2020 CROOKED RIVER WATER QUALITY REPORT

Deschutes River Alliance
April 2021

Key Findings:

- Water temperature and pH in the lower Crooked River at Smith Rock State Park, River Mile 27, continued to violate Oregon's water quality standards throughout most of the sampling period - May 15, 2020 to June 24, 2020.
- Anthropogenic alterations to flow regimes in the lower Crooked River impair water quality at Smith Rock State Park, with water release from Bowman Dam, multi-source irrigation, and non-point source pollution being the main contributors.
- Large diel swings in pH indicate excess nutrients (due to agricultural runoff and wastewater) that result in high amounts of nuisance algae and aquatic plant matter in the lower Crooked River.
- Standards for water quality are set independently from each other but violations often combine and interact with other constituents to pose harmful and potentially lethal effects on trout, salmonids, and other aquatic life.
- Poor water quality in the Crooked River affects the water quality and aquatic life in Lake Billy Chinook and subsequently, the lower Deschutes River.

Ecological Consequences

Aside from the immediate impact that water quality violations have on resident and transient aquatic life in the lower Crooked River, these violations also affect the reintroduction efforts of anadromous fish in the three tributaries above Lake Billy Chinook (LBC), as well as the water quality in Lake Billy Chinook and in the lower Deschutes River.

Excessive nutrient loads from the lower Crooked River contribute to expansive algal blooms in the epilimnion (upper layer) of Lake Billy Chinook. This results in an elevated pH (>9.0 standard units) and eutrophication of the epilimnion, which is the primary migration corridor of ocean-bound anadromous salmon and steelhead smolts in LBC (DRA Reports). A review of data and literature available in 2017 indicates that the exceedingly low survival rate of anadromous smolts collected at the Selective Water Withdrawal Tower (SWWT) in Lake Billy Chinook may be related to poor water quality (DRA Poster).

The SWWT was implemented by PGE in December, 2009 to help reintroduced anadromous salmon and steelhead smolts navigate through the reservoir. It collects and discharges a disproportionate amount of Crooked River Water from Lake Billy Chinook into the lower Deschutes River. Although expansive algal blooms in Lake Billy Chinook contribute to the sequestration of nutrient pollution from the Crooked River, this benefit does not outweigh the cost to the lower Deschutes River ecosystem and its aquatic life. Poor water quality in the Crooked River (due to temperature, nutrient loads, and flow regime) has impacted reintroduction efforts of anadromous fish and is changing the lower Deschutes River chemistry and ecology. While the effects from these changes are clear (particularly in the rooted aquatic plant life, periphyton growth, and macroinvertebrate communities), the long-term impact to fish populations is currently unknown. Nevertheless, it is likely that poor water quality in the Crooked River will negatively impact reintroduction efforts and fish health if left unmanaged.

The DRA recognizes these changes and has committed to monitoring river quality and ecology in the lower Deschutes River since 2013. While these changes are not favorable for the outcome of fish health and water quality in Lake Billy Chinook and the lower Deschutes River, the DRA believes there are viable alternatives. Using modeling studies, Portland General Electric (PGE) and the Confederated Tribes of the Warm Springs (CTWS) have confirmed that changes to the present operations of the SWWT (that can comply with the law) can improve river water quality in the lower Deschutes River and increase the chances for successful anadromous fish reintroduction in the Deschutes River Basin. (DRA Position Statement).

Table of Contents

Key Findings ii

Ecological Consequences iii

Table of Contents iv

Acknowledgements v

List of Figures vi

List of Tables vi

List of Abbreviations vii

Introduction 1

Study Sites 3

Methods 6

Results 7

Discussion 12

Summary 16

References 18

Appendix A - Oregon Administrative Rules for 340-041-0130: Temperature & Maps 22

Appendix B – OAR 340-041-0130: Maps, Tables, and Figures 23

Appendix C - Oregon Administrative Rules for Dissolved Oxygen 27

Appendix D - Oregon Administrative Rules for Dissolved Oxygen: Table 21 28

Appendix E - Audit Data 29

Cover Photo: Crooked River. Photo by Rick Hafele.

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Last, thanks to all of 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.

List of Figures

Figure 1. Land classification of Crooked River Basin (DRA 2019b) 1

Figure 2. Lower Crooked River sub-basin and 2019/2020 monitoring sites 3

Figure 3. YSI 6600v2 (left) and Onset® HOBO® Pendant data logger (right).................. 6

Figure 4. 2020 hourly water temperature at Smith Rock State Park 7

Figure 5. 2019-2020 hourly water temperature at Smith Rock State Park 8

Figure 6. 2019 7-Day Average Daily Maximum (7-DADM) water temperature at the five original monitoring sites; state maximum water temperature standard of 18°C (64.4°F) shown in red 9

Figure 7. 2020 7-DADM at Smith Rock State Park; state maximum water temperature standard of 18°C (64.4°F) shown in red 9

Figure 8. 2020 hourly pH at Smith Rock State Park; state upper pH limit standard of 8.5 standard units shown in red.. 10

Figure 9. 2020 hourly dissolved oxygen at Smith Rock State Park; state minimum limit standard (11 mg /L) for trout spawning and fry-rearing shown in red........................... 11

Figure 10. Crooked River below Bowman Dam. Excessive aquatic plant and algae production is circled in red. Photo by: Rick Hafele 14

List of Tables

Table 1. Monitoring site name, site ID, and river mile 4

Table 2. Segment, listed parameters, parameter criteria (2018/2020 ODEQ)................... 5

List of Abbreviations

CFS	- Cubic Feet per Second
CTWS	- Confederated Tribes of the Warms Springs
ODEQ	- Oregon Department of Environmental Quality
DO	- Dissolved Oxygen
DRA	- Deschutes River Alliance
DS	- Data Sonde (YSI 6600v2 model)
LBC	- Lake Billy Chinook
OAR	- Oregon Administrative Rules
ODFW	- Oregon Department of Fish & Wildlife
OWQI	- Oregon Water Quality Index
PGE	– Portland General Electric
Project	- Pelton Round-Butte Hydroelectric Project
RM	- River Mile
SWWT	- Selective Water Withdrawal Tower
TMDL	- Total Maximum Daily Load
7-DADM	- 7-Day Average Daily Maximum

Introduction

In 2019, the Deschutes River Alliance (DRA) began monitoring water quality in the Crooked River Basin between Bowman Dam and Smith Rock State Park (Figure 1) to evaluate its effects on Lake Billy Chinook, the lower Deschutes River, and the reintroduction of anadromous fish. The DRA conducted hourly temperature monitoring at four sites between Bowman Dam and the City of Prineville, and hourly temperature and pH monitoring at Smith Rock State Park (Figure 2). Results from that study can be found in the [Deschutes River Alliance's 2019 Crooked River Quality Monitoring Report]. This 2020 Crooked River Water Quality report is a continuation of those monitoring efforts. Due to sampling restrictions caused by the COVID-19 pandemic, this report focuses primarily on water quality in the lower Crooked River at Smith Rock State Park (Figure 2, RM 27; Table 1, Site 5). Monitoring efforts were not conducted at the other four sites in 2020.

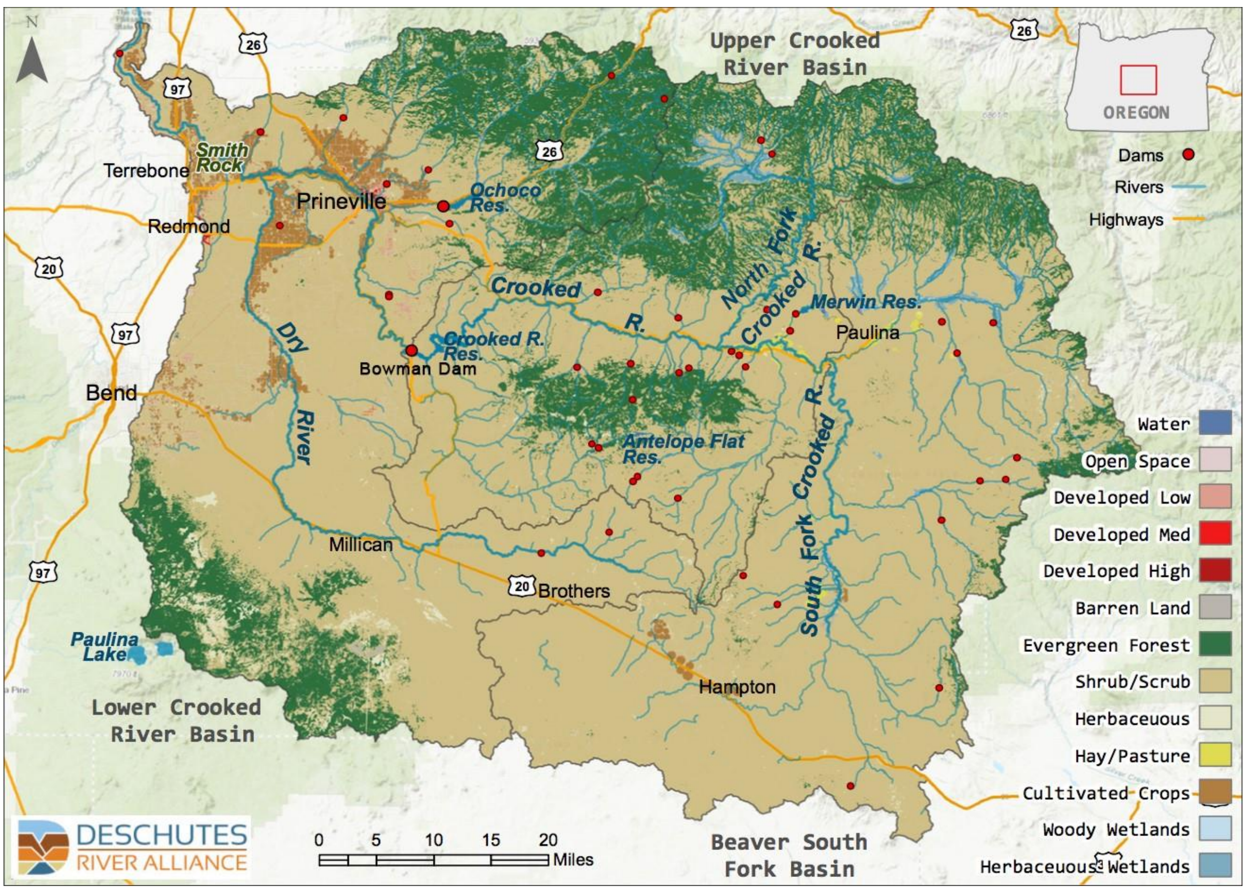

Figure 1. Land cover classification map of the Crooked River Basin in Oregon (DRA 2019b).

The lower Crooked River begins at the base of Bowman Dam and flows northwest to Lake Billy Chinook. Bowman Dam releases cool water year-round and provides habitat for a popular tailwater trout fishery from River Mile (RM) 62-70. In addition to supporting resident trout populations, the Crooked River has become a focal point for the reintroduction of anadromous salmon and steelhead. However, as stated in the DRA's 2019 Crooked River Water Quality Report and in previous studies, the quantity and quality of water in the lower Crooked River are not up to state standards for resident and anadromous fish (ODFW 2016 summary report). Deficiencies in water quality and quantity in the lower Cooked River impact conditions in both Lake Billy Chinook and, subsequently, the lower Deschutes River.

In 1964, The Pelton-Round Butte Hydroelectric Project (Project) blocked anadromous fish from reaching spawning and rearing habitat in the Crooked, Whychus Creek, and Metolius rivers and their tributaries. Reintroduction efforts for anadromous salmonids upstream of the Project began in 2007 and have relied heavily on the construction and operation of a Selective Water Withdrawal Tower (SWWT, hereinafter Tower) in 2009 to produce a surface current in Lake Billy Chinook. The surface current was intended to facilitate the movement of migrating juveniles downstream through the reservoir to a collection facility where they are captured, marked for re-capture as adults, trucked and released downstream from the Project.

As a consequence of current Tower operations and resulting surface water discharge, the Crooked River now accounts for the majority of water flowing into the lower Deschutes River (Eilers & Vache 2019). Prior to Tower operation, the Metolius River accounted for nearly all water discharged to the lower Deschutes River from Lake Billy Chinook. Unfortunately, the Crooked River has significantly degraded water quality when compared to the other two tributaries of Lake Billy Chinook (the Metolius and Deschutes rivers). This was evident during the DRA's water quality monitoring of the tributary arms of Lake Billy Chinook in 2015 and 2016 (DRA 2016b). During those sampling events, DRA staff recorded the highest pH of the study (9.9 standard units) in the Crooked River arm of Lake Billy Chinook as well as elevated nitrate concentrations (nitrate/nitrite range: 0.43-0.55 mg/L) at the Crooked River inflow (DRA 2016a).

In 2018, the DRA contracted Elinore Webb (Portland State University) to map water quality and land use in the Crooked River Basin from 2010-2014 (DRA 2019b). The Webb report concluded that nitrogen pollution originates from sources spread throughout both the lower and upper Crooked River sub-basins and that the primary source of nitrogen pollution came from agricultural activities. These findings were later corroborated in a report released by Portland General Electric on June 20, 2019 (Eilers & Vache 2019).

Past water quality monitoring downstream from Bowman Dam is limited to a few studies. Oregon Department of Environmental Quality (ODEQ) conducted extensive water quality monitoring throughout the basin in 2005/2006. In addition, airborne thermal imaging was completed for the watershed in 2005 (ODEQ 2006). The local watershed council published a watershed assessment in 2008 and developed a water quality monitoring program for grab samples and continuous temperature monitoring (CRWC 2008). The Oregon Department of Fish & Wildlife (ODFW) conducted continuous temperature monitoring in the winter of 2015/2016 to assess the effects of modified flow regimes on fish populations (ODFW 2016). The results of these studies will be further explained in the Discussion section.

Study Sites

DRA Monitoring sites in the lower Crooked River were reduced from five sites in 2019 to one site in 2020 due to the unforeseen COVID-19 pandemic. Monitoring continued at Smith Rock State Park (Figure 2, RM 27; Table 1, Site 5) based on historical use by the local watershed council and by the Oregon Department of Environmental Quality (ODEQ). This site is downstream from the City of Prineville and surrounding agronomic landscape, where municipal and agricultural practices are known to negatively impact water quality. It is the closest accessible monitoring site upstream from Opal Springs and its confluence at Lake Billy Chinook. Upon entry into LBC, the Crooked River greatly influences water quality within LBC and the lower Deschutes River.

Figure 2. Lower Crooked River sub-basin and 2019/2020 monitoring sites.

Table 1 lists the five original 2019 DRA monitoring sites where continuous water temperature data were collected: 1) below Bowman Dam (RM 70); 2) south end of Prineville city limits (RM 50); 3) Ochoco Creek confluence (RM 44.8); 4) Crooked R. at Elliott Ln. (RM 44.1); and 5) Smith Rock State Park (RM 27). All sites are located on public property and are accessible by public roads. Approval from the local watershed council was granted prior to monitoring so as to not duplicate efforts. A research permit was obtained from Oregon Parks and Recreation Department for access to the Smith Rock State Park site (valid 8/20/2019 to 11/30/2020). Monitoring in 2020 was only conducted at Smith Rock State Park, RM 27, Site 5.

Site Number & Name	Site ID	River Mile
1. Crooked R. 300m downstream of Bowman Dam	11778-ORDEQ	70
2. Crooked R. southern city limit of Prineville	36261-ORDEQ	50
3. Crooked R. downstream of Ochoco Cr.	36262-ORDEQ	44.8
4. Crooked R. at Elliott Ln.	32494-ORDEQ	42
5. Crooked R. at Smith Rock State Park	32520-ORDEQ	27

Table 1. Monitoring site name, site ID, and river mile[1].

Crooked River at Smith Rock State Park

At RM 32, the Crooked River enters a deep canyon where water quality is affected by numerous point-source irrigation withdrawals. As a result, extremely low summertime flows occur in Smith Rock State Park at RM 27 (Deschutes Basin Habitat Conservation Plan section 11.8.3.4, USFWS 2019) and contribute to water temperatures in the lower Crooked River exceeding state maximum standards. From RM 32 to 6.7, just above Opal Springs, the Crooked River is listed as water quality impaired for temperature, pH, biocriteria, anthropogenic flow regime, and elemental phosphorus[2] (Table 2).

From RM 15 to 8, the Crooked River is designated as a federal Wild and Scenic River including: scenic, recreational, geological, hydrological, wildlife, and botanical/ecological values (oregonwildandscenic.com).

[1]River mileages in this report are approximate and adapted from ODEQ (2006).

[2]Neither Oregon nor EPA has a numeric criterion limitation for phosphate phosphorus. EPA has recognized the relationship between phosphates and excessive aquatic weed and algae growth and lake or reservoir eutrophication. EPA recommends that total phosphate phosphorus (PO4–P) should not exceed 50 µg/L in streams to control excessive aquatic growths. DEQ uses this value as a benchmark to evaluate water quality (1986, Quality Criteria for Water, U.S. EPA Office of Water, EPA 440/5-86-001 for Phosphate Phosphorus). Excessive phosphate levels are evaluated for TMDLs as a possible cause contributing to violations of water quality standards for which there are numeric criteria, such as pH, dissolved oxygen, and chlorophyll-a. (ODEQ 2018/2020)

A number of groundwater springs provide significant input downstream from Smith Rock State Park and contribute directly to the cooling and stability of the Crooked River in summer months (ODEQ 2006; USGS 2007a). The largest of these springs, Opal Springs (at RM 6.7), contributes a stable flow input of approximately 1100 cubic feet per second (cfs) year-round (Eilers & Vache 2019). Opal Springs water temperatures are approximately 10°C (50°F)(USGS 2007a).

The Opal Springs Hydroelectric Dam is located at RM 6.9 on the Crooked River immediately upstream from Opal Springs. The dam was completed in 1985 and was fitted with a fish ladder in November, 2019 to allow up-and-downstream migration of anadromous fish (salmon and steelhead), bull-trout, and other trout species. The dam is operated as a run-of-the-river dam and is used primarily to generate hydroelectric power. Approximately one mile downstream from Opal Springs Dam is the Crooked River confluence with Lake Billy Chinook. The Crooked River Arm of Lake Billy Chinook extends for several miles before converging with the arms of the Deschutes and Metolius rivers. Exiting from Lake Billy Chinook is the lower Deschutes River; historically a blend of the Metolius, Deschutes and Crooked Rivers.

Oregon DEQ's Oregon Water Quality Index (OWQI) provides a general assessment of water quality by combining information from eight different sub-indexes: temperature, dissolved oxygen, pH, BOD (biological oxygen demand), total solids, nitrogen, phosphorus, and bacteria. The index was designed to assess water quality among different watersheds on a scale of 10-100; Excellent 90-100, Good 85-89, Fair 70-84, Poor 60-79, Very Poor 10-59. Water quality affecting our study area was reported as poor in a 2010-19 statewide assessment of non-point source water pollution (ODEQ Water Quality Index). Prior to 1992, discharges from the Prineville sewage treatment facility into the Crooked River resulted in chronic violations to state water quality standards downstream (ODFW 1996). Since 1992, the City of Prineville has made multiple efforts to treat and dilute sewage and wastewater with the construction of an artificial wetland and the irrigation of a city owned golf course. Portions of the lower Crooked River were first added to Oregon's Clean Water Act Section *303*(*d*) *list*[3] in 1998. The *303*(*d*) *list* includes those waterbodies in Oregon that do not meet state water quality standards and require Total Maximum Daily Load (TMDL) studies. As of January, 2021, no TMDL studies for the lower Crooked River have been completed. Table 2 shows the stream segments listed by the Oregon DEQ for impairment and their respective impaired parameters (ODEQ 2018/2020). Results from our monitoring efforts in 2019 and 2020 echo these findings.

Stream Segment	Listed Parameters for Impairment	Parameter Criteria
Prineville Reservoir to Dry Creek (RM 70-RM 57)	Iron (total); BioCriteria; Total Dissolved gas; Phosphorus Elemental	Total Dissolved gas: 110% of Saturation, presence of bubble gas disease in fish
Dry Creek to Lone Pine Road Bridge (RM 57-RM 32)	Temperature- Year Round; BioCriteria; Flow Modification; Phosphorus Elemental; Total Dissolved gas;	Temperature: 7-DADM not exceeding 18°C (64.4°F); pH: within a range of 6.5-8.5 standard units
Lone Pine Road Bridge to Opal Springs (RM 32-RM 6.7)	Temperature- Year Round; pH; BioCriteria; Flow Modification; Phosphorus Elemental; OWQI (Poor)	Temperature: 7-DADM not exceeding 18°C (64.4°F); pH: within a range of 6.5-8.5 standard units

[3]For more information about the Clean Water Act Section *303(d) list* see for e.g., Link

Table 2. Segment, listed parameters, parameter criteria (2018/2020 ODEQ).

Methods

In 2020, one multi-parameter data sonde (DS) YSI 6600v2 model was programed with the YSI EXO Handheld Display (Figure 3) to record in-stream data on a 60-minute collection interval that included: temperature, pH, dissolved oxygen, turbidity, and chlorophyll-*a*. The DS was successfully deployed at site 5 (Smith Rock State Park) from May 15 through June 23, 2020 (Table 1). Monitoring was limited to 40 days and ended in June due to State of Oregon COVID-19 mandates and accessibility restrictions.

Figure 3. YSI EXO Handheld Display (left) and YSI 6600v2 4- port data sonde (middle, right).

The DS was placed at a depth of 2-3 feet, in a non-turbulent segment of laminar flow flatwater. A metal cable was used to secure the data logger to the bank.

Temperature was verified for accuracy with a NIST traceable thermometer prior to and after field deployment (ODEQ 2009) and quality control checks were conducted periodically according to ODEQ protocols (ODEQ 2009). Field audits were conducted prior to field deployment and once a month throughout the monitoring season. A quality control check was conducted post-deployment by checking the DS against factory calibration standards to assess sensor drift.

DRA staff reviewed the data and used quality control measures to determine the overall viability and quality of the data. Hourly water quality parameters were graphed for the site and applicable state water quality standards were added to the graphs. Graphs were compared to data collected by the DRA in 2019.

Results

Temperature 2020:

Figure 4 shows the hourly water temperature data at Smith Rock State Park from May 15 through June 23, 2020, with the state maximum water temperature standard of 18°C (64.4°F) shown in red. The daily temperature is shown over 24-hour daily periods, and shows the daily minimum (just before sunrise) and daily maximum (typically around 3pm). Figure 5 shows the daily water temperatures obtained from Smith Rock State Park in both 2019 and 2020.

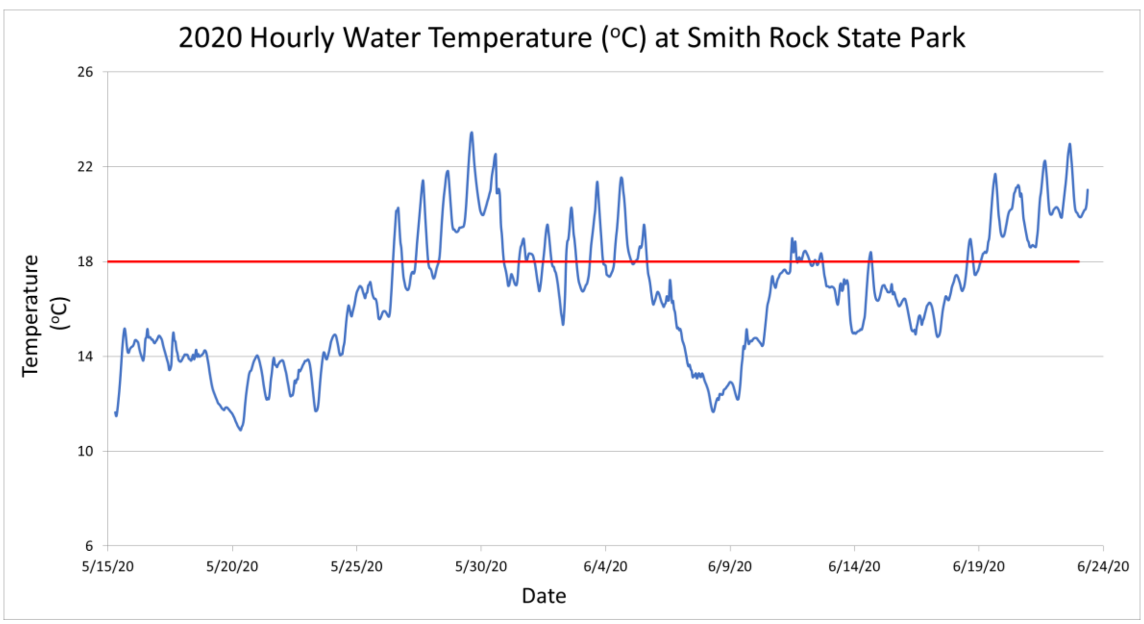

Figure 4. 2020 Crooked River hourly water temperature at Smith Rock State Park (RM 27). The state maximum temperature standard of 18°C (64.4°F) is shown in red.

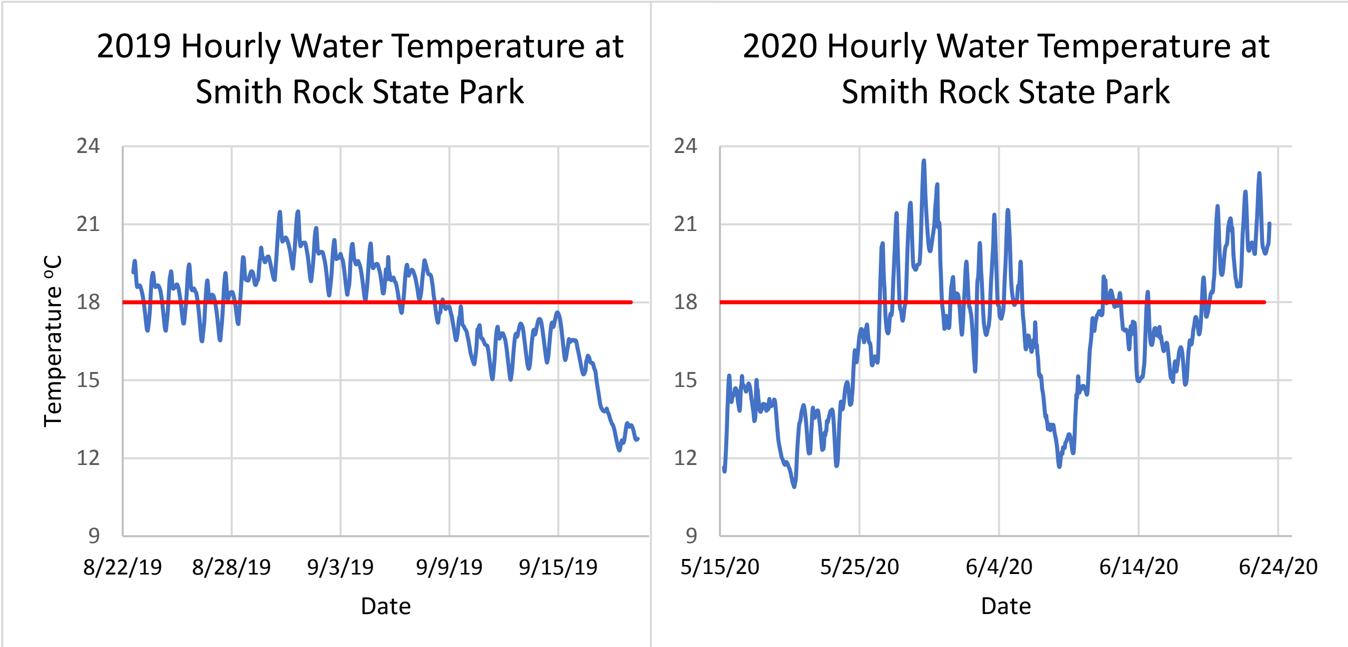

Figure 5. 2019 and 2020 Crooked River hourly water temperature at Smith Rock State Park (RM 27) with the state maximum temperature standard of 18°C (64.4°F) shown in red. *Note that the sampling dates between years are not the same

In 2020 the maximum diel range at RM 27 at Smith Rock State Park was 4.94°C (8.89°F) and occurred on 6/2/20. The minimum diel range at this site was 0.46°C (0.82°F) and occurred on 5/18, 2020. The average diel range was 2.71°C (4.88°F). The maximum recorded temperature was 23.45 °C (74.21°F) on May 29 at 1501 hours. The minimum recorded temperature was 10.89°C (51.60°F) on May 20 at 0801 hours.

7-Day Average Daily Maximum Temperature:

Oregon's stream temperature standard is based on a 7-day moving average of the daily maximum water temperatures (7-DADM). The standard applied in the Crooked River Basin is 18°C (64.4°F) based on salmon and trout rearing and migration (see Appendix for maps and criteria). The 7-DADM was calculated for the five monitoring sites in 2019 and graphed in Figure 6, where it exceeded basin standards from late July through early September. Although monitoring started later in the Crooked River at Smith Rock State Park, it had the highest recorded 7-DADMs compared to other sites in 2019. By mid-September, the 7-DADM returned to state standards for all monitoring sites.

In 2020, the 7-DADM at Smith Rock State Park fluctuated above and below the state standard from May 15 to June 23 (Figure 7). However, the 7-DADM was exceeded for significant periods and likely continued after monitoring ended on June 23, 2020.

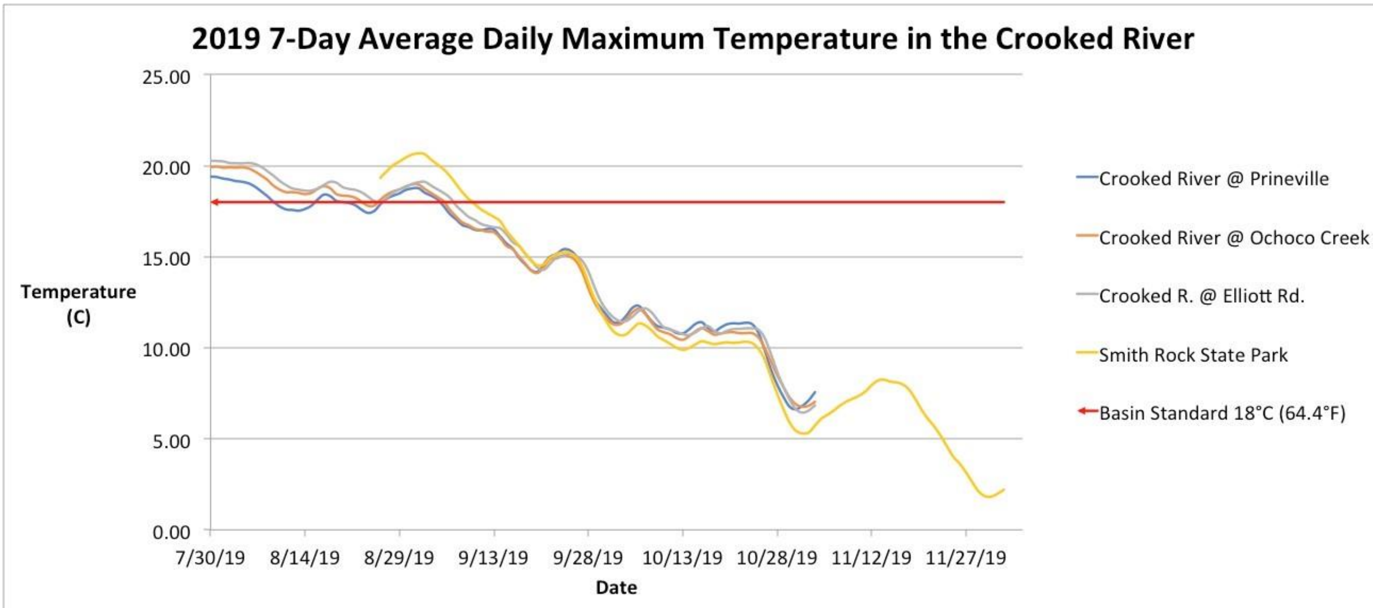

Figure 6. 2019 Crooked River 7-Day Average Daily Maximum water temperature at the monitoring sites. The state maximum water temperature standard of 18°C (64.4°F) is shown with a red line.

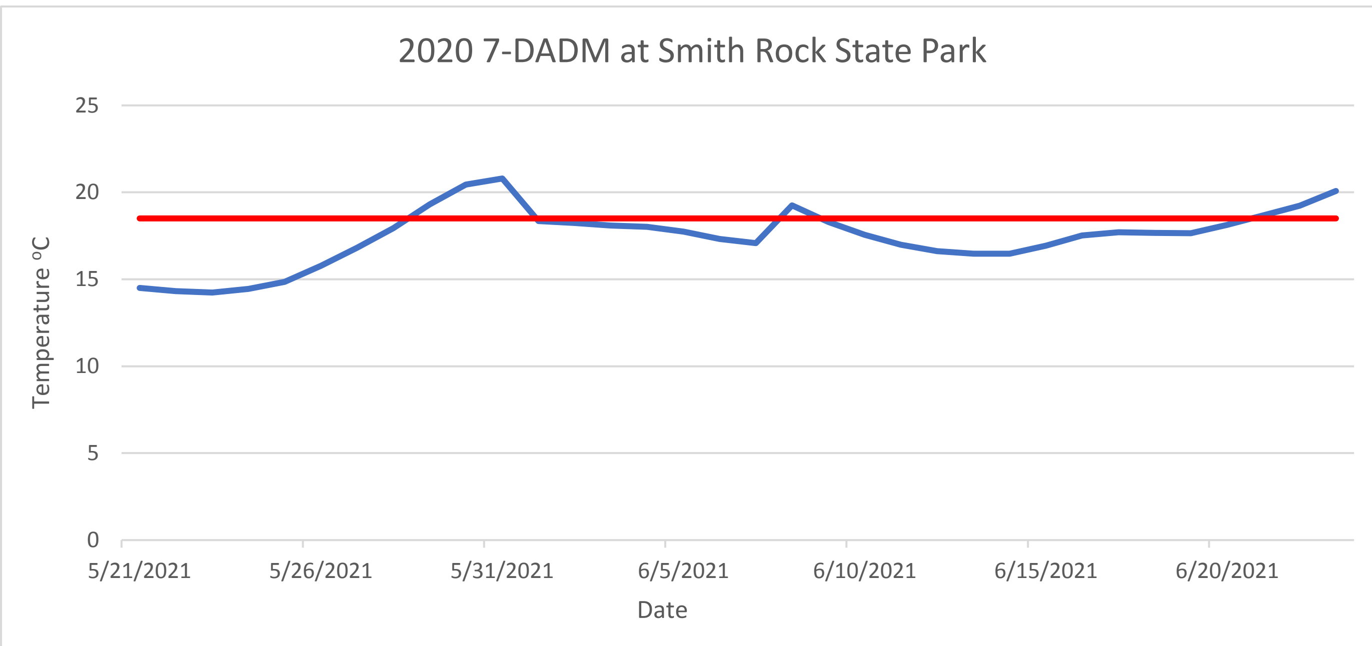

Figure 7. 2020 7-DADM at Smith Rock State Park (RM 27). The state maximum water temperature standard of 18°C (64.4°F) is shown with a red line.

pH:

Figure 8 shows the hourly pH measurements recorded from May 15-June 23, 2020 at Smith Rock State Park (Site 5, RM 27). As with temperature, the amplitude of the line shows the daily swing in pH (diel range), and the red line indicates the Oregon limit standard (8.5 standard units).

Oregon's water quality standards for pH in the Deschutes Basin including the Crooked River require pH levels to be in a range between 6.5-8.5 standard units and are applied to the lower Crooked River (OAR § 340-041-0135). Like other water quality standards, the pH standard was set to protect aquatic life. While pH just above 8.5 is not lethal to aquatic life, such levels do not provide adequate protection (Robertson-Byron 2004).

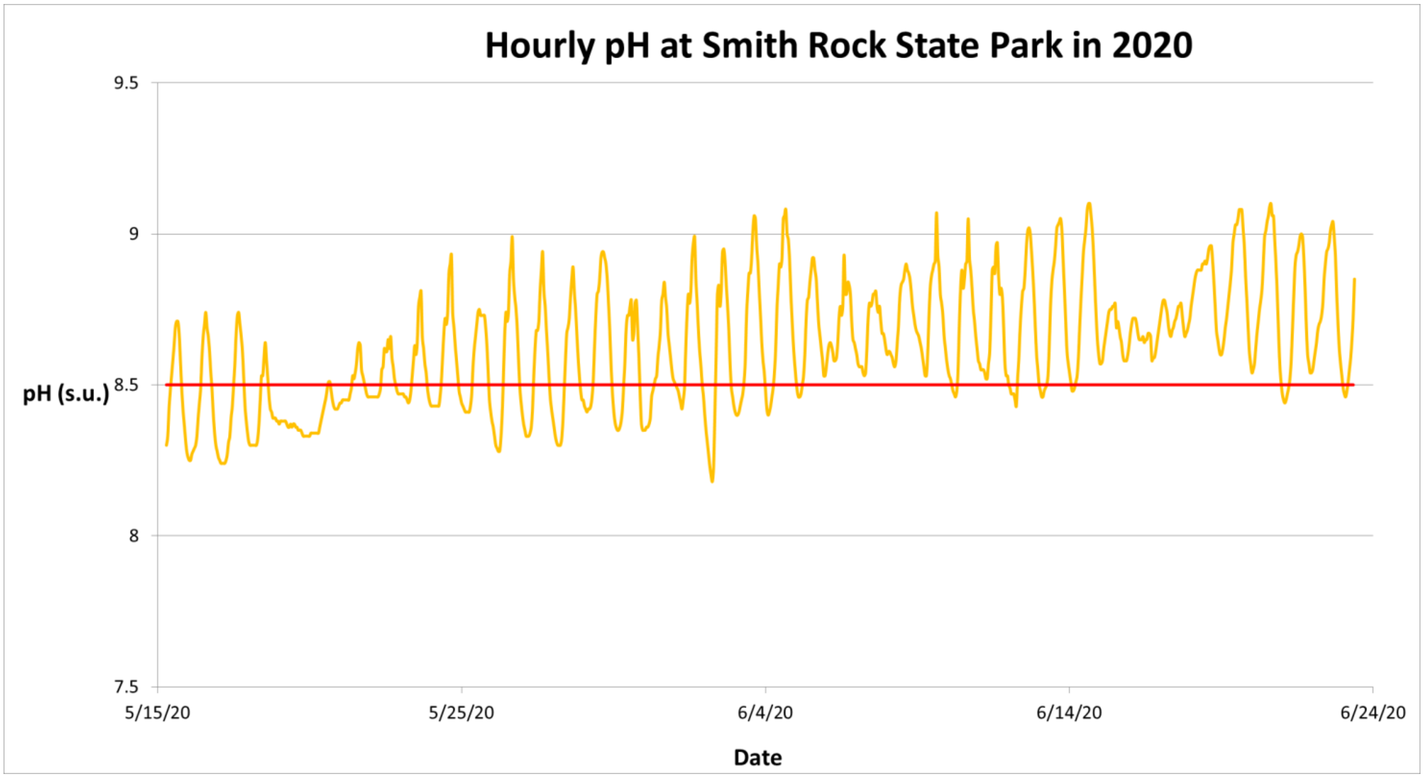

Figure 8. 2020 Crooked River hourly pH at Smith Rock State Park (RM 27). The red line shows the upper pH limit for the Deschutes Basin (8.5 standard units).

Daily peak pH recordings were consistently above the 8.5 standard during the sampling period (figure 8). The maximum recorded pH was 9.10 on two occurrences June 14 & 20, 2020 between 1501 and 1701 hours. The minimum recorded pH was 8.18 on June 2, 2020 at 0601 hours. The maximum diel range was 0.77 standard units on June 2, 2020. The minimum diel range was 0.05 standard units on May 19, 2020. pH maximums exceeded the basin standard during the entire monitoring period with the exception of May 19-20, 2020. Thirty-eight of the 40 of days monitored were above the basin standard of 8.5 standard units and exhibited pH in the highly basic range (8.5-9.0). Exceedances of the pH limit likely continued well after monitoring ended on June 23rd.

Dissolved Oxygen:

The state water quality standard for dissolved oxygen (DO) varies depending on fish and aquatic life use designations (Appendix B). Appendix C shows the DO standards applicable in the lower Crooked River. Although the Crooked River at Smith Rocks is not currently designated as salmon or trout spawning habitat, it is listed for salmonid and trout rearing and migration (DEQ OAR 340-041-130, figures 130A and 130B). The applicable DO standard from OAR 340-041-0016 for the Crooked River at Smith Rock State Park is 8mg/L.

Figure 9 shows dissolved oxygen concentrations recorded at Smith Rock State Park. Throughout our study period, dissolved oxygen fluctuated greatly on a diel period. The maximum recorded DO was 13.31 mg/L in the afternoon of June 14, 2020. The minimum recorded DO was 6.28 on June 2, 2020. The maximum diel range was 5.89 mg/L units on May 29, 2020. The minimum diel range was 0.87 mg/L on May 19, 2020. DO minimums fell below the 8.0 mg/L basin standard during the night, when photosynthesis stopped and respiration began.

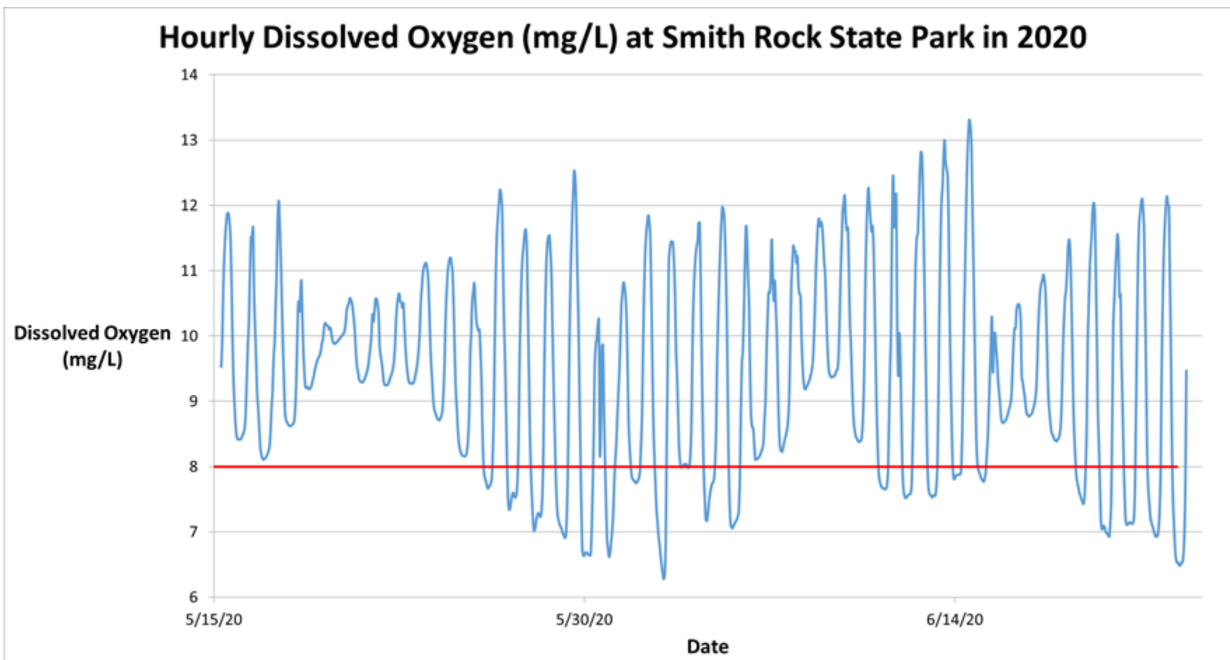

Figure 9. 2020 Crooked River hourly dissolved oxygen concentrations (mg/L) at Smith Rock State Park (RM 27). The red line shows the DO limit standard (8.0 mg/L) for trout spawning and fry emergence in the Deschutes Basin.

Discussion

Efforts by PGE and the Confederated Tribes of Warm Springs Reservation of Oregon (CTWS) began in 2009 to reestablish migration, rearing, and spawning of anadromous fish into the three rivers that flow into Lake Billy Chinook; the Crooked, Deschutes, and Metolius. However, these efforts will prove unsuccessful if measures are not taken to ensure that water quality standards set by ODEQ are upheld. Oregon's stream standards are set to protect beneficial uses and to preserve the health of aquatic ecosystems (Boyd & Sturdevant 1997).

Temperature:

The applicable temperature standard in the lower Crooked River for migration and rearing of trout and salmonids is the 7-DADM; a maximum of 18°C (64.4°F). In streams that support the spawning of anadromous fish (in this case salmon and steelhead), the 7-DADM is reduced to 13°C (55.4°F) during spawning periods for those species (Appendix A). A third standard (16°F) is applied to some stream segments designated as having core cold-water habitat (Appendix A). Based on our findings in 2019 and 2020, none of the stream segments we sampled in the lower Crooked River met any of these standards throughout our sampling period.

Aside from effects on fish (e.g. migration, spawning, and rearing) temperature is a well-known driver of many other biological processes (metabolism, plant growth) and physical properties (dissolved oxygen, un-ionized ammonia) of aquatic ecosystems. Fish and aquatic insects are cold-blooded; their body temperature and metabolism are directly affected by changes in water temperature. Temperatures exceeding 21.1°C (70°F) can lead to lethal and sub-lethal effects in salmonids (Boyd & Sturdevant 1997) and the DRA has recorded temperatures exceeding 21.1°C (70°F) at Smith Rock State Park (Site 5, RM 27) on multiple occurrences. In 2019, a survey maximum of 21.49°C (70.7°F) was recorded on August 31, 2019 at 1601 hours (Figure 5). On May 29, 2020 at 1501 hours a maximum of 23.45 °C (74.2°F) was recorded (Figure 4).

Water temperature exceeding the state maximum standard is not the only temperature problem known to affect aquatic life in the lower Crooked River. Conversely, extremely cold water combined with low in-stream flows are also a concern. The 2016 annual fish population survey conducted by ODFW in the Chimney Rock Wild and Scenic River segment (RM 70-RM 62), documented a significant decline in the redband trout population compared to the 2015 survey (ODFW 2016). ODFW examined the hydrological data and concluded that a prolonged period of reduced flows (approximately 35 cfs for 50 days in October 2015-January 2016), combined with unusually cold temperatures led to a significant reduction in habitat for fish due to the formation of anchor ice; ice that originates from the stream bottom. As a result, fish mortality occurred (ODFW 2016). Such low flows are characteristic of this stream segment during the winter when irrigation managers aim to fill Prineville Reservoir by reducing water releases from Bowman Dam. The reduction of habitat for fish due to low winter flows and high spring discharges due to flow management for irrigation are major contributors affecting fish populations in the lower Crooked River (ODFW 2016).

Stakeholders of Bowman Dam and the Bureau of Reclamation have arranged minimum "winter flows" to protect fish habitat in winter months. However, even these minimum flows have been reduced from 65 cfs to 50 cfs in recent years and may not provide adequate protection (USBR 2018). In drought years, retaining water for irrigation takes priority over stream flows in winter and can further reduce flows below the 50 cfs "winter flow" minimum. Inspections of Bowman Dam also occur in some years and result in extremely low flows between 10 to 25 cfs for up to 8-10 hours (USBR 2018).

It is worth noting that the temperature data presented in this study are from sites known to have degraded water quality. In addition, studies in the Crooked River have documented that the majority of native trout congregate in the area around Opal Springs (RM 6.9) and the area below Bowman Dam (RM 70) where water temperatures are cooler (ODFW 2016; USGS 2007b). The segment of river between Smith Rock State Park and the southern city limits of Prineville (RM 27-RM 50) is the primary migration corridor for anadromous salmonids (ODFW 2010). At the time of this writing, low flows and poor water quality characterize this river segment during both the juvenile and the adult migration periods. The success of anadromous fish reintroduction in the lower Crooked River sub-basin may depend on how effectively these problems are corrected.

pH:

Daily changes in pH are driven by photosynthetic activity of aquatic plants: pH rises during the day due to increased photosynthesis and drops at night when photosynthesis stops. As a result, maximum daily pH typically occurs mid-afternoon between 1400 and 1600 hours, while minimum pH levels occur early in the morning, generally just before sunrise. An increase in the range of pH between early morning and mid-day (shown by the amplitude of the line) indicates greater plant biomass and sunlight, which results in more photosynthesis. Because pH changes in response to algal density, large diel swings in pH are also a useful indicator of excess nutrients in contaminated water (EPA 2013), and can reflect trends in expected dissolved oxygen concentration.

Measurements of pH collected at Smith Rock State Park continue to show large diel swings and high daily pH values (above the 8.5 standard) from mid-May through June (Figure 9), and illustrate the effects of excess nutrients contributing to high aquatic biomass production. In addition, excessive algae, and periphyton were again observed at Smith Rock State Park and are a visual indicator of excessive nutrients (EPA 2013). Figure 10 shows an example of the dense growths of rooted aquatic vegetation and algae as a result of nutrient enrichment.

Figure 10. Crooked River below Bowman Dam (RM 65). Excessive aquatic plant and algae production is circled in red.

Prior water quality studies have shown that the Crooked River contributes a disproportionately higher concentration of nitrates to Lake Billy Chinook compared to the Deschutes and Metolius rivers (DRA 2016a; Eilers & Vache 2019). Oregon DEQ has listed the Crooked River as water quality limited for high elemental phosphorus levels (Table 2). In addition to in-stream pollution, nitrates and their sources contaminate groundwater in the basin (CRWC 2008; DRA 2019b). Reductions in agricultural pollutants, primarily nitrogen and phosphorous, must be addressed to reduce the excessive aquatic plant and algal growth in the Crooked River. This will lead to a reduction in excessive biomass production, and thus, decrease the large range of diel swings in pH.

Aside from occasional low pH values caused by algal respiration during the night, pH measurements consistently exceeded the basin standard (8.5 standard units) for the majority of the monitoring period. These diel swings are characteristic of the lower Crooked River sub-basin (CRWC 2008). Reducing agricultural pollutants is recommended to minimize the effects of eutrophication from decomposing algae in Lake Billy Chinook (Eilers & Vache 2019). Adhering to water quality standards in the Crooked River, particularly with respect to nitrogen pollution, have the potential to reduce nutrient load and periphyton biomass in the lower Deschutes River below Lake Billy Chinook (Eilers & Vache 2019).

Dissolved Oxygen:

Dissolved oxygen (DO) is a result of several characteristics in a body of water such as plant and algal growth, streamflow, turbulence, and temperature. DO in the lower Crooked River at Smith Rock State Park is directly influenced by aquatic plants, algae, and temperature. Like pH, DO measurements obtained in this study followed a large diel-swing pattern: photosynthesis by aquatic plants and algae temporarily increase dissolved oxygen concentrations during daylight hours, while DO concentrations decrease through the night when plants consume oxygen during respiration. These large diel-fluctuations in DO are shown in Figure 9.

In addition to large diel swings, decomposing plant material can create hypoxic (extremely low DO) conditions when bacteria that decompose plants and algae consume dissolved oxygen. Excessive plant and algae growth caused by agricultural runoff into the Crooked River (Figure 10) result in a boom-and-bust cycle that negatively impacts critical habitat and migration corridors, as well as water quality in Lake Billy Chinook and lower Deschutes River.

Warm water also reduces a stream's ability to hold dissolved oxygen and encourages plant and algae growth. Low-flowing, stagnant surface water reduces atmospheric mixing and absorption of atmospheric oxygen into the river, further contributing to low DO.

As stated in the introduction, the Crooked River above Smith Rock State Park is a well-known trout fishery. However, it is unlikely that the spawning and rearing of resident trout occurs in or around Smith Rock State Park due to the present water quality and quantity conditions. Improving the low flowrates caused by irrigation and the management of water release at Bowman Dam, reducing nutrient loads from municipal and agricultural landscapes in the Crooked River Basin, and decreasing water temperatures would all enhance dissolved oxygen concentrations for fish and other aquatic life in the Crooked River. Doing so may enable resident trout and anadromous fish to utilize currently uninhabitable key habitat for successful spawning and reproduction.

Summary

Results from monitoring efforts in 2019 and 2020 clearly indicate that there are a multitude of violations to water quality in the lower Crooked River at Smith Rock State Park. Exceedances of the state standards for temperature, pH, and dissolved oxygen set for salmon and trout were observed and recorded throughout most of the sampling period.

As stated in the 2019 Crooked River Water Quality report, Oregon sets water quality standards to protect aquatic life. While these water quality standards are set independently for each parameter (such as pH, temperature, and dissolved oxygen), these parameters are not independent of one another and can interact with each other to compound, exacerbate, and create new harmful effects on aquatic life. For example, salmonids experience an increase in metabolic rate (and subsequently, oxygen consumption) in response to rising water temperatures. As water temperature increases, its physical ability to hold dissolved oxygen decreases. Increased water temperatures lead to additional problems such as increased parasitic loads and susceptibility to disease, which are not regulated by state standards (Connolly & McLean 2017; Schaaf et al. 2017).

The pH of water can magnify the impact of other dissolved constituents. For example, the toxicity of un-ionized ammonia (NH3) increases as pH increases (Shiwanand & Tripathi 2013). Therefore, when pH standards are exceeded, the potential for initiating negative impacts from other constituents also increases. When multiple standards are exceeded over long periods of time as we have seen in this study (i.e. days and weeks), the negative effects on aquatic life intensify substantially.

Irrigation withdrawals (e.g., flow regime) severely impact the quantity and quality of water in the lower Crooked River. Excessive nutrients and low-flow conditions directly contribute to excessive aquatic plant growth and resulting eutrophication, and mortality induced by freezing (as seen in the winter of 2015/2016) or lack of water due to the sudden lowering of in-stream flows. Other potentially serious impacts to water quality by agriculture include: high water temperatures due to reduced in-stream flow; riparian zone disturbance; pesticide/insecticide use; turbidity and sedimentation; and bacterial loads such as (*E. coli*), among others (ODFW 1996).

The DRA is committed to improving water quality in the lower Deschutes River. Addressing water quality in the Crooked River Basin by adhering to state standards is a starting point, and will take years of collaboration and effort among agricultural landowners and municipal stakeholders in the region. Reducing pollutants in the

Crooked River, specifically agricultural runoff and municipal wastewater, has the potential to decrease eutrophication in Lake Billy Chinook. As presently managed, the quality of water entering and eventually released from Lake Billy Chinook is the number one contributor to extreme changes in nuisance periphyton growth, and the resulting ecosystem shift documented in the lower Deschutes River.

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Appendix A - Oregon Administrative Rules for Temperature & Maps

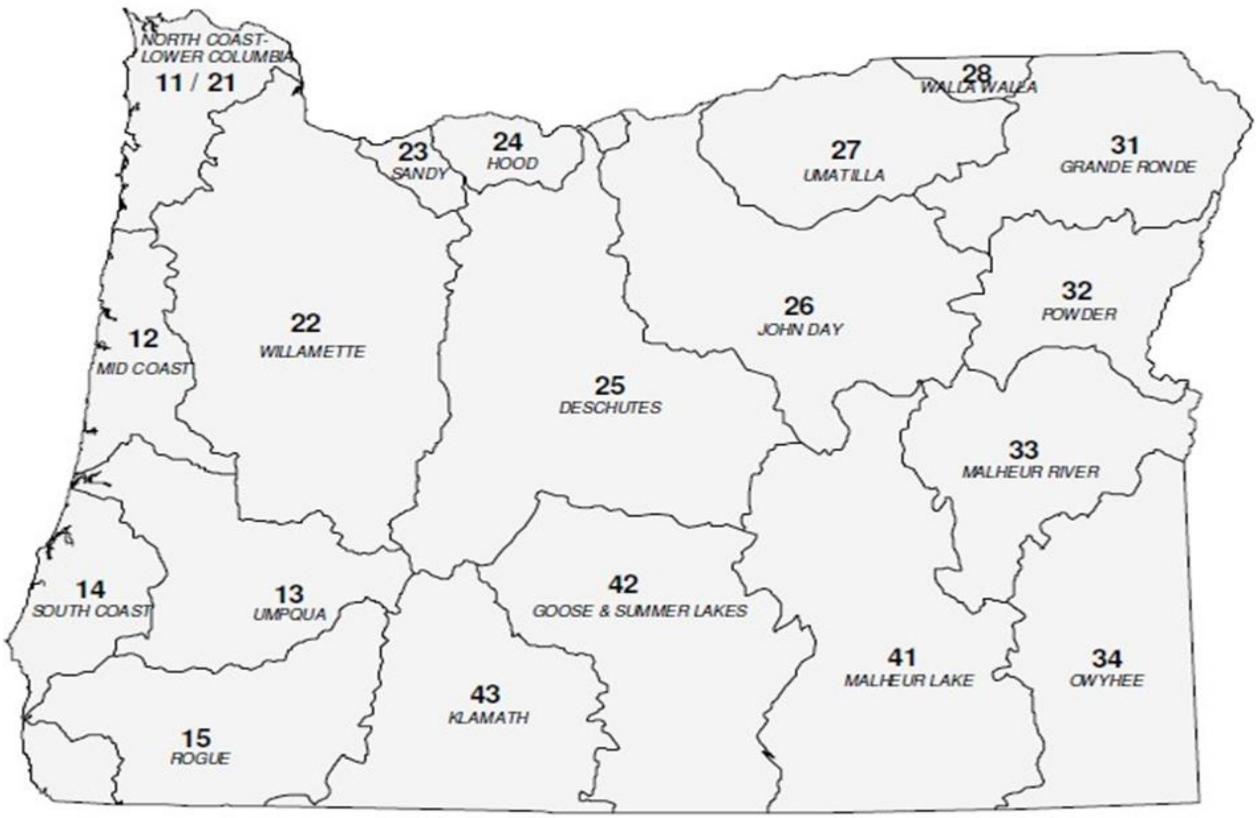
The seven-day-average maximum temperature of a stream identified as having salmon and steelhead spawning use on subbasin maps and tables set out in OAR 340-041-0101 to 340-041-0340: Tables 101B, and 121B, and Figures 130B, 151B, 160B, 170B, 220B, 230B, 271B, 286B, 300B, 310B, 320B, and 340B, may not 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 subbasin 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 subbasin 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)

Adapted from: Oregon Secretary of State

Appendix B - OAR 340-041-0130 - Maps, Tables and Figures:



Oregon Basin Index Map

Adapted from: [Oregon Secretary of State]

Basin Name	Basin #	OAR #
DESCHUTES	25	340-041-0130
GOOSE & SUMMER LKS	42	340-041-0140
GRANDE RONDE	31	340-041-0151
HOOD	24	340-041-0160
JOHN DAY	26	340-041-0170
KLAMATH	43	340-041-0180
MALHEUR LAKE	41	340-041-0190
MALHEUR RIVER	33	340-041-0201
MD COAST	12	340-041-0220
NORTH COAST-LWR COL	11-21	340-041-0230
OWYHEE	34	340-041-0250
POWDER	32	340-041-0260
ROGUE	15	340-041-0271
SANDY	23	340-041-0286
SOUTH COAST	14	340-041-0300
UMATILLA	27	340-041-0310
UMPQUA	13	340-041-0320
WALLA WALLA	28	340-041-0330
WILLAMETTE	22	340-041-0340

Appendix B - OAR 340-041-0130: Table 130A

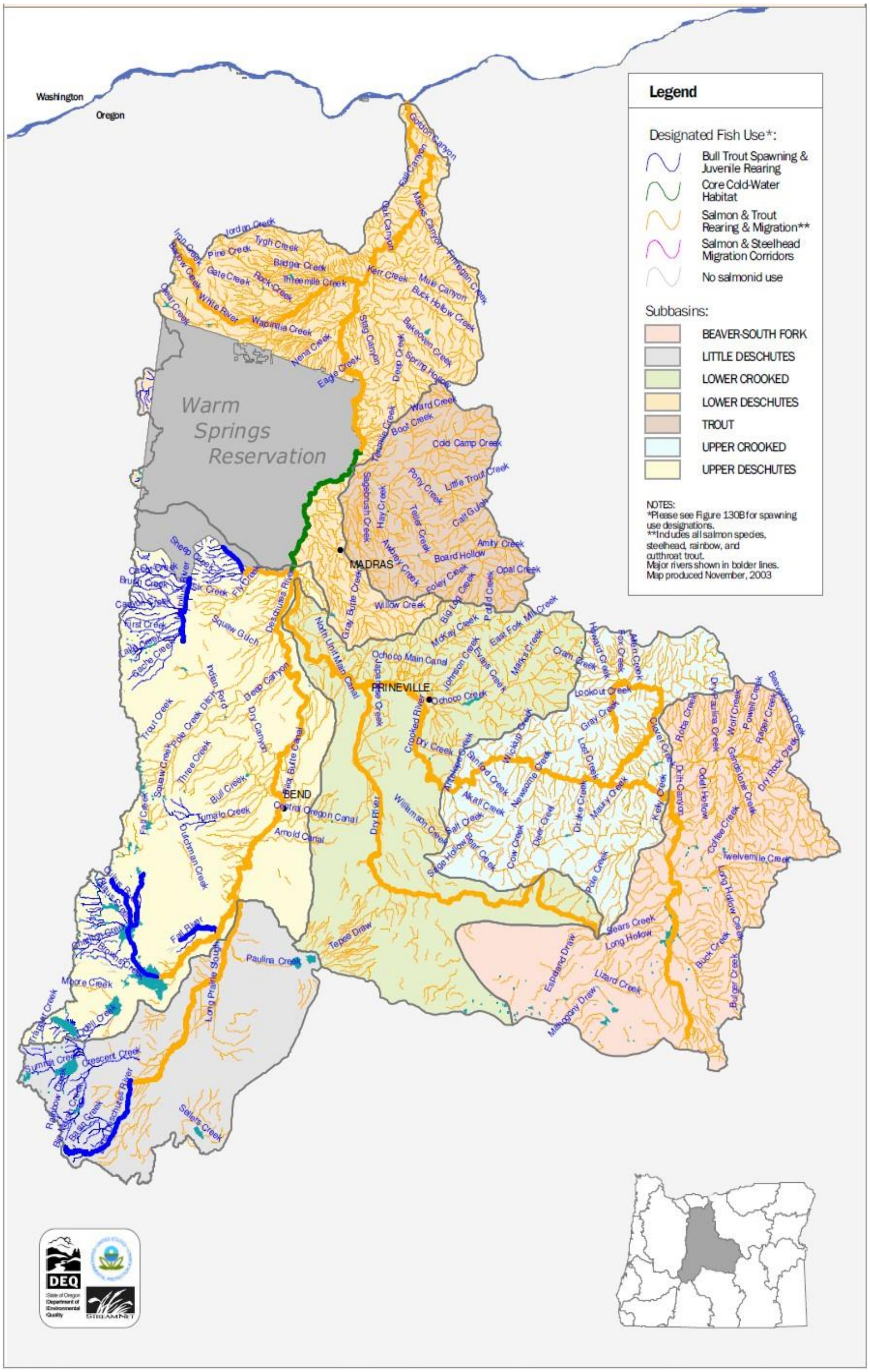
OAR 340-041-0130 Table 130A Designated Beneficial Uses Deschutes Basin				
Beneficial Uses	**Deschutes River Main Stem from Mouth to Pelton Regulating Dam**	**Deschutes River Main Stem from Pelton Regulating Dam to Bend Diversion Dam and for the Crooked River Main Stem**	**Deschutes River Main Stem above Bend Diversion Dam & for the Metolious River Main Stem**	**All Other Basin Stems**
Public Domestic Water Supply[1]	X	X	X	X
Private Domestic Water Supply[1]	X	X	X	X
Industrial Water Supply	X	X	X	X
Irrigation	X	X	X	X
Livestock Watering	X	X	X	X
Fish & Aquatic Life[2]	X	X	X	X
Wildlife & Hunting	X	X	X	X
Fishing	X	X	X	X
Boating	X	X	X	X
Water Contact Recreation	X	X	X	X
Aesthetic Quality	X	X	X	X
Hydro Power		X		
Commercial Navigation & Transportation				

[1] With adequate pretreatment (filtration and disinfection) and natural quality that meets drinking water standards.

[2] See also Figures 130A and 130B for fish use designations for this river.

Adapted from: [Oregon Secretary of State]

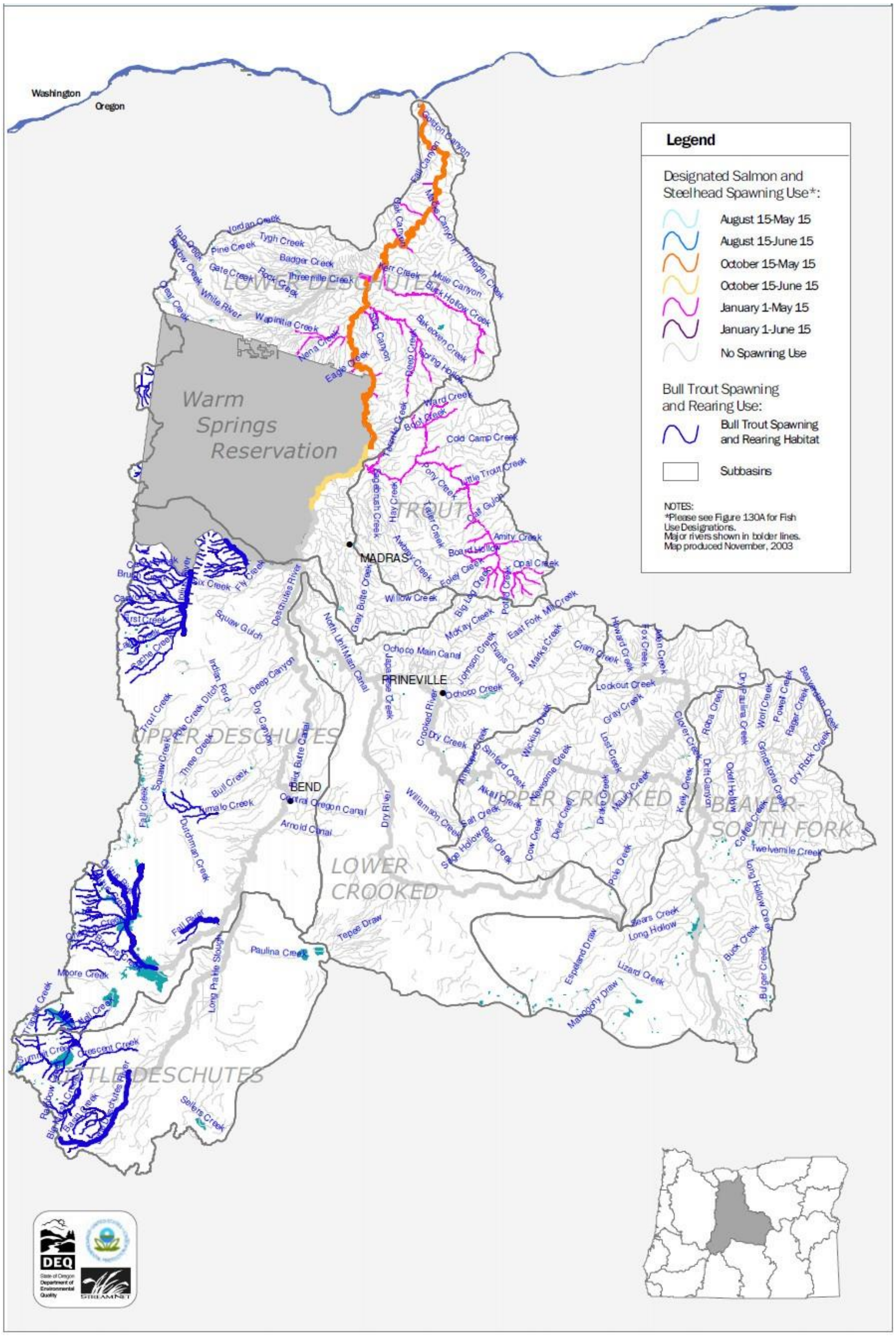
Appendix B - OAR 340-041-0130: Figure 130A



Fish Use Designations: Deschutes Basin, Oregon

Adapted from: [Oregon Secretary of State]

Appendix B - OAR 340-041-0130 Figure 130B



Salmon and Steelhead Spawning Use Designations: Deschutes Basin, Oregon
Adapted from: [Oregon Secretary of State]

Appendix C - Oregon Administrative Rules for Dissolved Oxygen

Dissolved oxygen (DO): No wastes may be discharged and no activities may be conducted that either alone or in combination with other wastes or activities will cause violation of the following standards: The changes adopted by the Commission on January 11, 1996, become effective July 1, 1996. Until that time, the requirements of this rule that were in effect on January 10, 1996, apply:

(1) For water bodies identified as active spawning areas in the places and times indicated on the following Tables and Figures set out in OAR 340-041-0101 to 340-041-0340: Tables 101B, 121B, and 190B, and Figures 130B, 151B, 160B, 170B, 180A, 201A, 220B, 230B, 260A, 271B, 286B, 300B, 310B, 320B, and 340B, (as well as any active spawning area used by resident trout species), 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:

(a) The dissolved oxygen may not be less than 11.0 mg/l. However, if the minimum intergravel dissolved oxygen, measured as a spatial median, is 8.0 mg/l or greater, then the DO criterion is 9.0 mg/l;

(b) Where conditions of barometric pressure, altitude, and temperature preclude attainment of the 11.0 mg/l or 9.0 mg/l criteria, dissolved oxygen levels must not be less than 95 percent of saturation;

(c) The spatial median intergravel dissolved oxygen concentration must not fall below 8.0 mg/l.

(2) For water bodies identified by the Department as providing cold-water aquatic life, the dissolved oxygen may not be less than 8.0 mg/l as an absolute minimum. Where conditions of barometric pressure, altitude, and temperature preclude attainment of the 8.0 mg/l, dissolved oxygen may not be less than 90 percent of saturation. At the discretion of the Department, when the Department determines that adequate information exists, the dissolved oxygen may not fall below 8.0 mg/l as a 30-day mean minimum, 6.5 mg/l as a seven-day minimum mean, and may not fall below 6.0 mg/l as an absolute minimum (Table 21);

(3) For water bodies identified by the Department as providing cool-water aquatic life, the dissolved oxygen may not be less than 6.5 mg/l as an absolute minimum. At the discretion of the Department, when the Department determines that adequate information exists, the dissolved oxygen may not fall below 6.5 mg/l as a 30-day mean minimum, 5.0 mg/l as a seven-day minimum mean, and may not fall below 4.0 mg/l as an absolute minimum (Table 21);

(4) For water bodies identified by the Department as providing warm-water aquatic life, the dissolved oxygen may not be less than 5.5 mg/l as an absolute minimum. At the discretion of the Department, when the Department determines that adequate information exists, the dissolved oxygen may not fall below 5.5 mg/l as a 30-day mean minimum, and may not fall below 4.0 mg/l as an absolute minimum (Table 21)

Adapted from: Oregon Secretary of State

Appendix D - Oregon Administrative Rules for Dissolved Oxygen: Table 21

OAR 340-041-0016 - TABLE 21

DISSOLVED OXYGEN & INTERGRAVEL DISSOLVED OXYGEN CRITERIA

(Applicable to All Basins)

Class	Concentration and Period[1] (All Units are mg/L)				Use/Level of Protection
	30-D	7- D	7- Mi	Min	
Salmonid Spawning		11.0[2,3]		9.0[3] 8.0[4]	Principal use of salmonid spawning and incubation of embryos until emergence from the gravels. Low risk of impairment to cold-water aquatic life, other native fish and invertebrates.
Cold Water	8.0[5]		6.5	6.0	Principally cold-water aquatic life. Salmon, trout, cold-water invertebrates, and other native cold-water species exist throughout all or most of the year. Juvenile anadromous salmonids may rear throughout the year. No measurable risk level for these communities.
Cool Water	6.5		5.0	4.0	Mixed native cool-water aquatic life, such as sculpins, smelt, and lampreys. Waterbodies includes estuaries. Salmonids and other cold-water biota may be present during part or all of the year but do not form a dominant component of the community structure. No measurable risk to cool-water species, slight risk to cold-water species present.
Warm Water	5.5			4.0	Waterbodies whose aquatic life beneficial uses are characterized by introduced, or native, warm-water species.
No Risk	No Change from Background				The only DO criterion that provides no additional risks is "no change from background". Waterbodies accorded this level of protection include marine waters and waters in Wilderness areas.

Note:
Shaded values present the absolute minimum criteria, unless the Department believes adequate data exists to apply the multiple criteria and associated periods.

[1] 30-D = 30-day mean minimum as defined in OAR 340-41-006.
7-D = 7-day mean minimum as defined in OAR 340-41-006.
7-Mi = 7-day minimum mean as defined in OAR 340-41-006.
Min = Absolute minimums for surface samples when applying the averaging period, spatial median of IGDO.

[2] When Intergravel DO levels are 8.0 mg/L or greater, DO levels may be as low as 9.0 mg/L, without triggering a violation.

[3] If conditions of barometric pressure, altitude and temperature preclude achievement of the footnoted criteria, then 95 percent saturation applies.

[4] Intergravel DO criterion, spatial median minimum.

[5] If conditions of barometric pressure, altitude, and temperature preclude achievement of 8.0 mg/L, then 90 percent saturation applies.

Adapted from: [Oregon Secretary of State]

APPENDIX E – Audit Data

2020 Crooked River Audit Data Available by request. Please contact Deschutes River Alliance at: https://deschutesriveralliance.org/contact-information