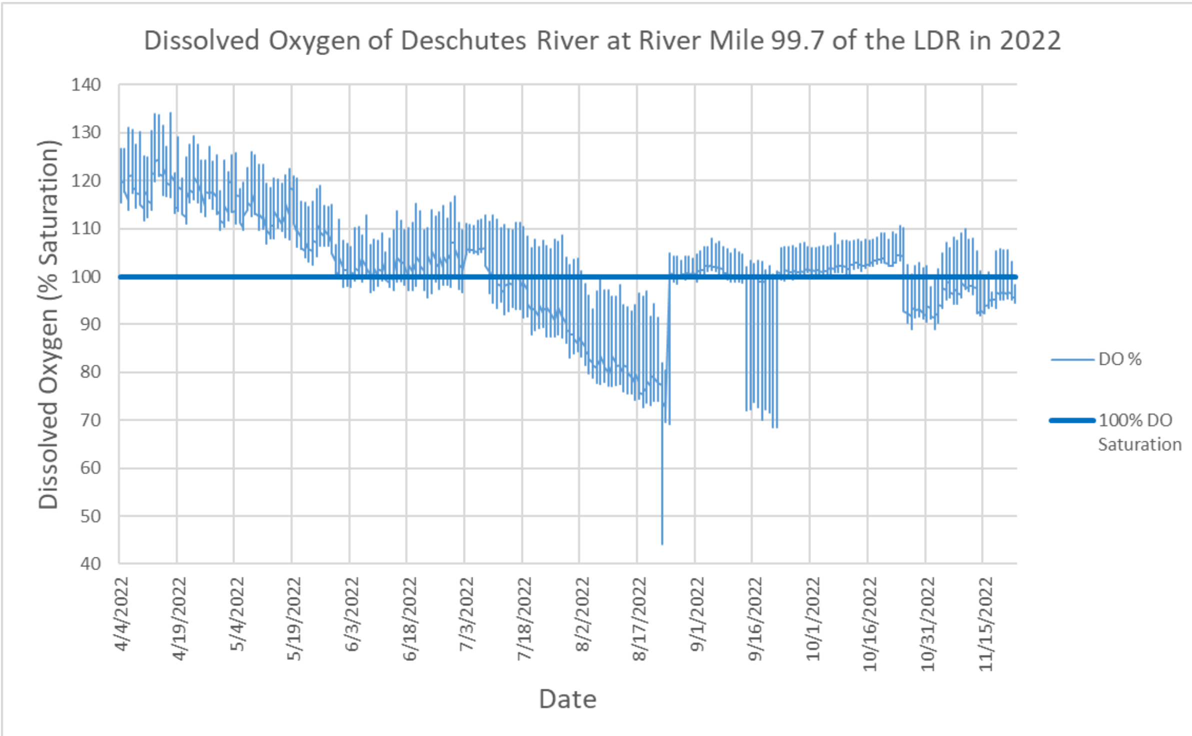

Figure 6. 2022 Hourly dissolved oxygen percent saturation (%Sat) at River Mile 99.7 of the lower Deschutes River. 100% saturation is shown with a dark-blue, horizontal line for reference.

The red/yellow lines and shaded areas in Figure 7 below show the DO criteria and standards applied during salmon and steelhead spawning. The area highlighted in pink indicates the designated salmon and steelhead spawning period, the period when the minimum DO standard applies. The area highlighted in blue indicates trout spawning through fry emergence. The DO standard for spawning also applies “where and when” resident trout spawn, but DEQ is not currently enforcing that standard in the lower Deschutes River. This issue is discussed further in the Discussion section.

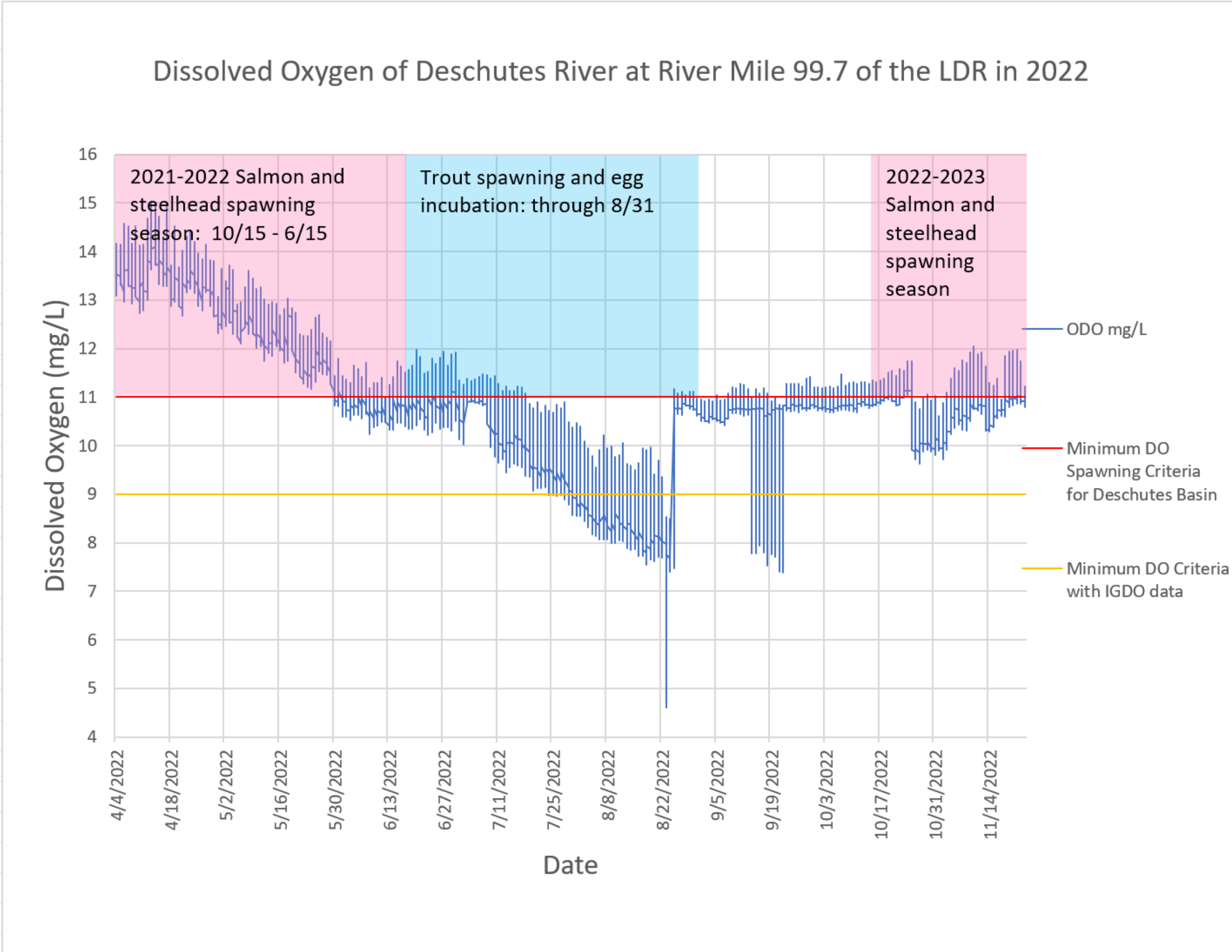

Figure 7. 2022 Hourly dissolved oxygen concentration (mg/L) at River Mile 99.7 of the lower Deschutes River. The red and yellow lines show the minimum dissolved oxygen basin standards based on two separate criteria. Designated salmon and steelhead spawning period highlighted in pink until June 15th, with residential trout spawning highlighted through August 31st in blue.

DO concentration in mg/L was in compliance and above the salmon and steelhead spawning minimum standard (red line in Figure 7) of 11.0 mg/L until 5/30/22, at which point it daily dipped below 11.0 mg/L within the diel range until 7/18/22. After that date it was consistently below 11.0 mg/L every day until 8/25/22. DO fell below the DEQ minimum DO criteria with IGDO data (yellow line in Figure 7) of 9.0mg/L from 7/25/22 to 8/23/22, then again 9/14/22 to 9/22/22.

Interestingly, on 8/23/22 there was a dramatic drop in DO % saturation and concentration. On this date, DO declined from 8.53 mg/L at 1600 to 4.61 mg/L at 1700, before subsequently raising again to 8.88 mg/L at 1800. The same drop occurred in percent saturation. However, this was likely an anomaly with the DO sensor given the other water quality parameters (temperature, pH) did not change drastically at the same time and readings dipped for only one data point.

pH:

Figure 8 shows the hourly pH measurements recorded from 4/4/2022 to 11/23/22. As with temperature and DO, the amplitude of the line shows the daily swing in pH over a 24-hour period, or diel range. The red line shows the basin standard upper limit (8.5 standard units) that currently applies during the entire year in order to protect aquatic life.

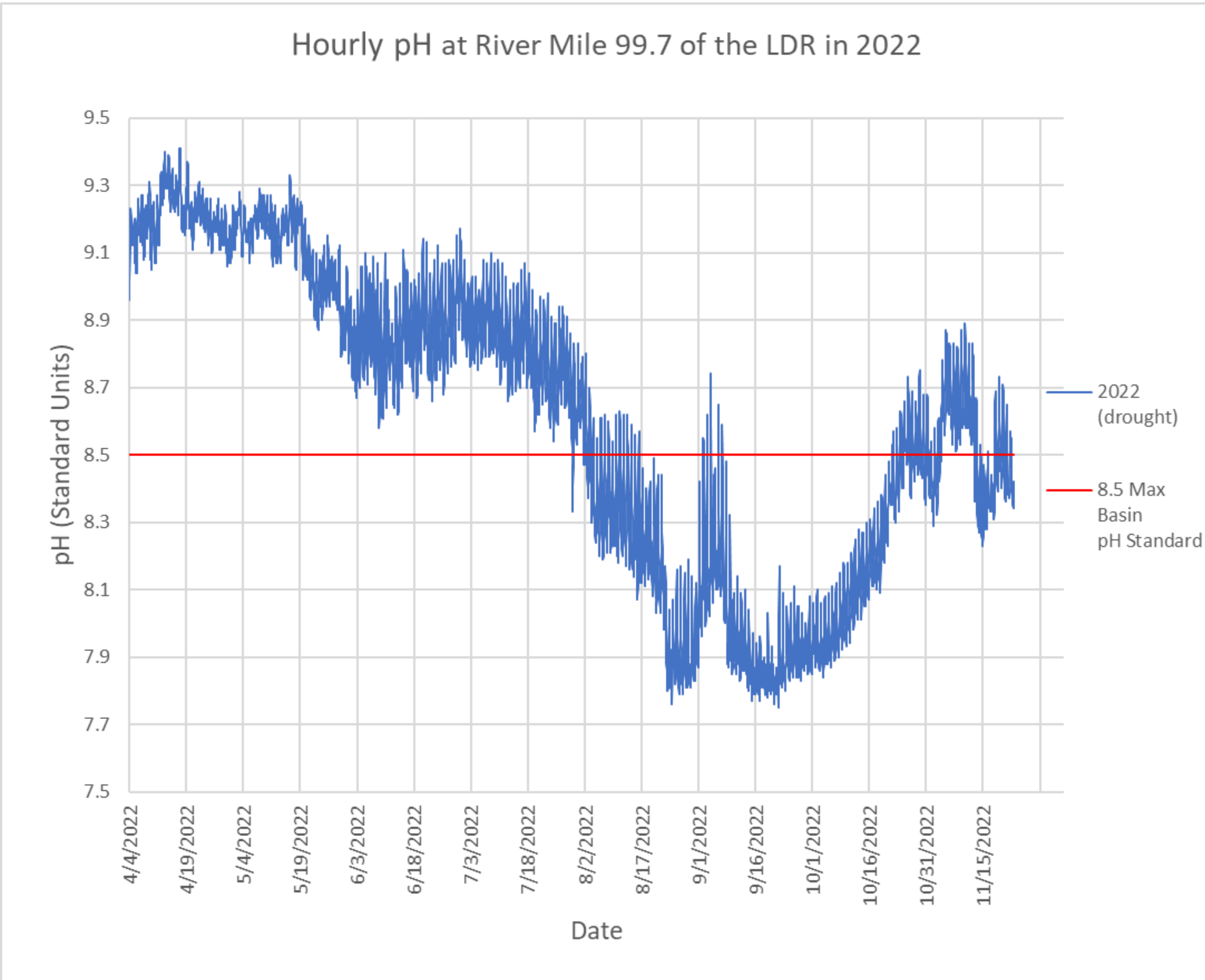

Figure 8. 2022 Hourly pH (standard units) at River Mile 99.7 of the lower Deschutes River with basin upper limit of 8.5 standard units shown with a red line**.**

From initial deployment on 4/4/22, pH continually violated the basin pH standard maximum of 8.5 until 7/30/22 (Figure 8). The maximum recorded pH was 9.41 on 4/17/22, at 1600 hours and the lowest recorded pH was 7.75 on 9/22/22 at 0900 hours. pH adhered to the basin standard from 8/17/22 to 10/23/22 aside from a stent from 9/4/22 -9/6/22 where daily maximum pH exceeded 8.5. After 10/23/22, pH again exceeded the 8.5 standard each day until the end of the monitoring period on 11/23/22, with the exception of a couple of days in mid-November.

Figure 9 contains the recorded daily maximum pH in 2022 and also outlines three separate instances where pH dropped around 0.3-0.6 standard units coinciding with significant increases in % bottom-draw at the SWW Tower. A similar event occurred in 2021. This relationship is discussed further in the Discussion section. The increase in pH late September/early October is discussed in the discussion section.

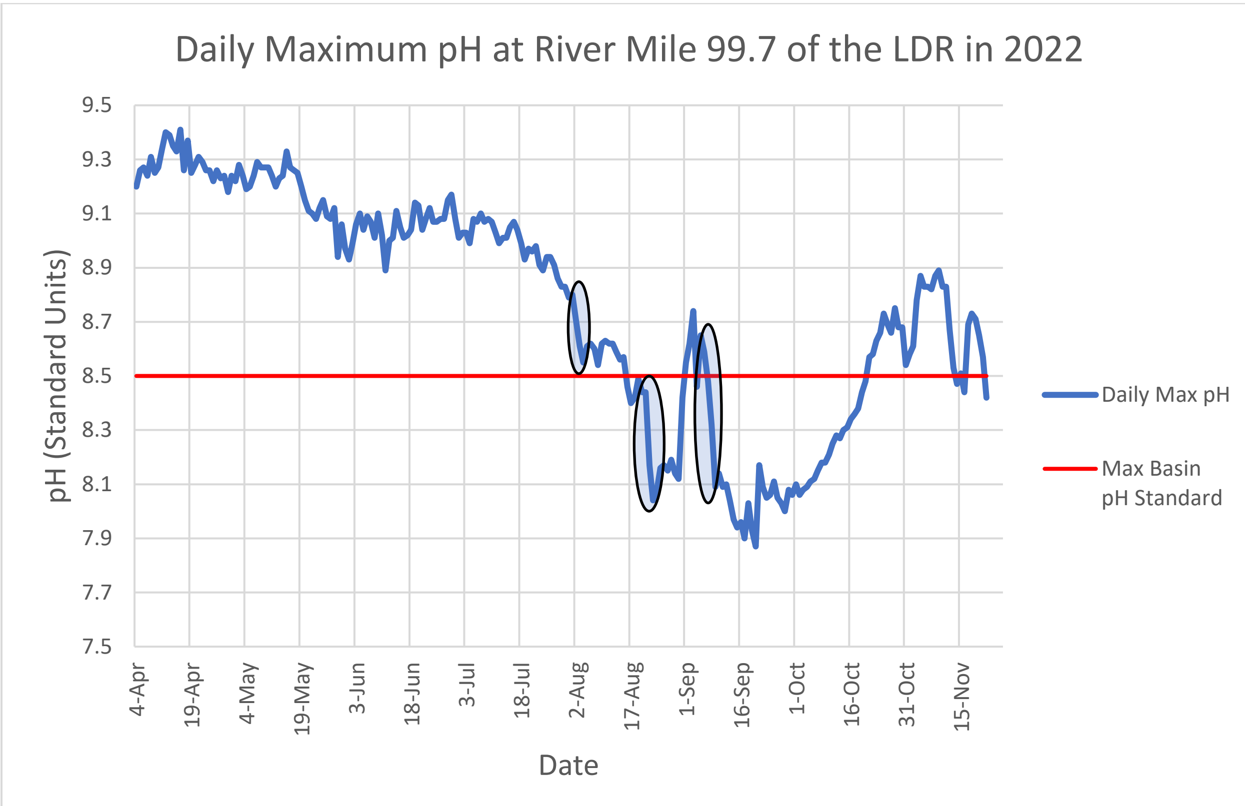

Figure 9. 2022 Hourly daily maximum pH at River Mile 99.7 with basin standard in red. Black circles emphasize drops in pH that directly coincided with increases in bottom draw at the SWW Tower.

Maximum daily pH levels typically occur mid-afternoon between 1400 and 1600 hours, while minimum pH occurs early in the morning (just before sunrise) due to daily changes in photosynthetic activity of aquatic plants and algae; pH rises with increased photosynthesis and drops when photosynthesis declines. When algal biomass increases, the difference between the daily minimum and maximum pH increases and produces large diel swings in pH. Thus, large diel swings in pH are a useful indicator of excessive algal and plant growth stimulated by excess nutrients in polluted water (EPA 2014). Seasonally, the time of year with the greatest sunlight and productivity is summer through late fall, which is the time of year with the greatest diel range. This is exactly what the DRA's pH data shows from the LDR: Figure 10 depicts the average diel range pH data by date from all of the continuous pH data collected by the DRA in the LDR (2016-2022). Since 2016, peak diel range and, by extension, peak algal productivity has occurred from early July to mid-September.

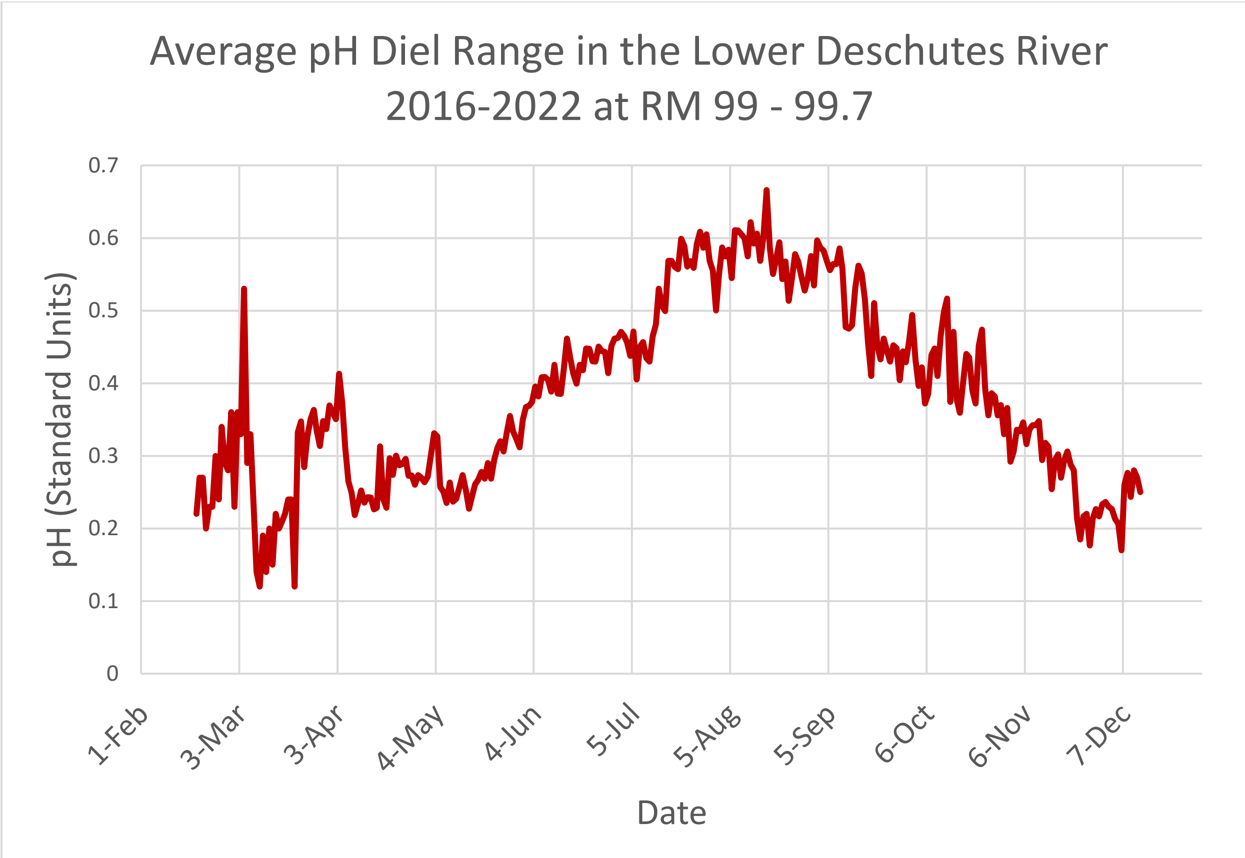

Figure 10: Average diel range in pH by date for the period of record (2016-2022) of DRA continual pH monitoring in the lower Deschutes River.

Regional Streamflow:

Streamflow in 2022 followed the same low flow trajectory observed in previous years. Table 1 shows differences in streamflow of the lower Deschutes River from 2016 to 2022 and during the period of record from the two USGS gauges in this reach. The Madras streamflow gauge (RM 100) is located just below the Reregulating Dam tailrace (about 0.2 miles upstream of the DRA monitoring station) and measures the flow released from the Project, which marks the start of the lower Deschutes River (USGS Gauge, Figure 2). The Moody streamflow gauge is located one mile from the mouth of the Deschutes River (RM 1) before its confluence with the Columbia River (RM 0). From 2016-2022, the peak flow in the lower Deschutes River was highest in 2019 (25,100 cfs at RM 1 on April 09). Flows in 2022 were similar to 2020-2021, with average annual flow ranging from 500-600cfs less than the average for the period of record. Additionally, the magnitude of the annual peak flows in 2020-2022 were fairly similar with maximum flows ranging between 5,000-6,000 cfs at Madras and 8,000-10,000 cfs at Moody (Table 1).

Average Stream Discharge - cubic feet per second (cfs)					
Gauge Location	**Study Period***	**Mean**	**Median**	**Min**	**Max (Date)**
Madras Gauge (RM 100)	**PoR****	4547	4280	2440	19100 **Feb 8, 1996**
	2016	4486	4360	3690	6580 **Mar. 10**
	2017	5024	4610	3760	9970 **Mar. 20**
	2018	4280	4300	3390	5060 **Apr. 9**
	2019	4383	4230	3620	11600 **Apr. 9-10**
	2020	3991	3980	3530	5060 **Dec. 21**
	2021	3939	3880	3480	5480 Jan. 14
	2022	3913	3920	3460	5920 Nov. 5
Moody Gauge (RM 1)	**PoR*****	5789	5520	2880	70300 **Feb 8, 1996**
	2016	5497	5150	4260	9380 **Jan. 20**
	2017	6398	5660	4330	13700 **Mar. 19**
	2018	5030	4840	3750	7370 **Apr. 9**
	2019	5449	4870	4160	25100 **Apr. 9**
	2020	4707	4660	3940	7980 **Feb. 8**
	2021	4690	4740	3860	10000 **Jan. 14**
	2022	4875	4690	3990	9610 **Nov. 6**

Table 1. Summary statistics of discharge in the lower Deschutes River during the last seven years and the period of record. Data source: USGS (monitoring locations 14092500 and 14103000).

* Daily average discharge USGS data used to generate summary statistics for the PoR, except for maximum discharge, which is the absolute maximum. For the rows of individual years 2016-2022 listed, USGS discharge data collected every 0.25hrs utilized to generate summary statistics.
**Period of Record for Madras Gauge: 12/28/1923 to 2/29/1924, 4/19/1924 to 6/30/1924, 7/25/1924 to 12/31/2022 (incomplete year) to 12/31/2022.
***Period of Record for Moody Gauge: 10/1/1897 to 12/31/1899 (USGS published as "near Moro" during this period), 7/1/1906 to 12/31/2022.

Table 2 depicts monthly springtime flows during the months of March-May from 2016-2022. The timing of annual peak flows during 2020-2022 was similar and occurred late fall to winter (November-January, see Table 1). During wetter years, peak flows typically occur during the early spring (March-April).

Max Daily Stream Discharge – cubic feet per second (cfs)				
Gauge Location	**Study Year**	March 1st Max Discharge	April 1st Max Discharge	May 1st Max Discharge
Madras Gauge (RM 100)	**2016**	5,280	5,200	4,150
	2017	5,580	8,640	5,510
	2018	4,560	4,930	4,180
	2019	4,740	4,480	4,700
	2020	4,250	4,280	4,280
	2021	4,030	4,100	4,200
	2022	4470	4040	3740
Moody Gauge (RM 1)	**2016**	6,900	6560 Apr. 2nd	4,860
	2017	7,140	12,000	7,770
	2018	5,710	6,240	5,330
	2019	5,330	6,110	7,150
	2020	5,140	5,070	5,530
	2021	5,100	5,000	5,440
	2022	6330	5310	4960

Table 2. Lower Deschutes River max daily stream discharge during the first day of the months of March, April, and May 2016-2022. Data source: USGS (monitoring locations 14092500 and 14103000).

Regional Drought and Snow Water Equivalent:

USDA drought and snow water equivalent data was monitored by DRA personnel during the 2022 season. Results in 2022 showed similar drought conditions to that seen 2020-2021, with annual average US Drought Monitoring (USDM) level of 2.86 (Table 3).

Year	Average US Drought Monitoring Level (scale of 0-4)
2016	1.34
2017	1.23
2018	2.02
2019	1.78
2020	2.30
2021	2.80
2022	2.86

Table 3. Average annual US Drought Monitoring levels from 2016-2022 of counties[11] in the Deschutes Basin: Crooked, Deschutes, Jefferson, and Wasco Counties. Scale: 1=abnormally dry, 2=moderate drought, 3=severe drought, 4=extreme drought, 5=exceptional drought. Data source: Univeristy of Nebraska-Lincoln, National Drought Mitigation Center.

Snow Water Equivalent (SWE) is the depth of liquid water stored within snow accumulation. Because snowpack is the largest contributor of streamflow in the Deshutes Basin (O'Conner et.al. 2003) , it is an important factor affecting streamflow in the Deschutes River. Figures 11a and 11b show annual SWE data grouped by relative drought and flow from 2016-2022. 11a depicts the "drought" years of 2018, 2020, 2021 and 2022, Figure 11b depicts the "wet" years of 2016, 2017, and 2019. Because snowfall affecting a given calendar year occurs late fall of the previous year through spring, the data in Figures 11a-11b and Table 4 are organized by water year (October 1-September 30 the following year). Given USDA stations in the Deschutes Basin collect SWE from November – May, SWE from the associated time period are included. For example, the water year 2022 includes SWE data from 11/1/2021 to 5/31/2022.

SWE data from the Deschutes Basin[12] from 2016-2022 (Figures11a and llb, table 4) correlates with the assoiciated US Drought data (Table 1) and USGS flow data in the LDR (Tables 1-2), with 2022 being a continuation of the recent drought years. The exception is the 2021 SWE data, which shows elevated snowpack levels (>20" SWE late February through early April) despite flow levels in the LDR remaining relatively low (Tables 1-2) and a elevated average US Drought Monitoring level (Table 3). It is not entirely clear why 2021 did not see higher flows despite the elevated snowpack, but ongoing drought conditions prior to 2021 (2020 had a ~56% average annual SWE relative to the average 1991-2020 SWE and an average annual USDM level of 2.30) in addition to diversions and impoundments in the Deschutes and Crooked tributaries may be part of the explanation.

[11] The listed counties were chosen since they reside within the Deschutes Basin. County lines do not line up exactly with the Deschutes Basin boundary, but this discrepancy was judged to be minor for the purposes of this study.

[12] Out of 18 total stations in the Deschutes Basin, one (Irish Taylor) was unintentionally omitted throughout the dataset. This omission is not believed to have any significant effect on the analysis of SWE trends in the Deschutes Basin.

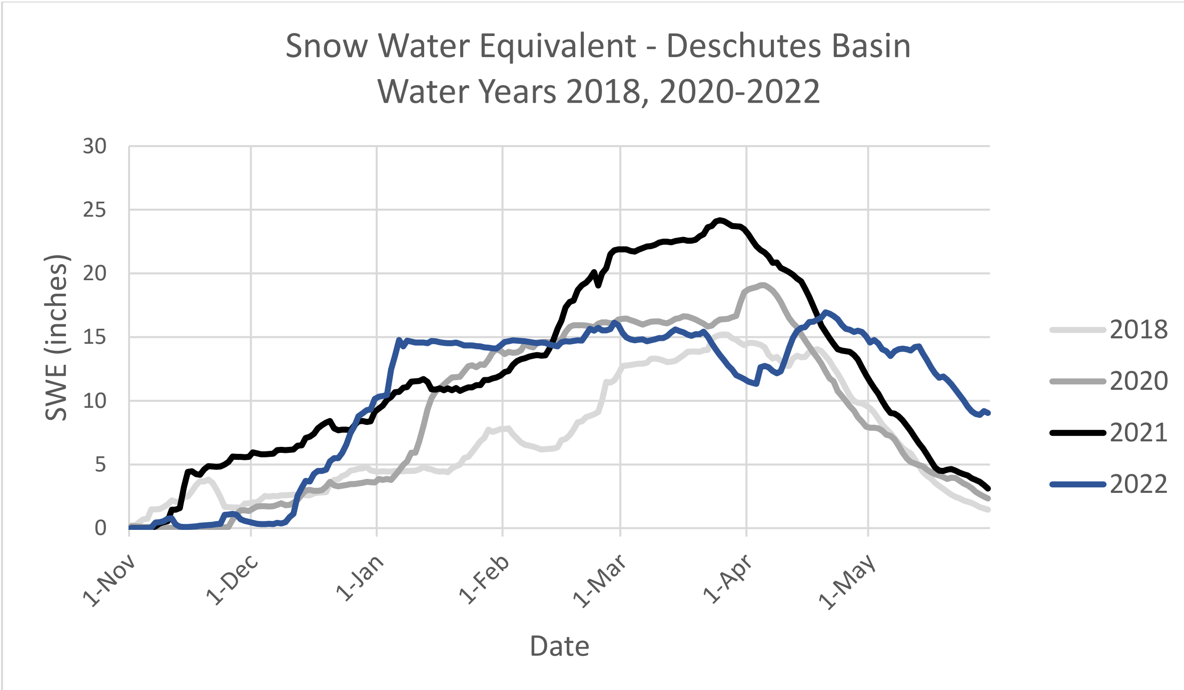

Figure 11a. Snow Water Equivalent in the Deschutes Basin during the "dry" water years 2018, 2020, 2021, and 2022. Dates depicted each water year are from November 1st of the previous year to May 31st of the year of concern. Data source: USDA Snowpack: Snow Water Equivalent (SWE) and Snow Depth

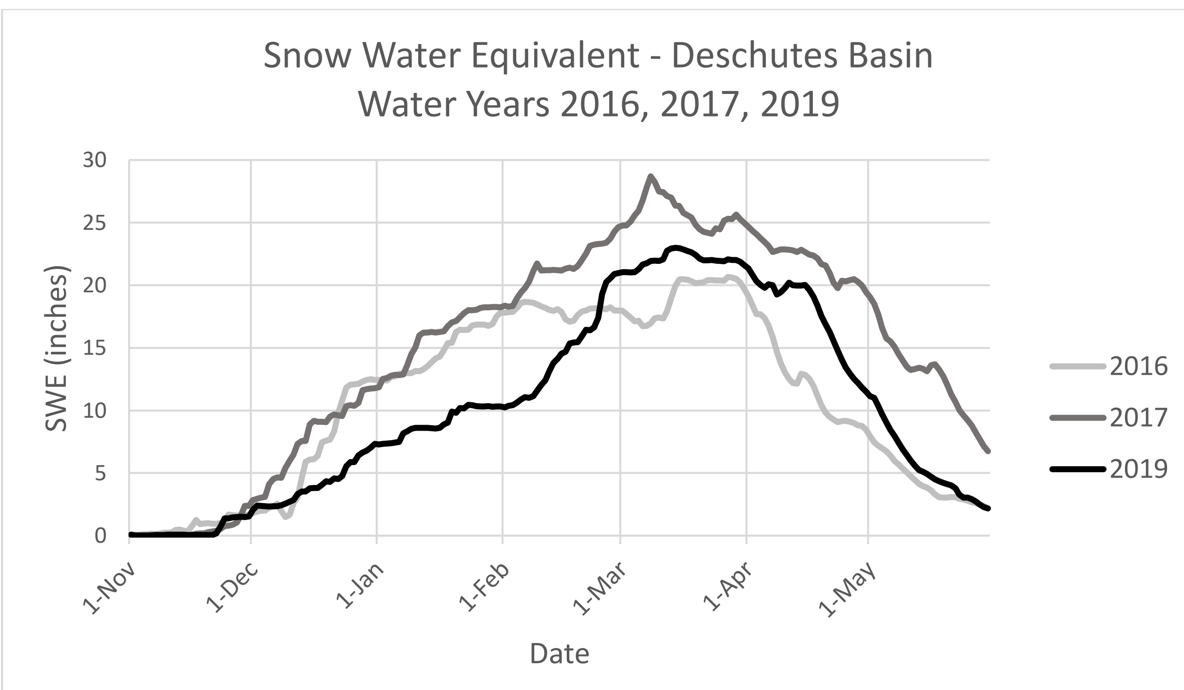

Figure 11b. Snow Water Equivalent during the "wet" water years 2016, 2017, and 2019. Dates depicted each water year are from November 1st of the previous year to May 31st of the year of concern. Data source: USDA Snowpack: Snow Water Equivalent (SWE) and Snow Depth

Water Year*	Average SWE	% of the 1991-2020 Overall Average
2016	10.9	83.3
2017	15.2	112.0
2018	7.1	51.2
2019	10.5	74.9
2020	9.0	56.4
2021	12.1	103.4**
2022	10.7	66.6

Table 4. Average annual snow water equivalent and relative percent of the SWE from 1991-2020 from 2016-2022 Data source: USDA Snowpack: Snow Water Equivalent (SWE) and Snow Depth
*A water year for this data is November 1st of the previous year to May 31st of the "water year" being considered
**Part of the reason why 2021 annual % SWE relative to the 1990-2020 average is high is there was a significant amount of snowfall during the late fall (beginning of the SWE year) relative to the 1991-2020 average.

NOAA daily air temperature data at the Redmond Airport, Pelton Dam, and near the mouth of lower Deschutes River at the Dalles Municipal Airport was also monitored. Like previous years, in 2022 ambient air temperatures near the LDR climbed at a steady rate from February and peaked by the end of July. See supplemental figures 21-22 in Appendix C for NOAA-generated temperature graphics at these monitoring stations.

Tower Operations:

Like recent years, the only bottom water releases of cold water from the SWW Tower occurred during summer months. However, unique to 2022 was three separate events of rapid increases in bottom draw that occurred within a 40-day period due to maintenance on the SWW Tower. From 7/28/22 to 7/31/22, licensees increased % bottom-draw from 30% to its maximum output of 60% for short-term maintenance (Figure 12). Bottom-draw was subsequently lowered to 40% until a second longer maintenance period from 8/22/22 to 8/27/22, again raised bottom-draw to a maximum of 60%. Bottom-draw was lowered again to 40% for a short period until the licensees switched to maximum bottom-draw on 9/6/22, which is typical for late summer tower operations. The effect that these increases in bottom draw had on water quality in the LDR is discussed further below.

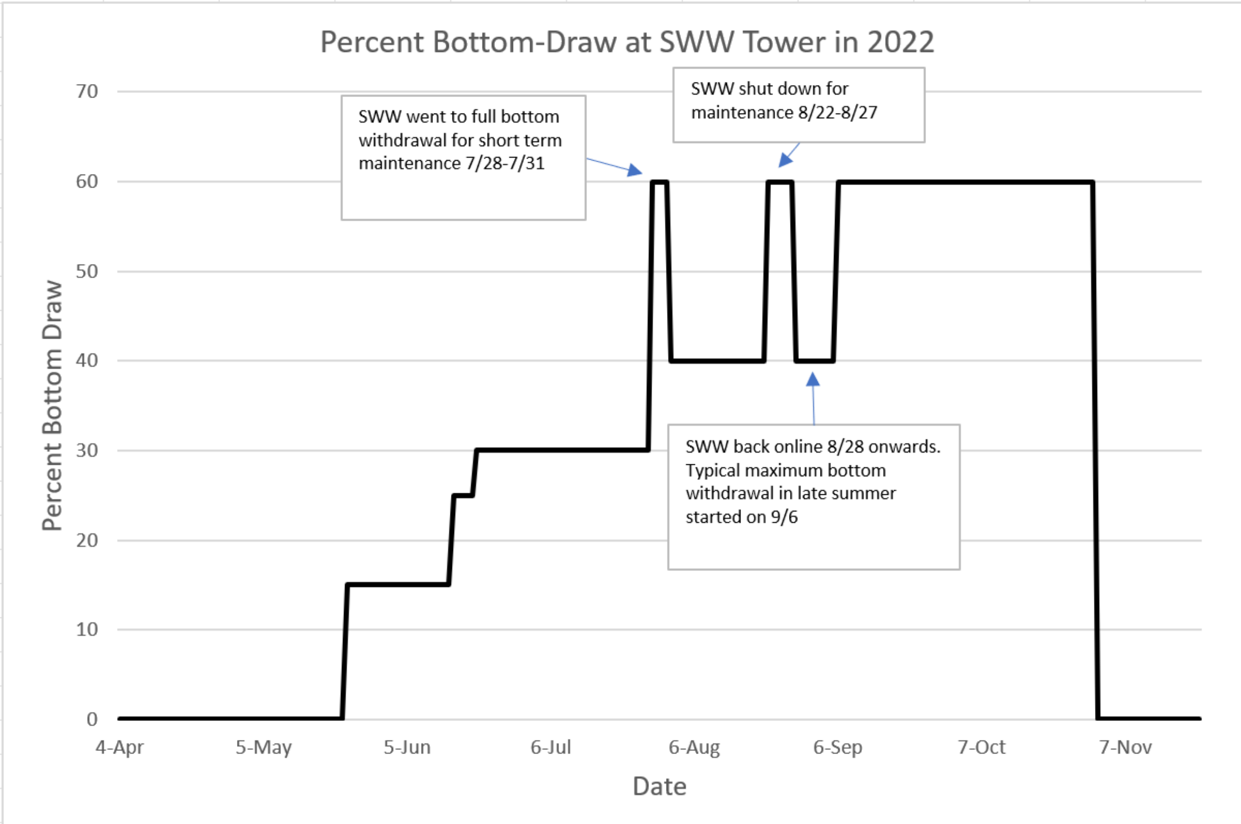

Figure 12. Percent (%) bottom-draw at the Selective Water Withdrawal Tower in 2022. Maximum bottom draw is ~ 60-65%. Data source: adapted from PGE data report to ODEQ 2022.

Discussion

SWW Tower operations - blending and increases in % bottom-draw:

Changing the operation practices of the SWW Tower is the primary way licensees can improve water quality in the lower Deschutes River. This hypothesis is supported by the models developed in the PGE Water Quality Study (Eilers & Vache 2021) and in the annual water quality monitoring conducted by PGE (PGE Annual Water Quality Reports) and the DRA (DRA 2015-2022).

From 2017 - 2022, licensees have released some surface water at night from March through June to increase smolt capture at the SWW Tower (PGE & CTWSRO 2022b; PGE, Our Story…). This minor modification of Project operations not only increased smolt capture (PGE & CTWSRO 2022c), but also likely provided slight improvements to water temperatures in the lower Deschutes, as the surface water of Lake Billy Chinook is cooler at night. This scenario was modeled in the PGE Water Quality Study and showed cooler temperatures during the months of night blend operations modeled (Eilers & Vache 2021). While this is a welcomed improvement, a much more significant impact to water temperatures, and other water quality parameters in the lower Deschutes River, can come from simply increasing the % bottom-draw throughout much of the year, including during late spring and summer months when water quality (temperature and pH) is at its worst in Lake Billy Chinook.

See 2019 and 2020 DRA Water Quality Report Discussion sections for additional details about the "Night Blend" in relation to current Tower operations (DRA 2020; DRA 2021). The following subsections present the effects from changes made to the blend ratios at the SWW Tower, and how they affected water quality parameters.

Current Temperature Model:

Water temperature data collected by the licensees from 2006-2009 (pre-SWW Tower) at RM 100.1 in the LDR just downstream of the Project shows that pre-Tower water temperatures peaked in early September (Figure 13). Following tower operations, water temperatures now peak in July. This is an intentional shift by the licensees and has led to a sustained increase in water temperatures in the LDR compared to pre-tower temperatures (DRA 2017-2022).

The current temperature model for calculating the target temperature to release from the Project uses a regression equation developed by a 1999 temperature study of the lower Deschutes River (Huntington et al. 1999) that takes the 7-day maximum average temperatures of the three tributaries (weighted by flow) entering Lake Billy Chinook and air temperature at the Redmond Airport. Despite being included in the licensee's current Clean Water Act Section 401 permit (ODEQ n.d) and WQMMP (PGE &CTWSRO 2002), this model is flawed because it allows the release of water based on the highest recorded temperatures of the tributaries entering LBC. This does not represent a "natural" temperature regime and has no biological basis or benefit.

As water at the Reregulating Dam approached the spawning and rearing maximum temperature standard of 13°C in the early summer, and as surface water temperature in Lake Billy Chinook climbed above incoming tributary temperatures, licensees respond by increasing the % bottom-draw at the SWW Tower to meet their modeled temperatures (Figures 13-14). Temperature and other water quality parameters showed immediate improvement with increase in bottom draw (Figure 14).

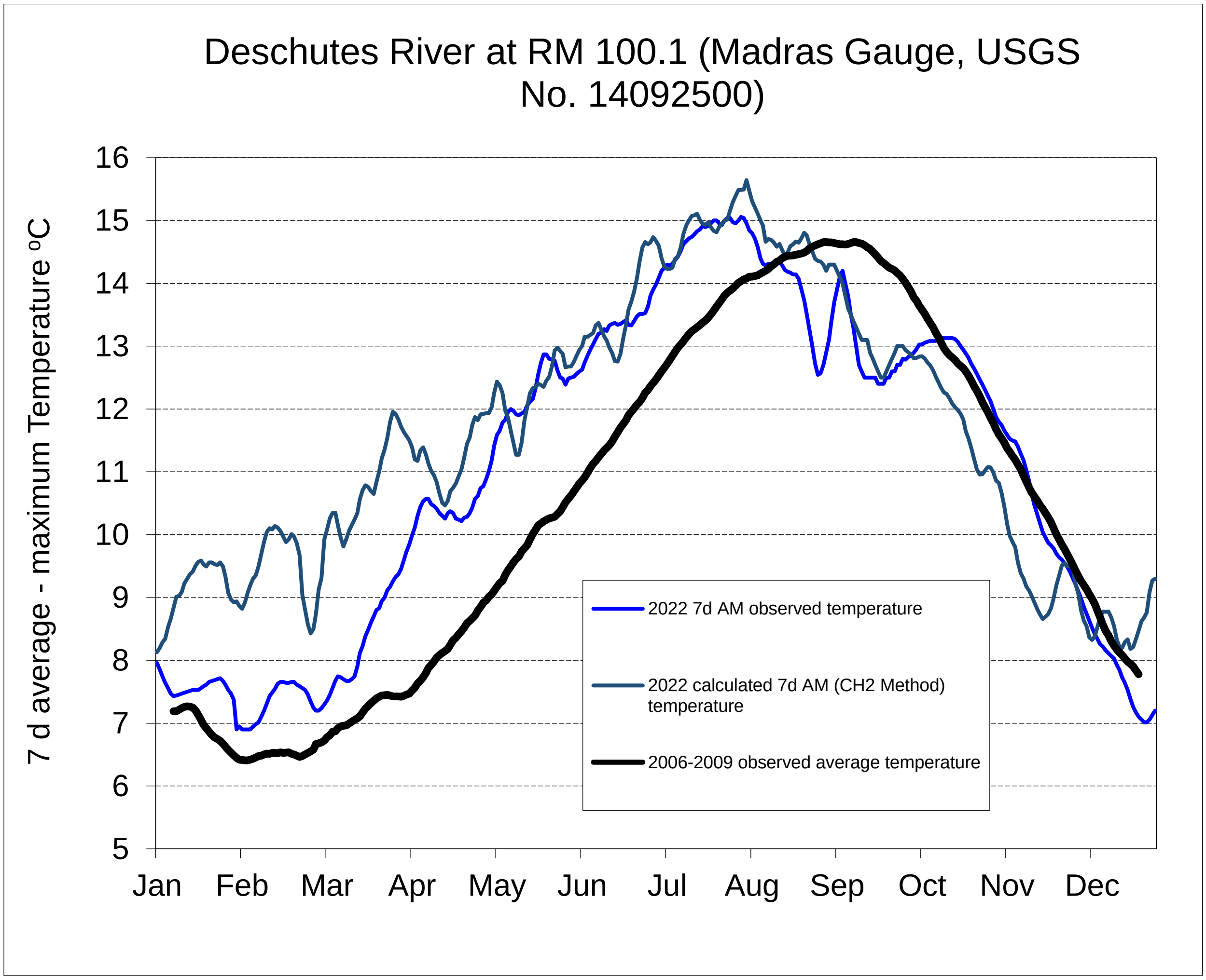

Figure 13. Licensees modeled and observed 7DADM water temperatures at the Reregulating Dam tailrace. Graphic depicts the intentional shift in water temperatures of the lower Deschutes River as a result of SWW Tower operations. Source: retrieved from PGE data reporting to ODEQ in 2022.

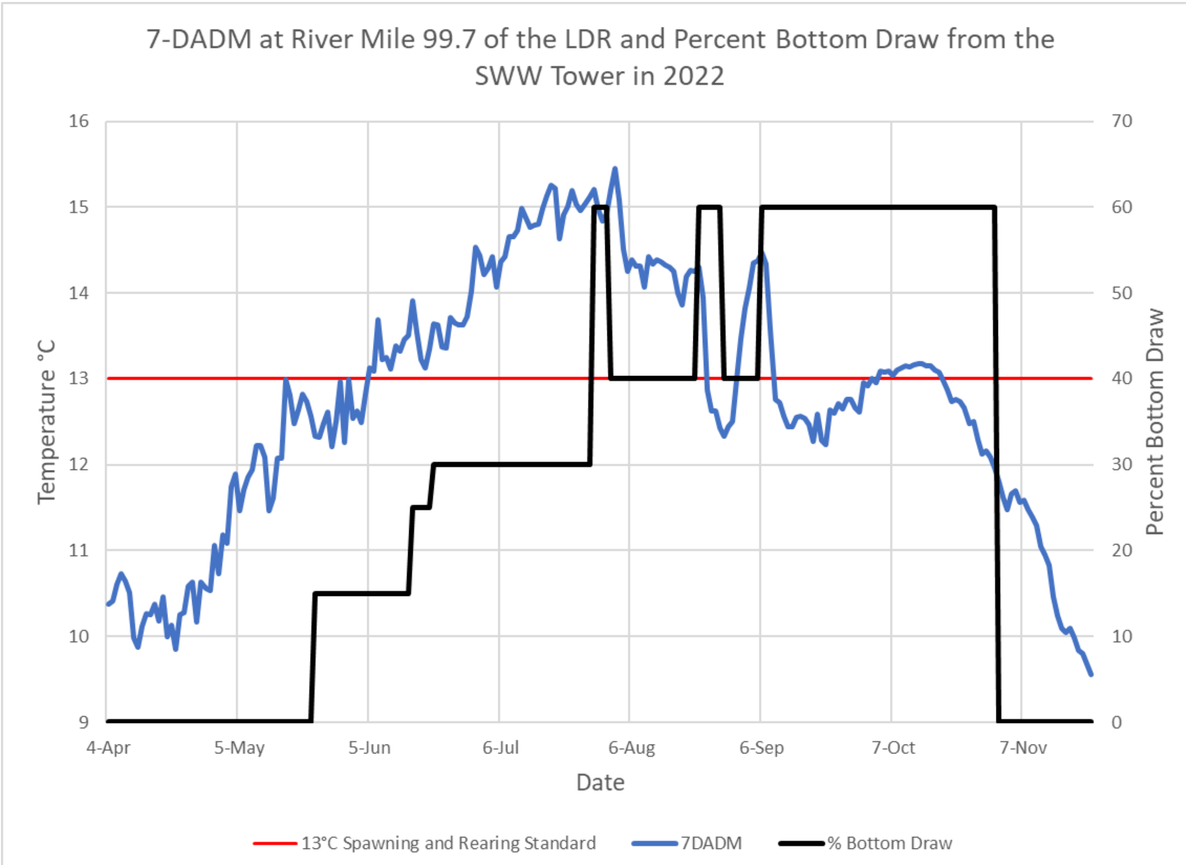

Figure 14. 7-Day Average Daily Maximum temperature at the DRA monitoring station with percent bottom draw from the SWW Tower. Percent bottom draw data source: retrieved from PGE data reporting to ODEQ in 2022.

Temperature and Bottom Draw in 2022:

As has been shown in previous years, increasing bottom draw had an immediate cooling effect on temperatures throughout the lower Deschutes River in 2022. The three rapid increases in bottom draw from late July through early September were directly followed by decreased water temperatures at the Madras (RM 100) and Moody (RM 1) USGS monitoring stations (Figure 15). Although these changes did not persist because of the return to warmer surface water withdrawal at the SWW Tower, they do show that increasing bottom water release from the Tower will lower water temperatures for the entirety of the lower Deschutes River and could provide relief to fish and other aquatic life by cooling the lower Deschutes River during periods of extremely high air temperatures. This may prove vital in coming years with warming temperatures and more extreme heat waves due to climate change. The current temperature model utilized by licensees will likely cause even more unnecessary warming in coming years to LDR temperatures when an easy solution is more bottom draw.

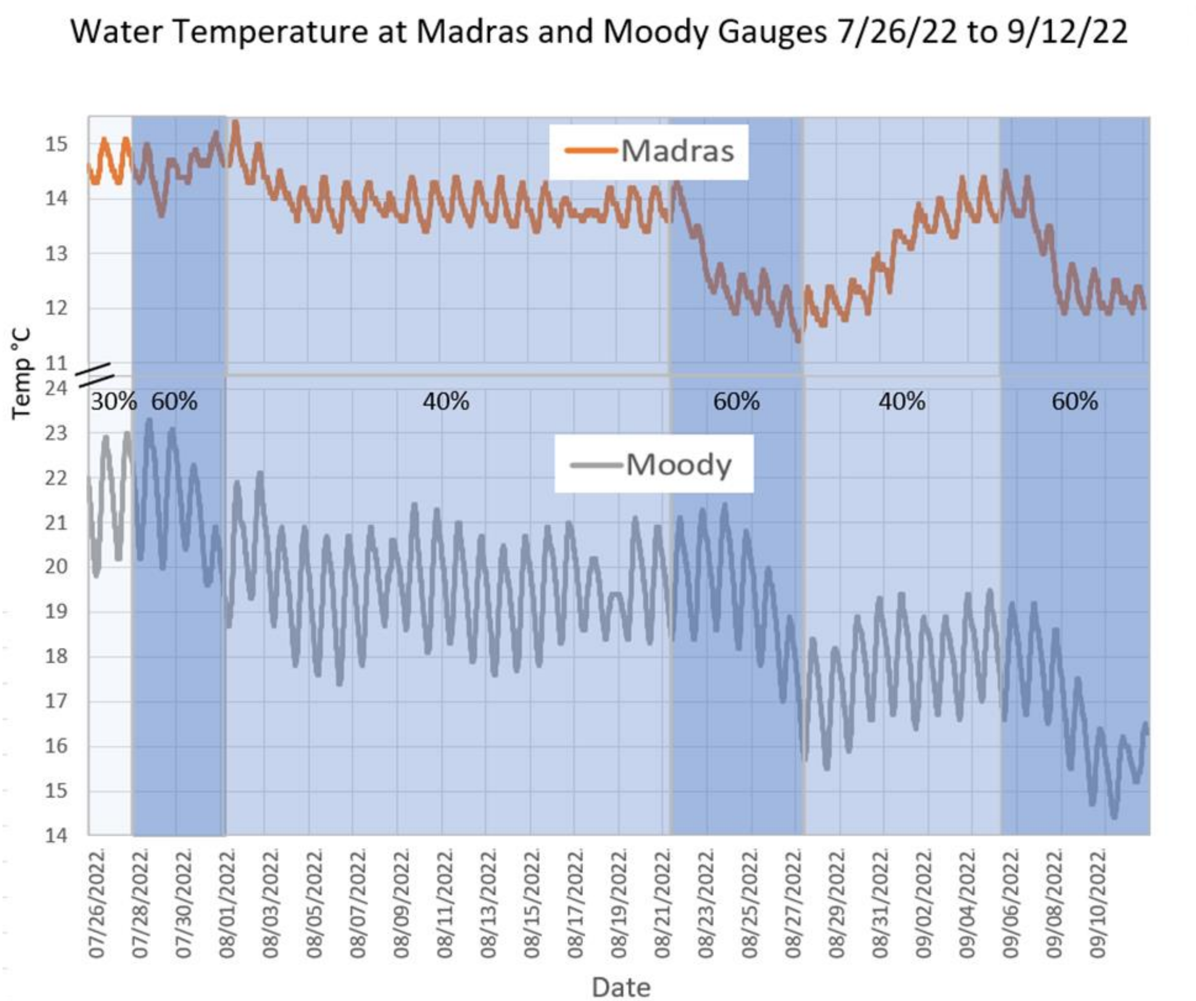

Figure 15. Water temperatures at the Madras (RM 100 just downstream of PRB complex) and Moody (RM 1, just upstream of the mouth of the lower Deschutes) USGS gauges from 7/26/22 to 9/12/22. Shaded blue areas depict real-time percent bottom draw during this period, with percent bottom draw depicted in the center of each area. Temperature data source: USGS (monitoring locations 14092500 and 14103000). % bottom draw data source: retrieved from PGE data reporting to ODEQ in 2022.

Net Warming Caused by the SWW Tower – A Long-term Analysis:

Project operators justify current operations of the SWW Tower to save more cold water for release in the late summer/fall and to mimic "without Project" temperatures (Eilers & Vache 2021, Parks 2022, PGE: our story…). While some cooling has occurred in the late summer and fall after SWW Tower operations started, the historical temperature data shows that, overall, operations have caused disproportionate warming the rest of the year. Figure 16a depicts the difference in the daily average 7-Day Average Daily Maximum (7DADM) temperatures at the USGS Madras Gauge just downstream of Reregulating Dam between:

1. All year's post-tower operations: December 2009-2022 and

2. Period of record prior to tower operations from the 1970s to December 2009.

Positive temperature difference values in red indicate warmer temperatures in average daily temperatures post-Tower operations relative to pre-Tower operations, and the opposite holds true for negative temperature difference values in blue. As depicted in Figure 16a, there is a small amount of cooling in the late summer through fall, but this cooling is relatively small compared to the warming during the rest of the year.

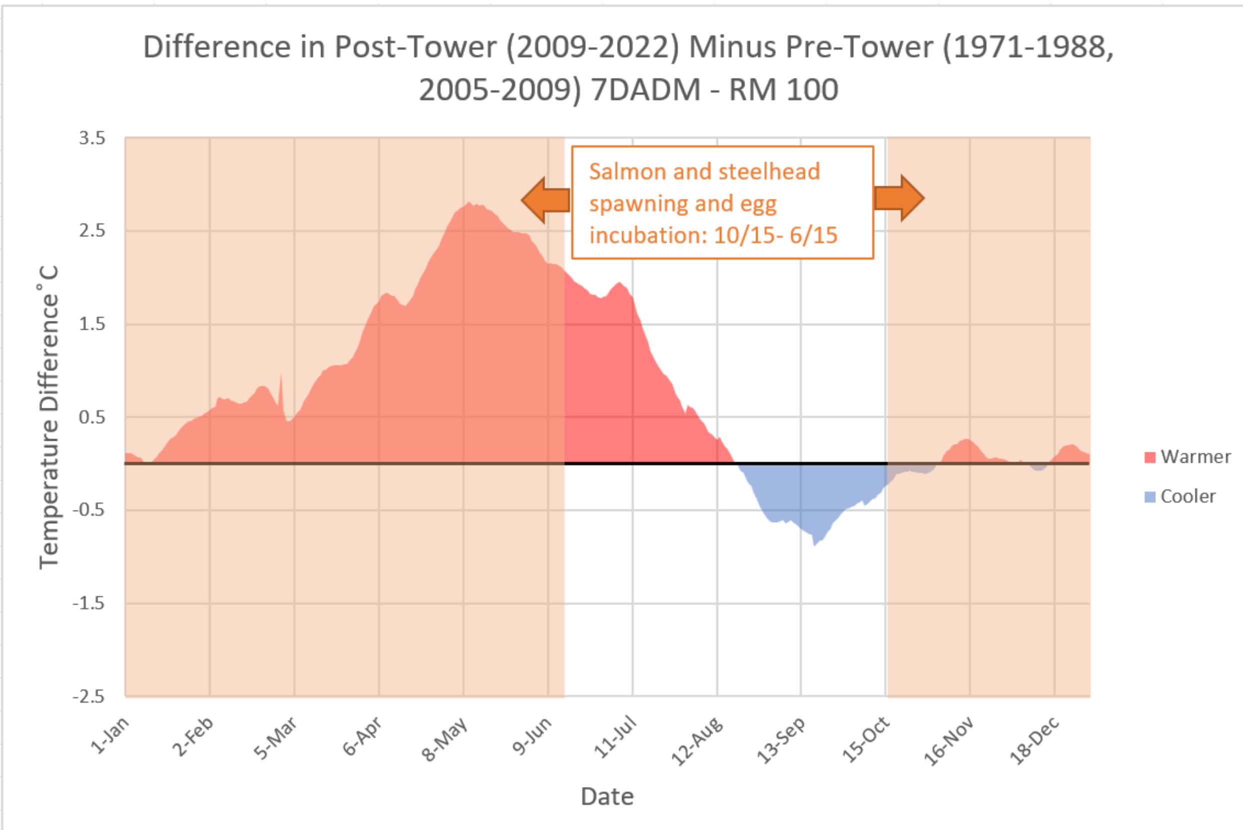

Figure 16a. Graphed values depict difference between (1) the average 7DADM calculated from 13 years during tower operations (12/02/09 to 12/31/22) and (2) the average 7DADM of lower during 21 years before Tower operations (10/01/1971 - 09/30/1988, 11/04/2005 - 12/01/2009) at RM 100 just downstream of the Reregulation Dam tailrace. Salmon/steelhead spawning and egg incubation period highlighted in orange. Data source: USGS (monitoring location 14092500).

In order to minimize differences in stream temperatures caused by temporal changes in temperature, drought, snow fall, and flow, a similar analysis was performed on climatically similar years prior to and after Tower operations. The four years during tower operations that were most similar in temperature, drought, snow fall, and flow conditions relative to the pre-Tower operation years of 2006-2009[13] were selected: 2010,

[13] Licensees use the temperature data from 2006-2009 in their annual reports for pre-tower temperature comparison (Figure17), which is why those years were selected.

2012, 2013 and 2017. See Appendix E for details on analysis used to select post-tower operation years.

Figure 16b depicts the difference between the 7DADM temperature of the LDR at the Madras Gauge between:

1. Four years during SWW Tower operations: 2010, 2012, 2013, 2017 and
2. Four years prior to operations: 2006-2009

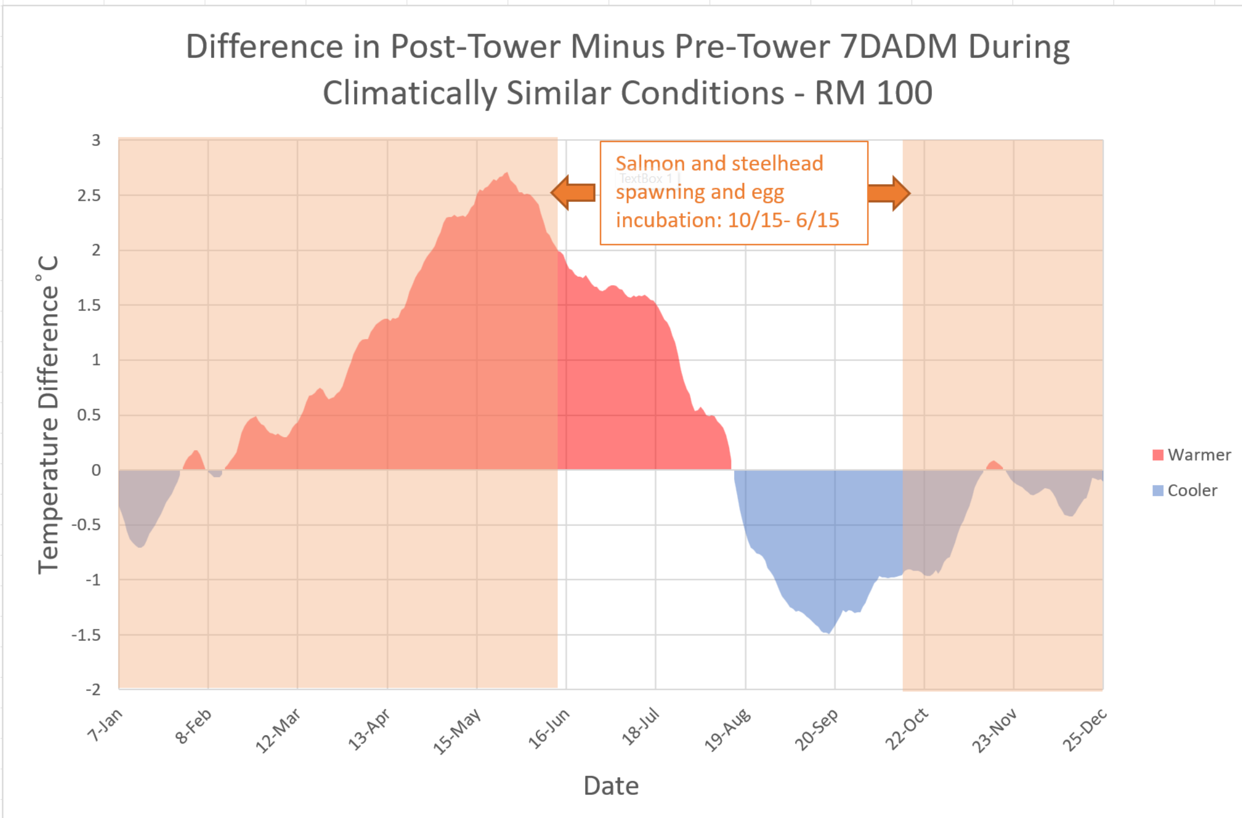

Figure 16b Graphed values depict difference between (1) the average 7DADM calculated from four years during Tower operations similar in drought conditions and snowpack to 2006-2009 (2010, 2012, 2013, 2017) and (2) the average 7DADM calculated from four years before SWW Tower operations (2006-2009). Salmon/steelhead spawning and egg incubation period highlighted in orange. Data source: USGS (monitoring location 14092500).

While the amount of warming is less severe relative to cooling shown in Figure 16a, both of these figures show that the warming in the early spring to summer is disproportionate to the cooling in the late summer and fall. Furthermore, as depicted in the graphs, the majority of the salmon and steelhead spawning and incubation period has significant warming, which may be causing unnecessary stress to these species, especially when temperature effects on dissolved oxygen are considered.

Dissolved Oxygen:

Aquatic animals require adequate dissolved oxygen to survive. The amount of available DO in water is affected by several factors, including water temperature, turbulence, and photosynthetic activity. In particular, cold water can physically hold more DO than warmer water. This means that warmer water temperatures seen in the lower Deschutes since SWW Tower operations started (Figures 16a-16b) has reduced the water's maximum amount of dissolved oxygen that it can hold. Additionally, when water and air mix due to turbulence (waterfalls, white water, spill from dams, etc.) oxygen from the air entrains in the water, increasing its concentration.

The concentration of DO necessary to support the life functions of fish (feeding, spawning, predator avoidance, etc.) varies among species and life stages. In cold water streams of North America, salmon and trout are typically the most sensitive and least tolerant species to low levels of DO (Willers 1991).

Oxygen requirements for developing salmonid eggs are greater than for juveniles and adults (ODFW 2000). For these reasons, Oregon's water quality standards for DO are set to higher standards during the most sensitive times of year: salmonid spawning and egg incubation periods (OAR 340-041-0016[14], Figures 130A, 130B [see Appendix D]). Oregon's complete DO criteria for the Deschutes Basin are listed in Table 5.

Beneficial Use	Dissolved Oxygen Criteria
Salmonid Spawning, **including where and when resident trout spawn through fry emergence.**	1) Not less than 11.0 mg/L, or - 2) If intergravel DO (IGDO), as a spatial median, is 8.0 mg/L or greater, then DO criterion is not less than 9.0 mg/L
Cold-water Aquatic Life (includes salmon and trout rearing).	1) Not less than 8.0 mg/L. If ODEQ determines adequate* data for DO exists, ODEQ may allow: 2) 8.0 mg/L as a 30-day mean minimum, 6.5 mg/L as a 7-day minimum mean, and 6.0 mg/L as an absolute minimum. All three requirements must be met.

Table 5. State of Oregon's dissolved oxygen criteria for the lower Deschutes River (OAR 340-041-0016[13]).
*No definition for what constitutes "adequate" data is given.

ODEQ's current application of the DO standard in the lower Deschutes does not protect resident trout spawning/incubation as required in Oregon's water quality standards. In prior water quality reports, the DRA expressed concerns about how the DO criterion is applied and how the designated spawning and incubation periods for species are covered (DO discussion section, DRA 2019b). In summary, Oregon's water quality standards for DO mandate that when determining the DO standard for a particular

[14] https://secure.sos.state.or.us/oard/viewSingleRule.action?ruleVrsnRsn=256028

water body, resident trout spawning must be included. Oregon Administrative Rules (OAR 340-041-0016[15]) states:

> "The following criteria apply during the applicable spawning through fry emergence periods set forth in the tables and figures **and**, **where resident trout spawning occurs, during the time trout spawning through fry emergence occurs**."

In other words, Oregon's DO standard requires that the DO criteria of 11.0 mg/L (or 9.0 mg/L when IGDO is above 8.0 mg/L) minimum concentration must be applied not just in the identified salmon and steelhead spawning time and place, but also during resident trout spawning through fry emergence. Trout spawning is known to take place at a minimum from February through the end of August in the lower Deschutes (Zimmerman & Reeves 2000**,** Seals et al. 2014, Seals et al. 2015, Figure 23 [Appendix D], French 2019**).** Spawning potentially occurs year-round as the ODFW LDR Redband trout monitoring study in 2014 observed spawned out individuals at the start of sampling in February (Seals et al. 2014).

Additionally, the current Dissolved Oxygen Management Plan of the ODEQ permit for tower operations (401 Certification) states that salmonid spawning standards for DO should apply year-round (ODEQ n.d., PGE &CTWSRO 2002):

> "The ODEQ and CTWS salmonid spawning DO criterion will apply to the Deschutes River downstream of the PRB Project during the periods of salmonid spawning and incubation, which in the lower Deschutes River is the entire year."

In March 2020, PGE applied to DEQ to revise the 401 certification, which in part requests reducing the year-round spawning requirement for dissolved oxygen. After almost three years DEQ has yet to draft a new 401 permit, and in the meantime have ignored the requirements of the current permit.

While the 2022 DO data show some slight improvements early in the year relative to last year, a similar pattern of basin violations occurred. Dissolved oxygen fell below the 11.0 mg/L standard in May and continued to decline below 9.0 mg/L July through August (Figure 7). Because the salmonid spawning DO criterion applies during the entire year in the LDR according to the current DEQ permit for tower operations, the DO concentration fell below and violated the applicable standard of 9 mg/L from 7/25/22 to 8/23/22, then again 9/14/22 to 9/22/22 during daily diel minimums (37 total days). Additionally, if IGDO levels are not above 8.0 mg/L, then DO should not fall below 11.0 mg/L. If the 11.0 mg/L standard were applied, then DO fell below the standard every day starting in early-May through the end of the monitoring period on 11/23/22. Project operations can correct this by spilling water over the Reregulating Dam to entrain oxygen as it is released into the lower Deschutes River.

[15] https://secure.sos.state.or.us/oard/viewSingleRule.action?ruleVrsnRsn=256028

pH:

The DRA believes that results from DRA water quality reports (DRA 2015-2022) and the existing data record clearly establish that surface water releases from LBC have had a rapid and negative impact on pH in the lower Deschutes River. Oregon's water quality standard for pH in the Deschutes Basin is between a minimum of 6.5 and maximum of 8.5 standard units (OAR 340-041-0135[16]). The pH standard is designed to protect aquatic life from the harmful effects of water that is too acidic or too alkaline. Exceedances of the Deschutes Basin upper pH limit were known to occur before the SWW Tower went into operation. However, surface water withdrawal has made the pH problem significantly worse.

Bi-monthly water quality data collected by ODEQ at the Warm Springs bridge during similar times of day[17] show that pH above 8.5 occurred in ~3% of measurements (3 out of 89 total measurements) from 1989-2009 prior to SWW Tower operations compared to 29% of measurements (20 out of 70 total measurements) above 8.5 from 2010-2022 following SWW Tower operations (Figure 16). This increase in the number of pH violations in ODEQ's data following tower operations clearly demonstrates the negative effect the Tower has had on water quality in the lower Deschutes River.

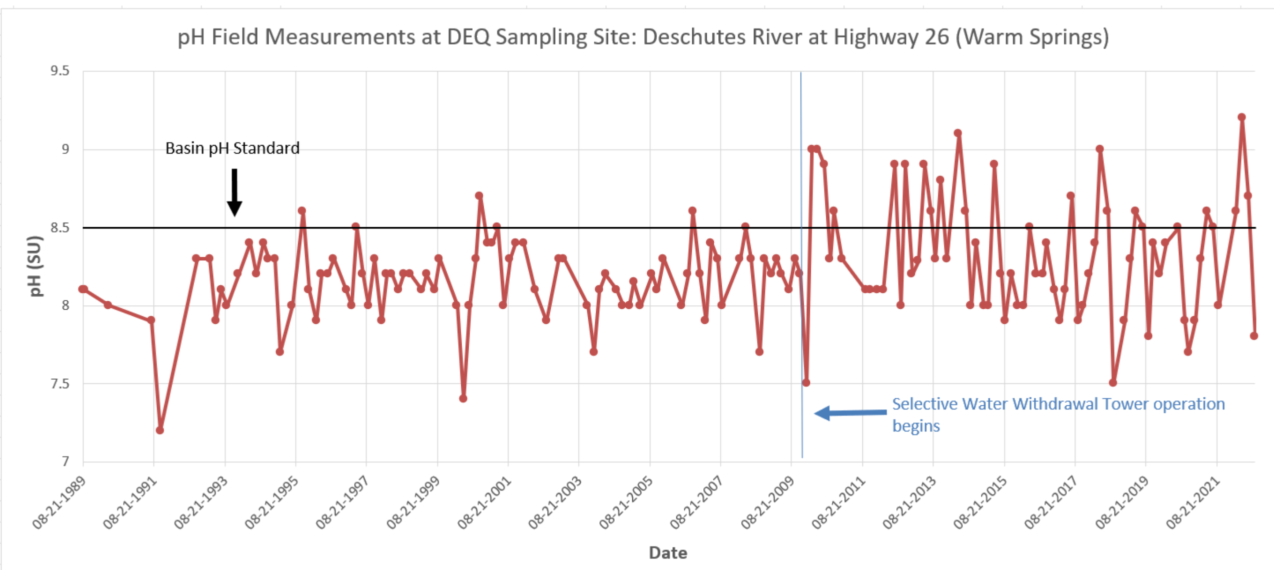

Figure 17. DEQ pH measurements taken from similar times of day and month from 1989 - 2022 (pre- and post-SWW Tower) on the LDR at the HWY26 bridge in Warm Springs. pH above 8.5 occurred in ~3% of measurements (n=89) from 1989-2009 (pre-SWW Tower) compared to 29% of measurements (n=70) from 2010-2022 (post-SWW Tower). Source: ODEQ Ambient Water Quality Monitoring System.

[16] https://secure.sos.state.or.us/oard/viewSingleRule.action?ruleVrsnRsn=68828

[17] DEQ pH data collected during the times of 0800-1200 were included. Any data points outside of this time frame (32 out of 189 total data points) were removed to eliminate variations in pH values caused by the natural daily fluctuations.

The DRA continued to document violations of the pH standard throughout the monitoring period in 2022. The most significant trend noted is three separate increases in % bottom draw from July through September (two of which were due to maintenance performed on the SWW Tower) lowered daily maximum pH values almost immediately (Figure 9, Figure 17). This illustrates that SWW Tower operations could be managed to meet pH standards in the lower Deschutes. The increase in pH late September into October is possibly explained by lake turnover in LBC, when surface water temperatures cool down enough to cause the thermocline to disappear and allow for even mixing throughout the water column. Similar increases in pH during the fall that coincide with turnover at LBC has been observed by the DRA when comparing previous years of DRA pH data (DRA 2020-2022) with annual PGE water quality reports (PGE & CTWSRO 2020-2022a).

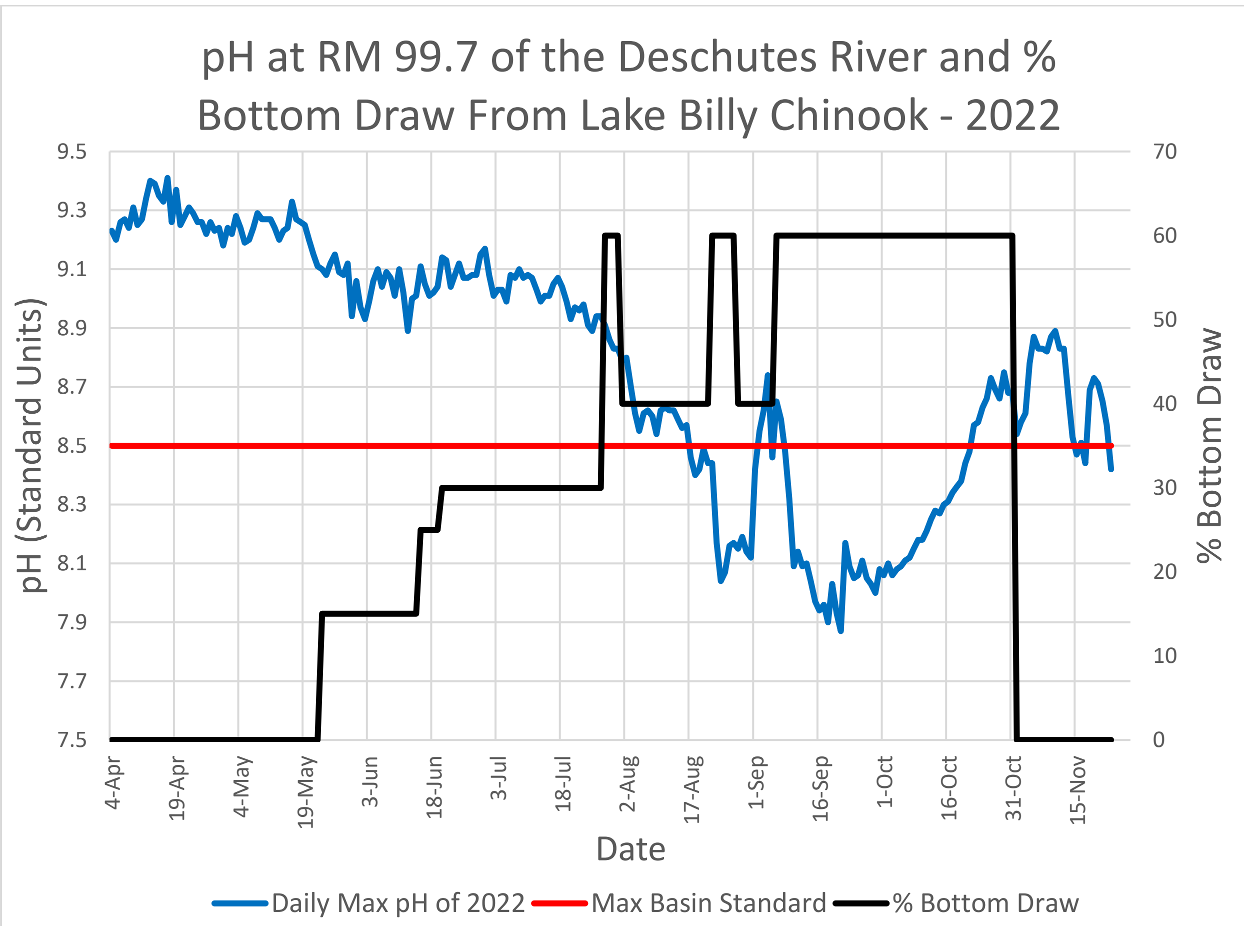

Figure 18. Daily maximum pH collected by the DRA just downstream of PRB complex and % bottom draw from the SWW Tower. Note the three abrupt declines in pH following large increases in bottom draw. % bottom draw data source: retrieved from PGE data reporting to ODEQ in 2022.

Regional Drought, Crooked River Streamflow, and Water Quality

It has been well documented that the majority of nitrogen entering LBC comes from the Crooked River. It's possible then that higher flows in the Crooked watershed will deliver higher levels of agriculturally-sourced nitrogen to LBC, which is subsequently released into the LDR. While it is evident that the LDR has experienced eutrophication since the installation of the SWW Tower (Eilers & Vache 2021, DRA 2015-2022), an analysis comparing Crooked River flows (USGS gauge at Opal Springs) to DRA continuous water quality data in the LDR from 2016-2022 shows no clear correlation between Crooked River streamflows and pH. Since pH is a good indicator of watersheds experiencing nutrient enrichment, increases or decreases in nutrient levels should cause an increase or decrease in pH, respectively. The DRA seasonal continuous pH data from 2016-2022 shows no clear correlation between annual variations in Crooked River flows and pH (Figure 18).

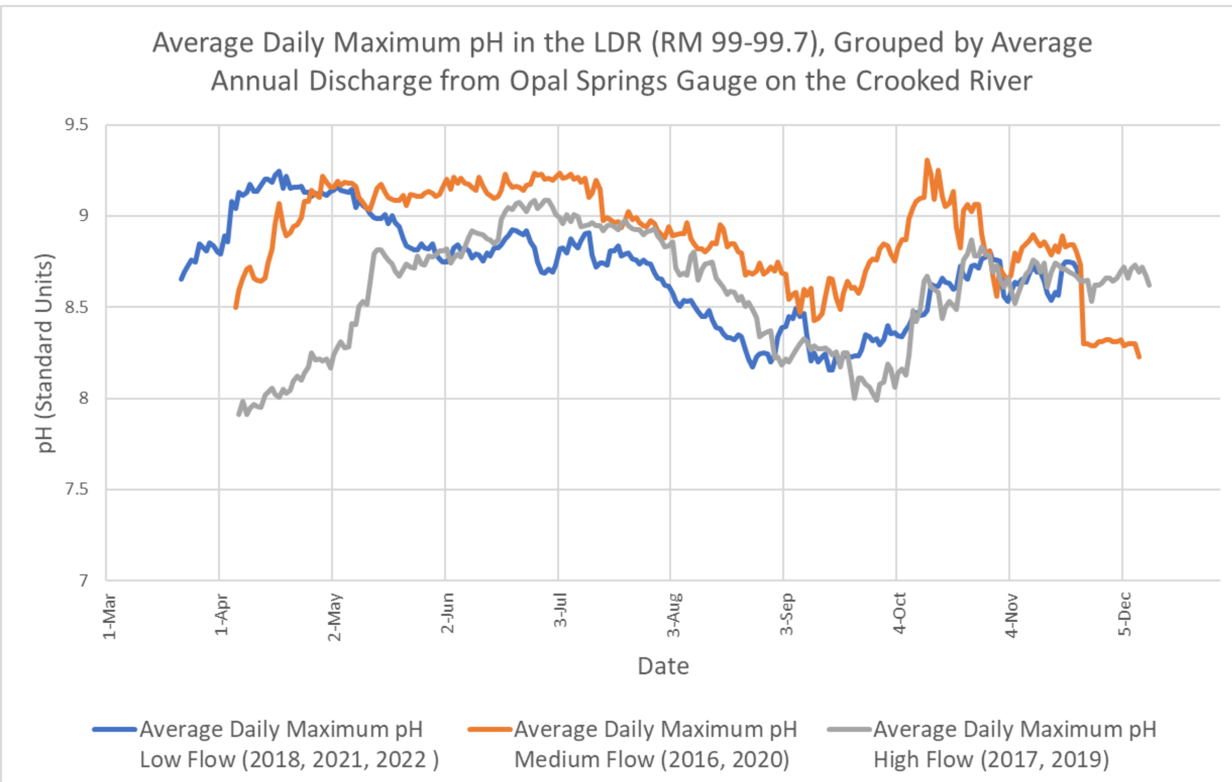

Figure 19. Average daily maximum pH at the DRA monitoring station located just downstream of the reregulating dam tailrace during all years monitored: 2016-2022. Years grouped and averaged according to the relative annual average discharge recorded at the Opal Springs USGS gauge (14087400) near the mouth of the Crooked River to LBC. Flow levels defined as follows: Low Flow – 0 to 1299 cfs mean annual discharge, Medium Flow – 1300 to 1399 cfs mean annual discharge, High Flow - >1400 cfs mean annual discharge.

The lack of correlation between runoff levels in the Crooked River watershed and water quality in the LDR may be explained by the 2022 Crooked River study's (MHE & CWRC 2022) finding that the majority of the nitrogen entering LBC from the Crooked River is sourced from the consistent flow of Opal Springs and other springs near the mouth of the Crooked River. Further research needs to be performed to determine whether the nitrogen from these springs is naturally or anthropogenically (e.g., agricultural runoff) sourced. However, regardless of the source, the fact remains that the Crooked River contributes the majority of nitrogen pollution to LBC and when surface water is released from LBC that water ends up in the lower Deschutes River.

Conclusions

Summary

Water quality data collected and analyzed by the DRA in 2022 again document numerous and ongoing violations of Oregon's pH and DO water quality standards in the lower Deschutes River. Additionally, temperature in 2022 exceeded maximum temperature of 13°C during the last 7 days of the designated salmon and steelhead spawning and egg incubation period.

The available record clearly indicates that Project and SWW Tower operations have continually contributed to the violations of Oregon's water quality standards for temperature, pH, and DO in the lower Deschutes River since it started operations in December 2009. When standards for multiple water quality parameters are violated together (as often is the case for pH and DO) the negative effects on aquatic life increase substantially. It is unacceptable that multiple water quality standards are habitually violated for any given periods of time (days and weeks on end as documented in this and past studies) in the lower Deschutes River.

Water quality standards are essential to protect the beneficial uses of Oregon's water and the aquatic life within them. The standards are the result of years of research and public process to ensure that the standards will adequately protect aquatic life in Oregon's waterways. Unfortunately, without strict enforcement and adherence to these standards the efforts taken to maintain acceptable water quality and reintroduce anadromous salmonids to tributaries upstream of LBC will prove difficult and potentially impossible in the long-term.

Below are the summarized findings and water quality exceedances documented by the hourly water quality data collected by the DRA at RM 99-99.7 from 2016-2022 and data reported in the PGE Water Quality Study (Eilers & Vache 2021).

Temperature:

The lower Deschutes River is one of the more important cold-water refugium for Upper Columbia River Basin adult salmon and steelhead (Keefer et al. 2018). Increasing the water temperature in the lower Deschutes is counterproductive to larger management goals for salmonids in the Columbia River Basin and potentially eliminates or seriously degrades this important cold-water refugium for anadromous fish migrating up the Columbia. Particularly since the Deschutes River is the only significant thermal refuge in the >250km reach of the Columbia River from The Dalles Dam to Lower Monumental Dam (EPA 2021). The current water temperature management approach with the SWW Tower has several serious impacts on aquatic life in the lower Deschutes River:

1. The "Without Project Temperature" equation used to set the temperature goals in the lower Deschutes River is unacceptable and does not represent a scheme to protect

and enhance aquatic life. Using the average of the 7-day **maximum temperatures** of the three tributaries entering Lake Billy Chinook, allows for the Project to constantly discharge the **maximum temperature** value from the three tributaries on a rolling 7-day average. [18] This does not recreate natural thermal conditions in the lower river that existed pre-dam construction since streams in temperate regions of North America experience a natural diel or daily temperature flux (Hauer et al., 2006), meaning that water temperature changes over a 24-hour period from a midafternoon high to a late night/early morning low (see for example Figure 4). Using only the average of the maximum tributary temperatures, as is currently done, does not recognize the natural temperature regime and does not account for the diel temperature flux in the tributaries. It also means that as climate warming increases temperatures of the tributaries the current management approach will also increase water temperature in the LDR when it can be avoided. Finally, there is no biological, or statistical justification for using maximum temperatures and this does not mimic a "natural" temperature regime in the lower Deschutes River.[19]

2. Releasing 100% surface water from Lake Billy Chinook from November through May (or June) each year raises the water temperature in the lower Deschutes River throughout the late winter, spring, and early summer. This warming is disproportionate to the relative cooling that has occurred during the late summer and fall by SWW Tower operations (see Figures 16a and 16b) and likely has negative biological consequences, as discussed in points 3 -6 below.
3. The warmer temperatures (in addition to excess nutrients) released from LBC into the lower Deschutes negatively affects aquatic biota, including altering aquatic insect life cycles and abundance. It is also likely contributing to the widely observed earlier-in-the-year and more dense growth of nuisance algae and diatoms that has further impacted aquatic invertebrate populations in the lower river. This is well supported by DRA's independent statistical analysis of aquatic macroinvertebrate data collected by R2 Resource Consultants. This analysis showed significant increases in non-insect taxa (worms and snails), increases in pollution tolerant invertebrates, and declines in pollution sensitive taxa after the SWW Tower started operating (Edwards 2018).
4. Also of concern is the increase in abundance of the polychaete worm, *Manayunkia occidentallis,* that is the obligate intermediate host for the parasite *Ceratonova shasta* that infects young, ocean-bound, as well as returning adult salmonids. DRA sampling of benthic invertebrates found over 8,000 *M. occidentallis* per square meter in September 2016 at RM 99 (DRA 2019c). It is thought that an increase in water

[18] The method outlined in the WQMMP for calculating the maximum temperature allowed for water released into the lower Deschutes River is based on a regression equation developed by Huntington et al. (1999). This equation is defined as *the flow- weighted, 7-day rolling average daily maximum temperatures of the three major tributaries to LBC, and the 7-day average daily air temperature at Redmond Airport*.

[19] See DRA's blog post, "The Low Down on High Temperatures in the Lower Deschutes River"

temperature and nutrient load favors *M. occidentallis* production and yields a higher incidence of *C. shasta*.

5. Project operations under the rubric of temperature management caused water temperatures to exceed the temperature standard for spawning salmon and steelhead during the month of June from 2020-2022 (7-day average daily maximum no greater than 13°C; Figure 5).
6. The increase in spring temperatures have resulted in Deschutes River water temperatures near the Columbia River reaching 60°F earlier than in previous years (Figure 13). The warmer water earlier in the year is likely what encourages smallmouth bass to migrate from the Columbia River, where they are abundant, up the Deschutes, possibly in search of food resources. The capture of smallmouth bass (*Micopterus dolumieu*) by steelhead anglers in the lower 40 miles of the Deschutes River during the summers of 2016 and 2017 exceeded anything in recent memory (S. Pribyl, pers. comm.) and remain seasonally very abundant. In 2017, walleye (*Sander vitreus*) were also caught in the lower Deschutes River near its mouth for the first time. Subsequent investigations by the Oregon Department of Fish & Wildlife confirmed smallmouth bass presence in numbers never previously observed by them (ODFW 2019). Conditions that triggered this increase are not completely clear, but higher water temperatures in the lower Deschutes River through July compared to pre-SWW Tower temperatures (Figures 16a-16b) is one explanation. The impact of increased smallmouth bass numbers in the lower Deschutes River is currently unknown, but an increase in predation of native fish is unavoidable.

Dissolved Oxygen:

Water with adequate dissolved oxygen is critical for the survival and reproduction of aquatic life. Incubating salmon and trout eggs and developing fry are the most sensitive life stages to inadequate DO concentrations. For this reason, water quality standards for DO are higher during salmonid egg incubation and fry development (Table 5).

Under the current DEQ permit for tower operations (401 Certification) states that salmonid spawning standards for DO should apply year-round (ODEQ n.d., PGE &CTWSRO 2002). Based on this, the DO concentration fell below and violated the applicable standard of 9 mg/L from 7/25/22 to 8/23/22, then again 9/14/22 to 9/22/22 during daily diel minimums. Additionally, if IGDO levels are not above 8.0 mg/L, then DO should not fall below 11.0 mg/L. If the 11.0 mg/L standard were applied, then DO fell below the standard every day starting in early-May through the end of the monitoring period on 11/23/22.

Additionally, under current Oregon standards (OAR 340-041-0016[20]), a minimum DO concentration of 11.0 mg/L (lower minimum of 9.0 mg/L if IGDO data available and

[20] https://secure.sos.state.or.us/oard/viewSingleRule.action?ruleVrsnRsn=256028

above 8.0 mg/L) should be extended to sufficiently support actual resident trout spawning and resulting incubation periods. Life history studies of resident trout in the lower Deschutes River confirm that trout spawning continues at least through the end of August (Zimmerman & Reeves 2000, Seals et al. 2014, Seals et al. 2015, French 2019). Resident trout incubation through fry emergence continues for between 4 and 6 weeks depending on water temperatures after spawning and the DO standards apply through that period, so the current DO standard as currently applied ending on June 15 is inadequate for protection of this sensitive life history period.

pH:

It is well established that pH can be an indicator of watersheds experiencing nutrient enrichment. High nutrient loads stimulate excessive algae and aquatic plant growth which in turn causes large diel swings in pH (EPA 2014). The pH levels measured by the DRA and DEQ show significant water quality exceedances of the pH standard since the SWW Tower started operating in 2009, which are largely due to the release of nutrient-laden surface water from LBC:

1. Similar to data collected 2016-2021, in 2022 hourly pH measurements exceeded the upper limit for the Deschutes Basin pH standard (8.5 s.u.) from the start of data collection on April 4 through the end of July. Measurements recorded between August and September showed improved pH within basin standards, but elevated pH measurements above the basin standard again occurred throughout October and into November.
2. Based on ODEQ data, pH in the lower Deschutes showed an immediate and sustained increase when SWW Tower operations began in 2009 (Figure 16). Yet, pH also showed a significant decrease following the abrupt increased % bottom-draw from the SWW Tower in July, August, and September (Figure 17), suggesting a viable operational scenario to meet pH standards.
3. No management plan for lowering pH has been developed by PGE, even though it is required by the WQMMP when pH measurements from the Project discharge exceed the weighted average pH of inflows into Lake Billy Chinook (PGE & CTWSRO 2002).

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Appendix A – 2022 Field Audit Data

Watershed Assessment Section Multiparameter Logger Monitoring Report

	SITENAME	FILENAME	CASE #
2022	DR01		

NOTE: GRADE F is a manual grade for "exceptional event" level data only(See DQM for further explanation). GRADE D is a manual grade for "missing" data. Grade E is data of an unknown quality or of known poor quality. **GRADES D, E AND F REQUIRE AN EXPLAINATION IN THE RUN COMMENTS SECTION.**

ELEVATION (f 1395

TEMPERATURE AUDIT RESULTS

#	Audit	DS Value		Status
1	9.8	9.76	0.04	A
2	11.1	10.9	0.20	A
3	13	13.1	-0.10	A
4	13.3	13.4	-0.10	A
5	9.5	9.49	0.01	A
6				
7				
8				
9				

Criteria:

GRADE A	GRADE B	GRADE C
=<±1.5	=<±1.51 - 2.00	=>±2.01

pH AUDIT RESULTS

#	Audit	DS Value	Abs. Differenc	Status
1	9.17	8.88	0.29	A
2	9.14	9.2	-0.06	A
3	9.01	8.89	0.12	A
4	7.78	7.97	-0.19	A
5	7.98	8.45	-0.47	B
6				
7				
8				
9				

Criteria:

GRADE A	GRADE B	GRADE C
=<±0.3	=<±0.31 -0.5	=>±0.5

CONDUCTIVITY AUDIT RESULTS

#	Audit	DS Value	Abs % Differenc	Status
1				
2				
3				
4				
5				
6				
7				
8				
9				

Criteria:

GRADE A	GRADE B	Grade D or E
=<±10%	=<±10.1% - 15%	=>±15%

DO AUDIT RESULTS

#	Audit	DS Value	Abs. Differenc	Status
1	12.89	12.94	-0.05	A
2	12.5	13.23	-0.73	B
3	11.4	11.3	0.10	A
4	7.88	8	-0.12	A
5	10.76	11.15	-0.39	B
6				
7				
8				
9				

Criteria: units in **mg/L**

GRADE A	GRADE B	GRADE E	GRADE C
(≤± 0.3)	(≤± 0.31-1.0)	(≤± 1.01-2.0)	(≥± 2.01)

Appendix B- Water Quality Sampling Quality Assurance/Quality Control Program and Methods

Instrument Calibration:

All instruments were calibrated per manufacturer instructions. A log of calibrations has been kept on all instruments. Calibration and/or accuracy checks on handheld instruments were done within 24 hours of each use event. Calibration on in-dwelling instruments (YSI data sonde) was done prior to initial placement and again after battery replacement.

Instruments were calibrated using name brand pre-formulated calibration standard solutions.

Instrument Data Audits:

The YSI data sonde was audited as often as possible using handheld instruments to determine temperature, pH, dissolved oxygen, oxygen saturation and turbidity. Use of multiple measures was employed as described below.

Use of Multiple Measures:

To ensure in-field accuracy, independent meters/instruments were used to measure temperature, pH and DO simultaneously with the YSI data sonde. Re-calibration and/or probe replacements were done when necessary.

Instrument Storage:

Instruments were stored in a secure and temperature-controlled environment when not in use.

Appendix C- Supplemental Figures

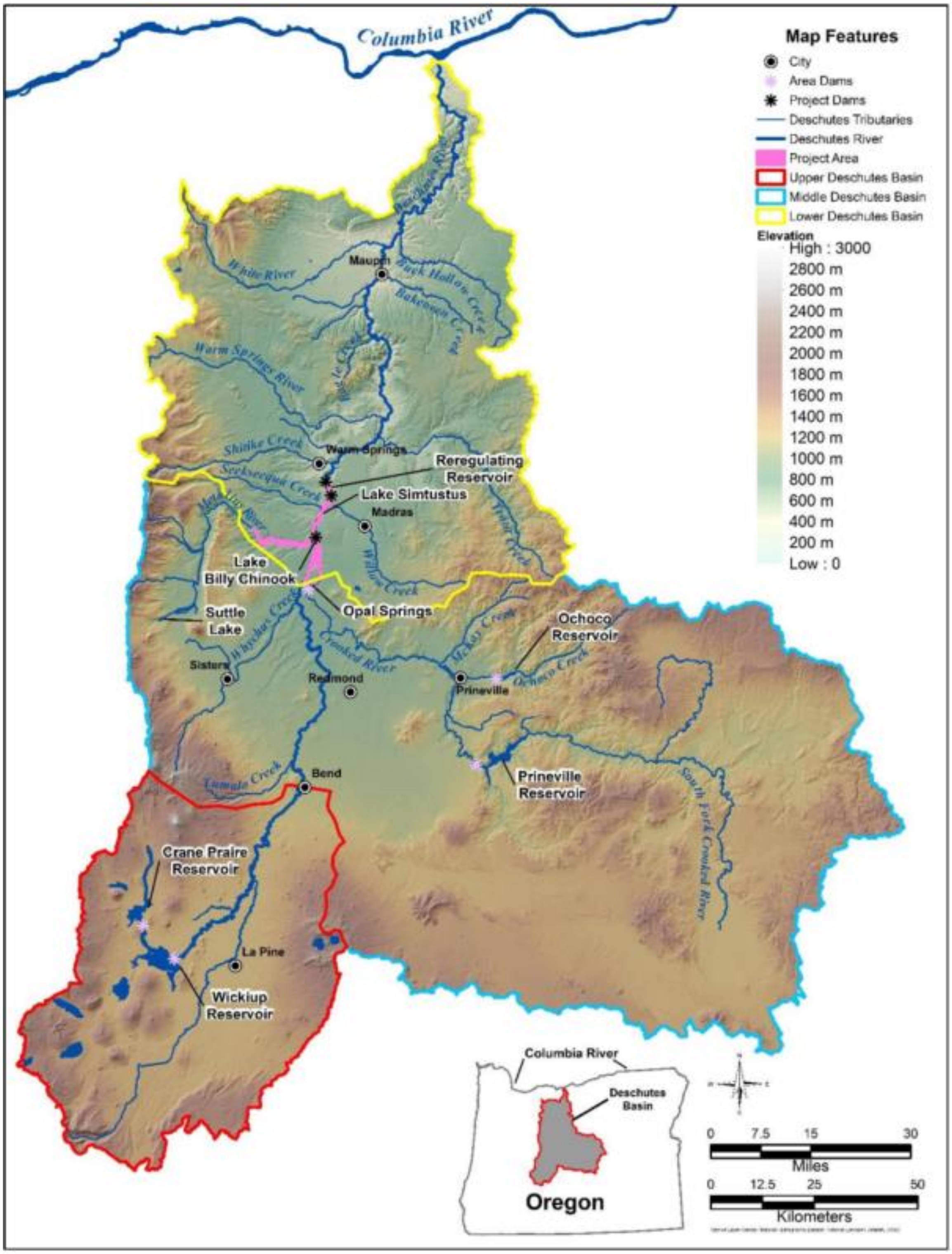


Figure 20. Map of Deschutes watershed. Source: PGE Water Quality Report (Eilers & Vache 2021)

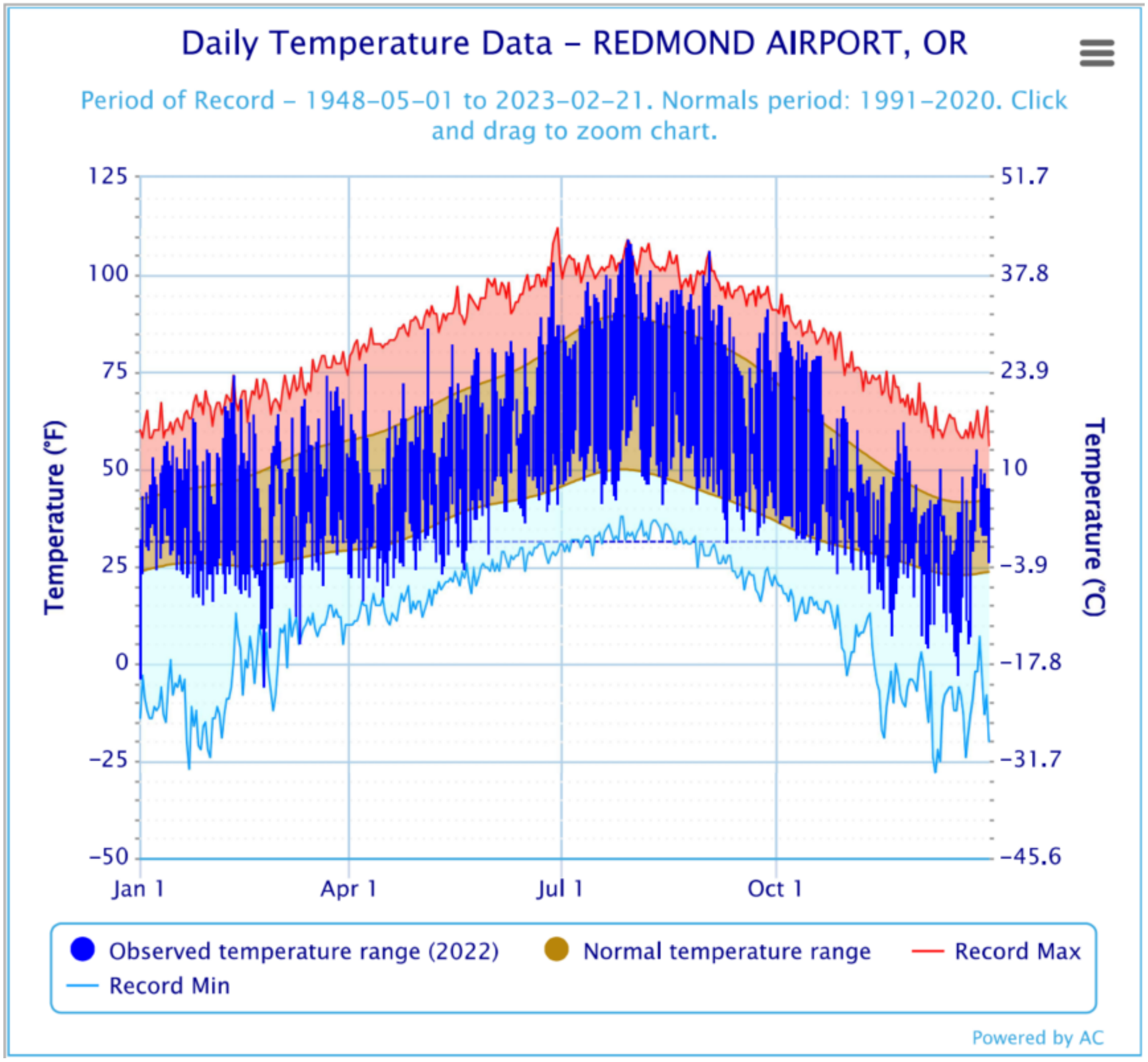


Figure 21. 2022 daily temperature data from the NOAA station at the Redmond Airport. Retrieved from: NOAA National Weather Service Climate NOWData, accessed at https://www.weather.gov/wrh/Climate?wfo=pdt

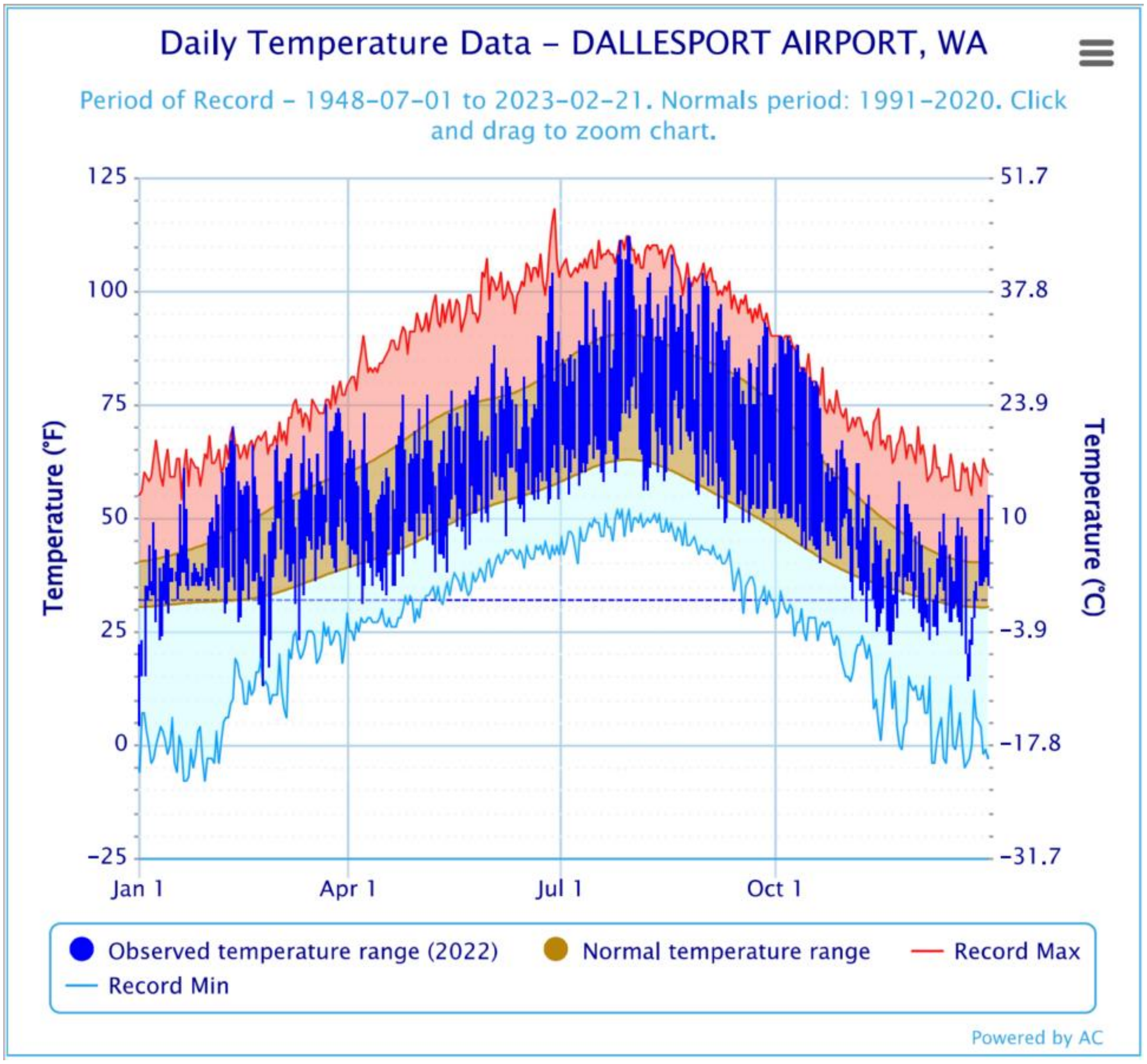


Figure 22. 2022 daily temperature data from the NOAA station at the Dalles Airport near the mouth of the LDR. Retrieved from: NOAA National Weather Service Climate NOWData, accessed at https://www.weather.gov/wrh/Climate?wfo=pdt

Appendix D- Oregon Administrative Rules for Temperature & Maps

The seven-day-average maximum temperature of a stream identified as having salmon and steelhead spawning use on sub-basin maps and tables set out in OAR 340-041-0101 to 340-041-0340: Tables 101B, and 121B, and Figures 130B, 151B, 160B, 170B, 220B, 230B, 271B, 286B, 300B, 310B, 320B, and 340B, may not exceed 13.0 degrees Celsius (55.4 degrees Fahrenheit) at the times indicated on these maps and tables;

The seven-day-average maximum temperature of a stream identified as having core cold water habitat use on sub-basin maps set out in OAR 340-041-101 to 340-041-340: Figures 130A, 151A, 160A, 170A, 180A, 201A, 220A, 230A, 271A, 286A, 300A, 310A, 320A, and 340A, may not exceed 16.0 degrees Celsius (60.8 degrees Fahrenheit);

The seven-day-average maximum temperature of a stream identified as having salmon and trout rearing and migration use on sub-basin maps set out at OAR 340-041-0101 to 340-041-0340: Figures 130A, 151A, 160A, 170A, 220A, 230A, 271A, 286A, 300A, 310A, 320A, and 340A, may not exceed 18.0 degrees Celsius (64.4 degrees Fahrenheit)

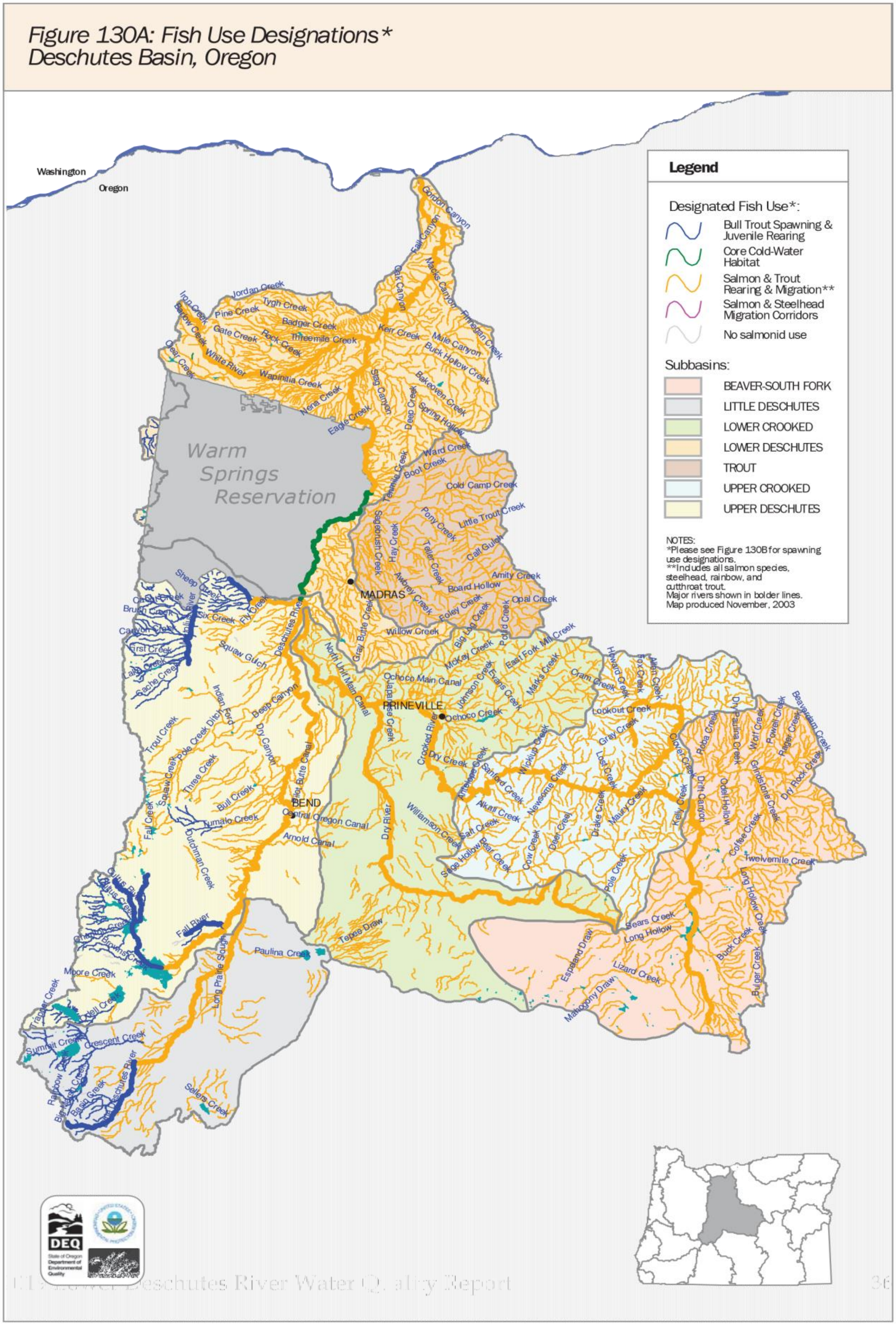
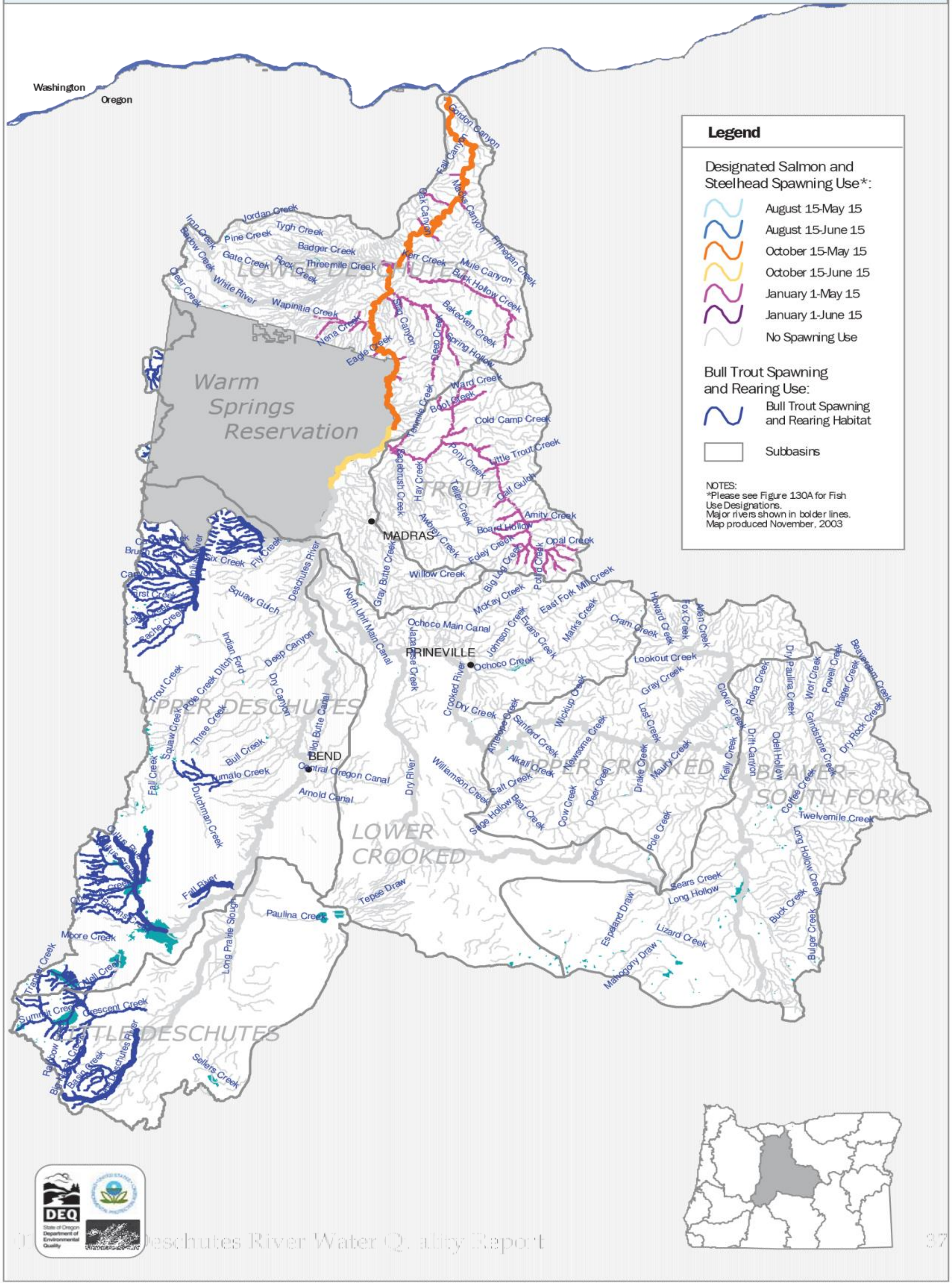


Figure 130A: Fish Use Designations*
Deschutes Basin, Oregon
Washington
Oregon
Legend
Designated Fish Use*:
Bull Trout Spawning & Juvenile Rearing
Core Cold-Water Habitat
Salmon & Trout Rearing & Migration**
Salmon & Steelhead Migration Corridors
No salmonid use
Subbasins:
BEAVER-SOUTH FORK
LITTLE DESCHUTES
LOWER CROOKED
LOWER DESCHUTES
TROUT
UPPER CROOKED
UPPER DESCHUTES
NOTES:
*Please see Figure 130B for spawning use designations.
**Includes all salmon species, steelhead, rainbow, and cutthroat trout.
Major rivers shown in bolder lines.
Map produced November, 2003
Warm Springs Reservation
MADRAS
PRINEVILLE
BEND
DEQ

*Figure 130B: Salmon and Steelhead Spawning Use Designations**
Deschutes Basin, Oregon



Appendix E – Analysis Used to Select Post-Tower Operation Years in Figure 16b

The following variables and data sources were utilized in order to find the four years during post-tower operations that were most climatically similar to the four pre-tower operation years of 2006-2009.

- Snow water equivalent data from USDA stations (aside from Irish Taylor station[22]) located in the Deschutes basin (retrieved from USDA Report Generator 2.0)
- Drought classification data from University of Nebraska-Lincoln (retrieved from US Drought Monitor Database)
- NOAA temperature data from the Redmond Airport station[23] (retrieved from NOAA Climate Data Online)
- USGS stream discharge data at the Madras station (retrieved from USGS monitoring location 14092500)

The following pages contain tables summarizing the analysis of each variable, and the final analysis combining all of the variables to select the four years of post-tower operations most similar to 2006-2009. Each year for each variable received a "rank" for its relative closeness to the 2006-2009 average for that variable. This ranking, and total number of appearances in the top 4 years for each variable were factored in to calculate the final four years most similar to 2006-2009. Ultimately, the final analysis determined that of the years 2010-2022, in order of similarity, 2012, 2017, 2013 and 2010 were most similar to the 2006-2009 overall averages of the climatic data listed above.

[22] Out of 18 total stations in the Deschutes Basin, one (Irish Taylor) was unintentionally omitted. This omission is not believed to have any significant effect on the analysis selecting four years from 2010-2022 most similar to 2006-2009 with regards to SWE data.

[23] The Madras NOAA station was also considered given its closer proximity to RM 100 of the LDR, which is the site being analyzed in the pre vs post water temperature analysis in Figures 16a and 16b. However, this station has incomplete temperature data during the period being considered. Separate analysis (not included in this report) utilizing the incomplete Madras NOAA station ultimately resulted in the same 4 years of post-tower operations being selected.

2006-2009 Average	Year	Average SWE	Absolute Difference from 2006-2009 Average	Rank
6.25	2011	16.34	0.22	1
	2017	15.15	0.97	2
	2021	12.10	4.02	3
	2012	11.70	4.42	4
	2016	10.89	5.23	5
	2022	10.66	5.47	6
	2013	10.58	5.54	7
	2019	10.47	5.65	8
	2010	9.88	6.24	9
	2020	9.02	7.10	10
	2018	7.09	9.03	11
	2014	6.70	9.42	12
	2015	2.17	13.95	13

Table 6. Snow water equivalent (SWE) component of the Figure 16b analysis. Highlighted years and associated rank included in the final analysis (Tables 10-11).

2007-2009* Average	year	Average USDM Level	Absolute Difference from 2007-2009 Average	Rank
1.17	2013	1.13	0.03	1
	2017	1.23	0.06	2
	2011	1.08	0.09	3
	2012	1.29	0.13	4
	2010	1.00	0.17	5
	2016	1.34	0.17	6
	2019	1.78	0.62	7
	2014	1.91	0.74	8
	2018	2.02	0.85	9
	2020	2.30	1.13	10
	2015	2.35	1.18	11
	2021	2.80	1.63	12
	2022	2.86	1.70	13

Table 7. US Drought Monitoring (USDM) Level component of the Figure 16b analysis. Highlighted years and associated rank included in the final analysis (Tables 10-11)

Month	2006-2009 Average	Year	Annual Sum of Absolute Monthly Differences*	Rank
		2013	15.80	1
Jan	42.81	2012	30.71	2
Feb	47.51	2018	32.91	3
Mar	52.11	2014	35.20	4
Apr	58.73	2017	35.72	5
May	70.28	2010	36.28	6
Jun	76.68	2016	43.25	7
Jul	89.16	2019	43.29	8
Aug	84.69	2020	44.00	9
Sep	78.00	2015	46.37	10
Oct	61.48	2021	47.14	11
Nov	51.63	2011	52.79	12
Dec	40.92	2022	57.47	13

Table 8. Air temperature component of the Figure 16b analysis. Highlighted years and associated rank included in the final analysis (Tables 10-11).

The difference in monthly average temperatures between the 2006-2009 average (left two columns) was taken from the associated month for every year 2010-2022. Values listed for each year in the "Annual Sum of Absolute Monthly Differences column is the summed total of the absolute difference from the 2006-2009 average values for all months of the given year. This method was utilized in order to factor in the seasonal changes in air temperature.

2006-2009 Average Discharge (cfs)	Year	Average Discharge (cfs)	Absolute Difference From 2006-2009 Average	Rank*
4690.35	2014	4681.34	9.05	1
	2010	4678.14	12.21	2
	2015	4420.13	270.22	3
	2012	4989.67	299.32	4
	2013	4500.80	189.55	5
	2016	4485.56	204.79	6
	2019	4383.13	307.22	7
	2017	5023.56	333.21	8
	2018	4280.06	410.29	9
	2011	5269.36	579.01	10
	2020	3990.98	699.37	11
	2021	3938.85	751.50	12
	2022	3913.12	777.23	13

Table 9. Stream flow component of the Figure 16b analysis. Highlighted years and associated rank included in the final analysis (Tables 10-11).

*The four years that, averaged together, was closest to the 2006-2009 average did not coincide with the four years, considered individually, with the least amount of absolute difference from the 2006-2009 average. The four years that, averaged together, was closest to the 2006-2009 average were automatically assigned the top 4 ranks, but all individual years were ranked from smallest to largest based on the individual year's absolute difference from the 20006-2009 average.

Primary Variable Year Rank	Primary Variable: **Temperature**	**Other Variable Ranking of that Year**	Primary Variable: **Drought**	**Other Variable Ranking of that Year**	Primary Variable: **SWE**	**Other Variable Ranking of that Year**	Primary Variable: **Flow**	**Other Variable Ranking of that Year**	**Other Variables**
Year 1	2013		2013	1	2011	10	2014	5	Temp
		1				3		8	Drought
		7		7				12	SWE
		5		5		10			Flow
Year 2	2012		2017	2	2017	2	2010	4	Temp
		4				2		5	Drought
		4		2				9	SWE
		4		8		8			Flow
Year 3	2018		2011	10	2021	9	2015	11	Temp
		9				12		11	Drought
		11		1				13	SWE
		9		10		12			Flow
Year 4	2014		2012	3	2012	3	2012	3	Temp
		8				4		4	Drought
		12		4				4	SWE
		1		4		4			Flow

Table 10. Summary of the top 4 years of each variable, and the associated rank of that year relative to the other variables.

Year	Total Number of Occurrences	Total "Other Variable Ranking" Score for that Year	Total "Other Variable Ranking" Score for that Year Divided by Number of Occurrences
2012	4	45	11.25
2017	2	12	12
2013	2	26	13
2010	1	18	18
2011	2	44	22
2014	2	46	23
2018	1	29	29
2021	1	33	33
2015	1	35	35

Table 11. Final analysis depicting (1) the ranking of each year and (2) the total number of occurrences each year made it into the top four of all the climatic variables. The last column takes into account these two factors and the lowest four numbers (highlighted) are the most similar to 2006-2009 averages of all variables being considered based on the methodology of the analysis.