2019 CROOKED RIVER WATER QUALITY REPORT

DESCHUTES RIVER ALLIANCE

Deschutes River Alliance
April 2020

KEY FINDINGS:

- Water temperature and pH measurements exceeded Oregon's water quality standards in the lower Crooked River (other parameters were not assessed during the study).
- Modified flow regimes in the lower Crooked River impair the water quality in the reach between Bowman Dam (River Mile 70) and Smith Rock State Park (River Mile 27). Water releases as presently managed from Bowman Dam are one factor. An additional factor is irrigation withdrawals directly from the river.
- Large diel swings in pH were an indicator of excess nutrients (due largely to agricultural runoff) in contaminated water leading to high amounts of nuisance algae and aquatic plant biomass.

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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.

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LIST OF ABBREVIATIONS

CFS - Cubic Feet per Second

DEQ - Department of Environmental Quality

DRA - Deschutes River Alliance

OAR - Oregon Administrative Rules

ODFW - Oregon Department of Fish & Wildlife

PGE – Portland General Electric

Project - Pelton Round-Butte Hydroelectric Project

RM - River Mile

SWW Tower - Selective Water Withdrawal Tower

TMDL - Total Maximum Daily Load

7-DADM - 7-Day Average Daily Maximum

INTRODUCTION

The Crooked River is a desert stream that flows through central Oregon and is a major tributary of the lower Deschutes River. Bowman Dam and the Crooked River Reservoir created by it are located southeast of the City of Prineville and divide the Crooked River Basin into upper and lower sub-basins (Figure 1). The lower Crooked River begins at the base of Bowman Dam and flows, generally, 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 focus for reintroduction efforts of anadromous salmonids. A number of impairments in both the quantity and quality of water in the Crooked River present problems for resident fish and reintroduced salmonids (ODFW 2016 summary report link).

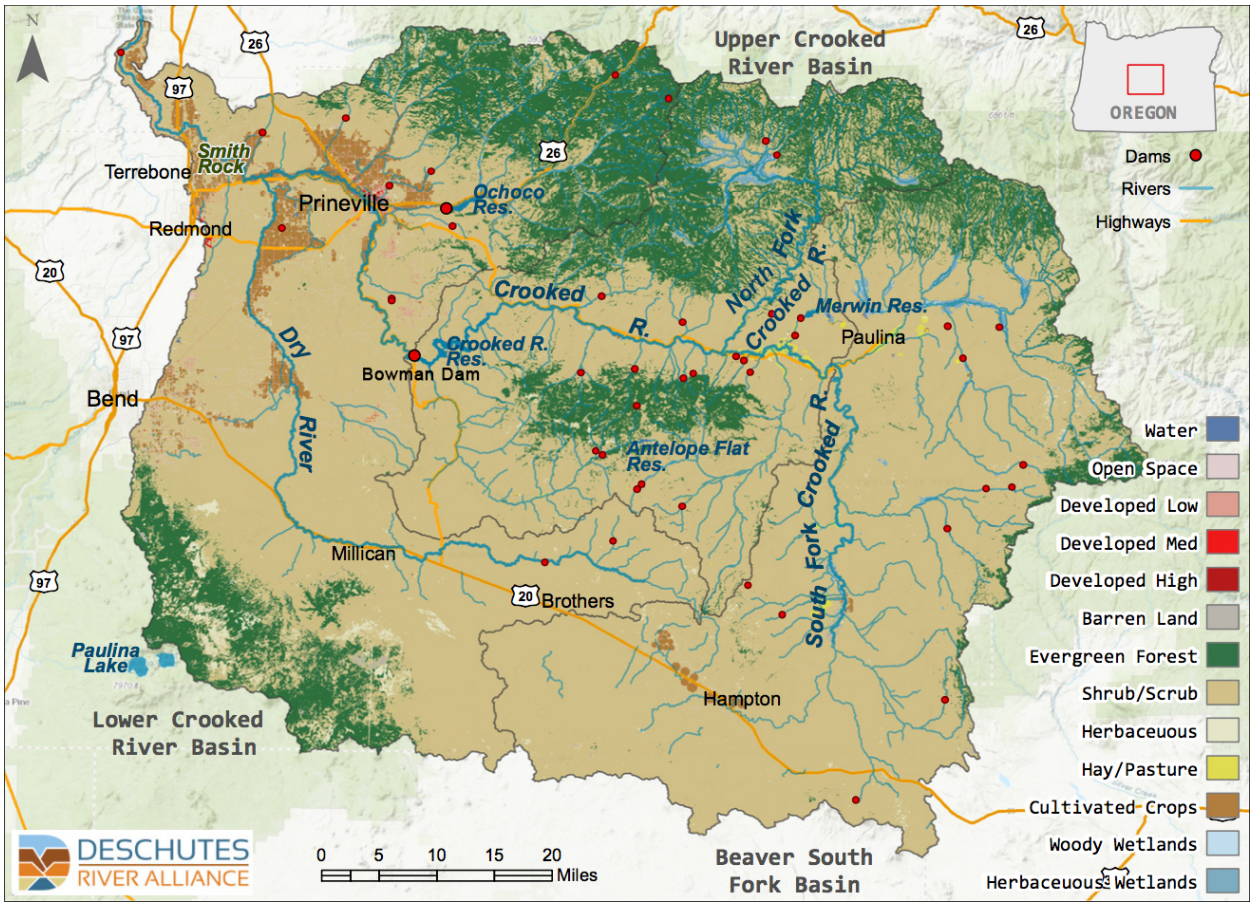

Figure 1. Land cover classification map of the Crooked River Basin in Oregon (DRA 2019b).

The Pelton-Round Butte Hydroelectric Project (Project), when construction was completed in 1964, blocked anadromous fish populations from reaching spawning and rearing habitat in the Crooked, Metolius, and Upper Deschutes rivers and their

tributaries. Reintroduction efforts for anadromous salmonids upstream of the Project began in 2007 and have relied on the Selective Water Withdrawal (SWW) Tower (hereinafter Tower) intended to create surface current in Lake Billy Chinook. The surface current is meant to guide downstream migrating juveniles to the collection facility associated with the Tower for re-capture and trucking around the Project.

One consequence of Tower operations to date is that the surface water released from Lake Billy Chinook contains a high proportion of Crooked River water (Eilers & Vache 2019). This is significant in that the Crooked River, when compared to the other two tributaries of Lake Billy Chinook (the Metolius and Deschutes rivers), has significantly degraded water quality. The degraded water quality of the Crooked River was evident during Deschutes River Alliance's (DRA) 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 in the Crooked River arm of Lake Billy Chinook (9.9 standard units) and 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 link). 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, *Water Quality Study* link).

Past water quality monitoring in the study area is limited to a few studies. Oregon Department of Environmental Quality (DEQ) conducted extensive water quality monitoring throughout the basin in 2005/2006. In addition, an airborne thermal imaging study was done 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 flows on fish populations (ODFW 2016). The results of these studies will be further explained in this report's Discussion section.

In 2019, the DRA began monitoring water quality in the Crooked River Basin. The purpose of that monitoring work was to investigate the level of water quality impairment in the lower Crooked River and the degree of impact on the water quality of Lake Billy Chinook and the lower Deschutes River (DRA 2019a). Beginning in late July 2019, DRA initiated hourly temperature monitoring at four sites in the lower

Crooked River in the reach between Bowman Dam and the City of Prineville. Temperature and pH monitoring was also conducted at Smith Rock State Park beginning in late August.

STUDY SITES

The DRA water quality study focused on the lower Crooked River sub-basin from Bowman Dam (RM 70) to Smith Rock State Park (RM 27, Figure 2). The monitoring sites were selected based on sites used by the local watershed council and Oregon DEQ in prior studies.

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

Table 1 lists the 2019 DRA monitoring sites. The sites were located downstream from where water temperature was anticipated to change including: below Bowman Dam (RM 70), at the southern end of the Prineville city limit (RM 50), Ochoco Creek confluence (RM 44.8), McKay Creek confluence (RM 44.1), and Smith Rock State Park (RM 27). All sites were located on public property. Field staff used public roads to access the sites and they obtained approval from the local watershed council prior to conducting the 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 (Permit approved 8/20/2019-11/30/2020).

Site 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].

Water quality in the study area was reported as moderate to severe for aquatic life in a statewide assessment of nonpoint sources of water pollution (ODEQ 1988). 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, multiple efforts have been made by the City of Prineville to treat and dilute sewage water including the use of diluted sewage water to irrigate a city-owned golf course and the construction of a wetland complex to treat wastewater. Portions of the lower Crooked River were first added to Oregon's **Clean Water Act Section** *303*(*d*) *list*[2] 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 April 2020, no TMDL for the lower Crooked River has been completed. Table 2 shows the stream segments listed by the Oregon DEQ for impairment and their respective impaired parameters (ODEQ 2018/2020).

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

[2] For more information about the Clean Water Act Section *303*(*d*) *list* see for e.g., https://www.epa.gov/tmdl/overview-listing-impaired-waters-under-cwa-section-303d

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[3]	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)
Lone Pine Road Bridge to Opal Springs (RM 32-RM 6.7)	Temperature- Year Round; pH; BioCriteria; Flow Modification; Phosphorus Elemental	Temperature: 7-DADM not exceeding 18°C (64.4°F) pH: within a range of 6.5-8.5 standard units

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

Beginning from Bowman Dam downstream for approximately eight miles is the Chimney Rock segment of the federal Wild and Scenic River portion of the Crooked River (RM 70-62). The outstanding remarkable values include: scenic, recreational, and fishery resource values (oregonwildandscenic.com). In this segment, the Crooked River flows through a deep canyon characterized by shrub/scrub land cover (Figure 1). This segment supports a classic tailwater fishery for Redband Trout and Mountain Whitefish. Because cold water is released from the bottom of the reservoir, there are cooler water temperatures in this reach of the Crooked River compared to downstream sites. Water temperature is not listed as impaired in this segment; however, high volume discharge of water from Bowman Dam has caused high total dissolved gas levels downstream which lead to gas-bubble disease in fish (ODFW 2016).

Downstream from the Wild and Scenic River Chimney Rock segment, the

[3] Neither Oregon nor EPA has set a criterion for phosphate phosphorus. EPA has recognized the relationship between phosphates, as major nutrients, 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 data for phosphate phosphorus (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)

Crooked River enters a large unconfined valley where the City of Prineville is located. Cultivated crops account for the majority of land use in this valley (Figure 1). Irrigation diversions located near the southern city limits of Prineville reduce flows in this segment of river in the summer (approximately RM 55). In the summer, water temperatures are higher and flows are lower when compared to upstream reaches of the lower Crooked River. A number of large properties lie adjacent to the Crooked River near Prineville including a golf course, the Les Schwab Tire warehouse and distribution facility, the City of Prineville Wastewater Treatment Plant, and the Crooked River Wetlands Complex. Both the treatment plant and the wetlands are designed to process the wastewater generated by residents, agriculture, and industry in this area. Large server centers owned by Apple and Facebook are also nearby and require water for their cooling operations.

Approximately five miles east of Prineville is Ochoco Reservoir on Ochoco Creek. Stored water in the reservoir is used primarily for irrigation. However, it also provides cool summertime water temperatures downstream to Ochoco Creek since water is released from the bottom of the reservoir (CRWC 2008). Ochoco Creek flows for approximately 10 miles from the outlet of Ochoco Reservoir downstream to the City of Prineville and provides habitat to native Redband Trout. In addition, the creek has been stocked with steelhead and Chinook Salmon fry since 2007 and 2008, respectively, as part of a reintroduction program (Hill & Quesada 2010). The Ochoco Creek confluence with the Crooked River is at RM 44.8 of the Crooked River near the north city limits of Prineville.

One-half mile downstream from the Ochoco Creek confluence is the McKay Creek confluence with the Crooked River at RM 44.1. McKay Creek flows for approximately 37 miles from its headwaters in the Ochoco Mountains with the majority of stream flowing through Ochoco National Forest. The lower segment of McKay Creek flows through cultivated crop land (Figure 1). Current irrigation practices have caused low and intermittent flow during summer months in this lower reach (ODEQ 2011).

Proceeding downstream from the McKay Creek confluence to the Lone Pine Road Bridge at RM 32, the Crooked River flows through a confined valley. Large agricultural fields border the river in this reach. In addition, irrigation return flows enter the lower Crooked River via Dry River Canyon at RM 33.2 with water originating from the Upper Deschutes River (ODA 2018). Irrigation return flow may be a contributor to poor water quality in this reach. The 25-mile segment of the Crooked River from RM 57-32 is listed as water quality impaired for the parameters temperature, pH, biocriteria, flow modification, and elemental phosphorus (Table 2).

At RM 32 the Crooked River re-enters a deep canyon. In the segment between

RM 32-27 water quality becomes severely degraded. Irrigation withdrawals result in extremely low summertime flows in Smith Rock State Park at RM 27 (Deschutes Basin Habitat Conservation Plan section 11.8.3.4 link, USFWS 2019). Low summertime flows contribute to high water temperatures in the state park. From RM 32-6.7 the Crooked River is listed as water quality impaired for the parameters temperature, pH, biocriteria, flow modification, and elemental phosphorus (Table 2).

From RM 15-8, the Crooked River is designated as a federal Wild and Scenic River. The outstanding remarkable values include: scenic, recreation, geology, hydrology, wildlife, and botanical/ecological values (oregonwildandscenic.com). A number of groundwater springs provide significant flow inputs in the reach downstream from Smith Rock State Park and contribute to direct cooling 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 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).

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 to allow upstream and downstream migration of salmon and steelhead in 2019. 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 downstream before converging with the arms of the Deschutes and Metolius rivers.

METHODS

Four temperature data loggers (Onset® HOBO® Pendant model) were used to record hourly in-stream water temperature data and a multi-parameter data sonde (YSI 6600v2 model) was used to record hourly in-stream water quality data including water temperature, pH, dissolved oxygen, turbidity, and chlorophyll-*a* (Figure 3). The temperature data loggers were deployed at sites 1-4 in the Crooked River between Bowman Dam and the City of Prineville from July 26 through November 7, 2019 (Table 1). The data sonde was successfully deployed at site 5 (Smith Rock State Park) from August 22 through December 6, 2019 (Table 1).

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

Equipment was programmed for 60-minute data collection intervals. Metal cables were used to fix the data loggers to the bank. Data loggers were placed mid-stream at a depth of approximately 2-3 feet. All the study sites were located in flat-water, non-turbulent segments of river with laminar flow. Information collected at each monitoring site included site name, date/time, GPS coordinates, site photos, site description, logger serial number, and the appropriate audit information.

All temperature data loggers were verified for accuracy with a NIST traceable thermometer prior to and after field deployment (ODEQ 2009). Quality control checks for the multi-parameter sonde were also conducted (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 data sonde against factory calibration standards to assess the drift of sensors.

DRA staff reviewed the data and appropriate quality control measures to determine the data quality level. One temperature data logger (1. Crooked R. 300m downstream of Bowman Dam) had a battery failure during the first week of data collection and the limited data set from that logger is not included in this report. The dissolved oxygen data from the data sonde deployed at Smith Rock State Park did not meet the quality control objectives due to a malfunctioning sensor during field deployment and that dissolved oxygen data is not included in this report. Turbidity and chlorophyll-*a* data are not included in this report because of inaccurate results caused by biofouling. Hourly water quality parameters were graphed for each site. The 7-Day Average Daily Maximum (7-DADM) temperature was calculated for each site and

graphed. Applicable state water quality standards were added to the graphs.

RESULTS

Temperature:

Figures 4-6 show the hourly water temperature data recorded from July 26 through November 7, 2019 at sites 2-4. Figure 7 shows the hourly water temperature data at Smith Rock State Park from August 22 through December 6, 2019. Monitoring was delayed those 26 days at Smith Rock State Park due to a pending research application that was required for the work. Figure 4 shows the results from RM 50 of the Crooked River at the southern city limit of Prineville (upstream of the city). The amplitude of the line shows the range in temperatures over a 24-hour period. The difference between the daily minimum (generally occurs just before sunrise) and daily maximum (typically around 3pm) is called the diel range.

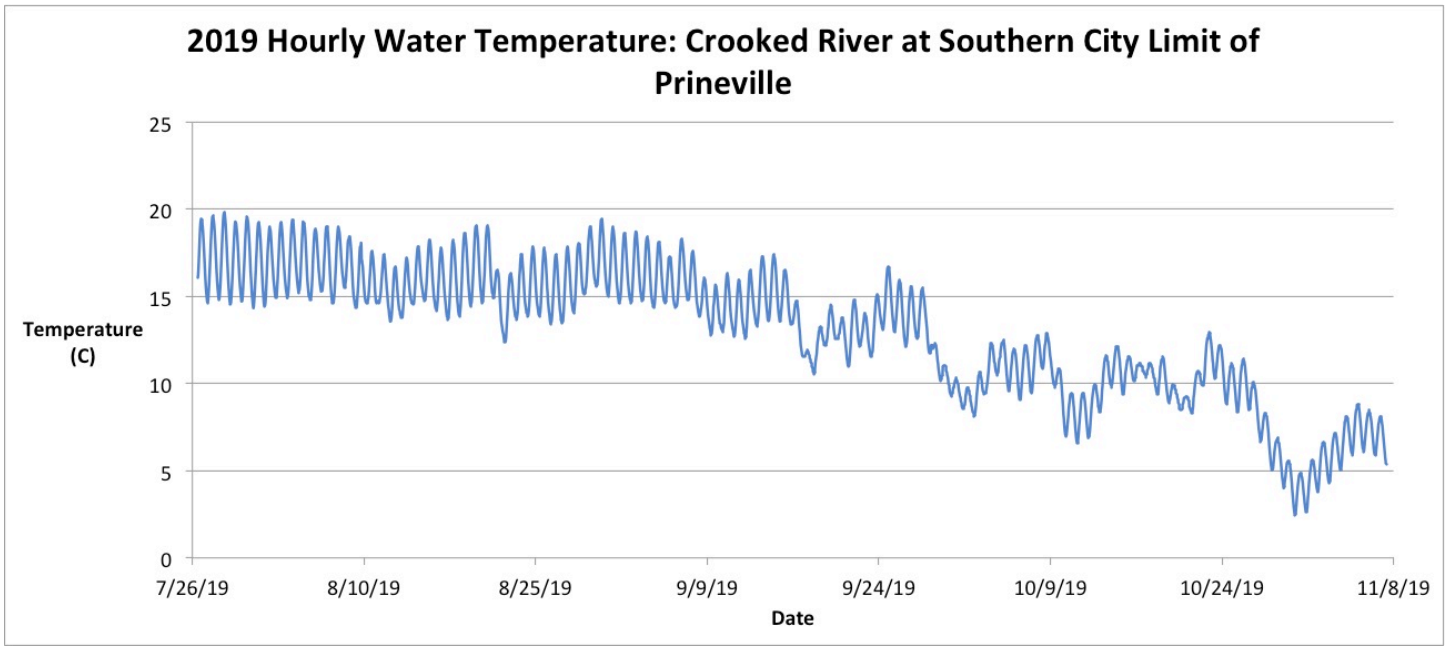

Figure 4. 2019 Crooked River hourly water temperature at city limits of Prineville (RM 50).

The maximum diel range at RM 50 was 5.05°C (~9°F) and occurred on July 27 and July 28, 2019. The minimum diel range at this site was 0.78°C (~1.4°F) and occurred on October 17, 2019. The average diel range was 3.16°C (~5.7)°F. The maximum recorded temperature was 19.85°C (67.7°F) on July 28 at 1900 hours. The minimum recorded temperature was 2.41°C (36.3°F) on October 30 at 0900 hours.

Figure 5 shows the results from RM 44.8 of the Crooked River at the Ochoco Creek confluence. The maximum diel range at this site was 4.39°C (~8°F) and occurred on August 13, 2019. The minimum diel range was 0.29°C (~0.5°F) and occurred on October 16, 2019. The average diel range was 2.22°C (~4°F). The maximum recorded temperature at this site was 20.33°C (68.6°F) on July 28, 2019 at 1800 hours. The minimum recorded temperature at this site was 5.24°C (41.4°F) on October 31, 2019 at 1000 hours.

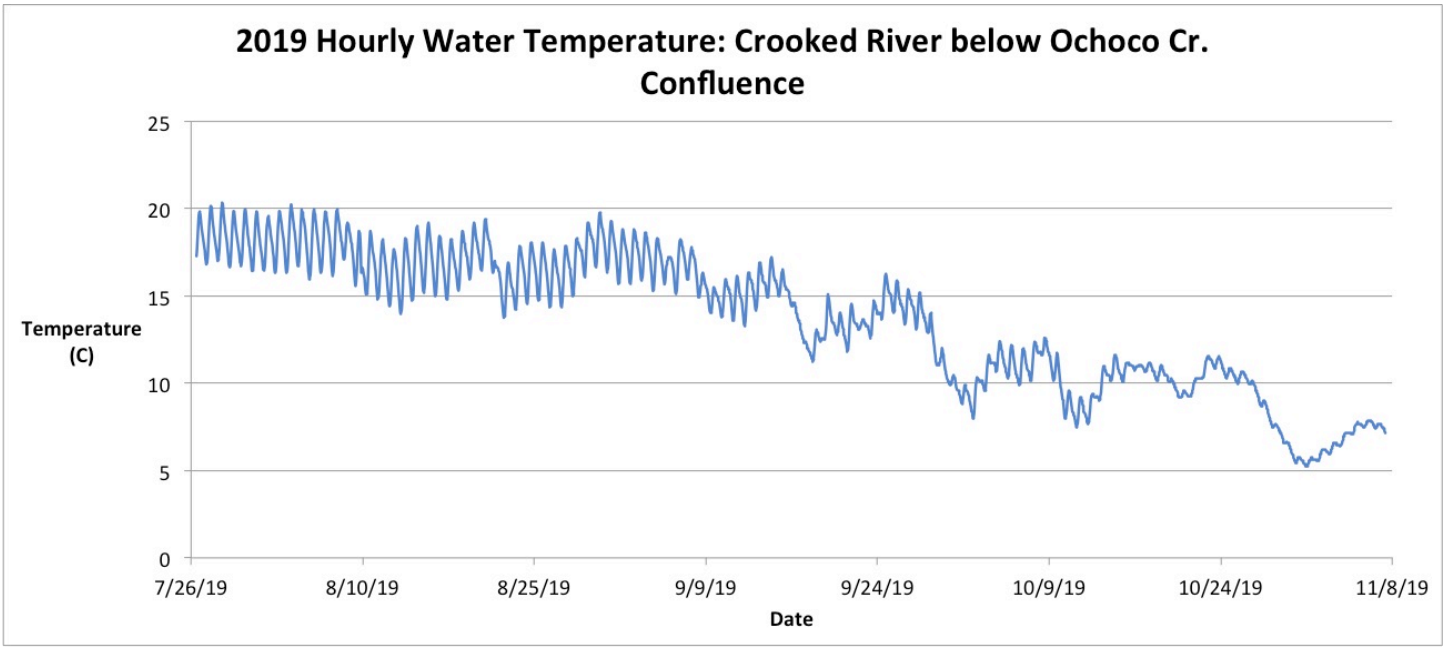

Figure 5. 2019 Crooked River hourly water temperature at Ochoco Creek confluence (RM 44.8).

Figure 6 shows the results from RM 42 of the Crooked River at the Elliott Road Bridge. This site is approximately two miles downstream from the confluence of McKay Creek. The maximum diel range at this site was 4.00°C (~7.2°F) on August 5, 2019. The minimum diel range at this site was 0.59°C (~1°F) on October 16, 2019. The average diel range was 2.40°C (~4.3°F). The maximum recorded temperature was 20.61°C (69.1°F) on July 28, 2019 at 1800 hours. The minimum recorded temperature was 3.05 °C (37.5°F) on October 30, 2019 at 0900 hours.

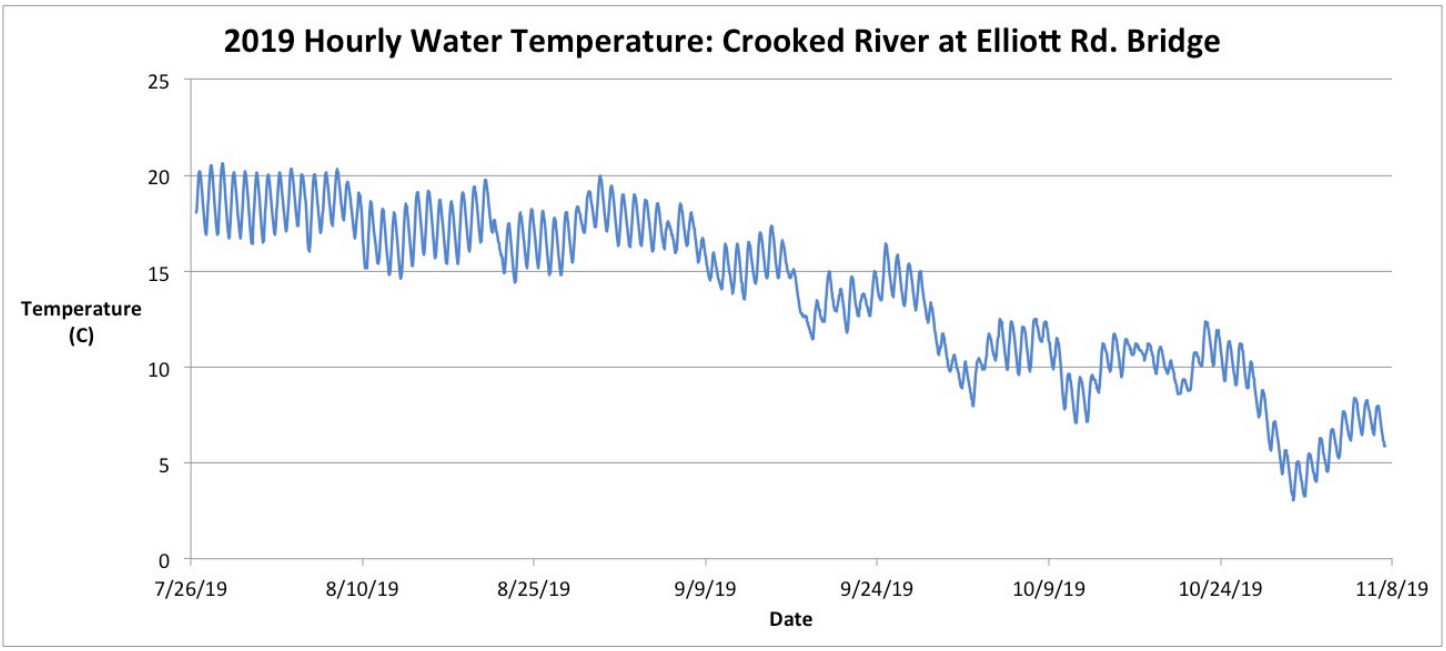

Figure 6. 2019 Crooked River hourly water temperature at Elliott Rd. Bridge (RM 42).

Figure 7 shows the results from RM 27 of the Crooked River at Smith Rock State Park from August 22, 1401 hours through December 6, 1101 hours. The maximum diel range was 2.96°C (~5.3°F) and occurred on September 19, 2019. The minimum diel range was 0.36°C (~0.6°F) and occurred on November 18, 2019. The maximum recorded water temperature at this site was 21.49°C (70.7°F) on August 31 at 1601 hours. The minimum recorded water temperature at this site was 0.08°C (32.1°F) on December 1, 2019 at 0101 hours.

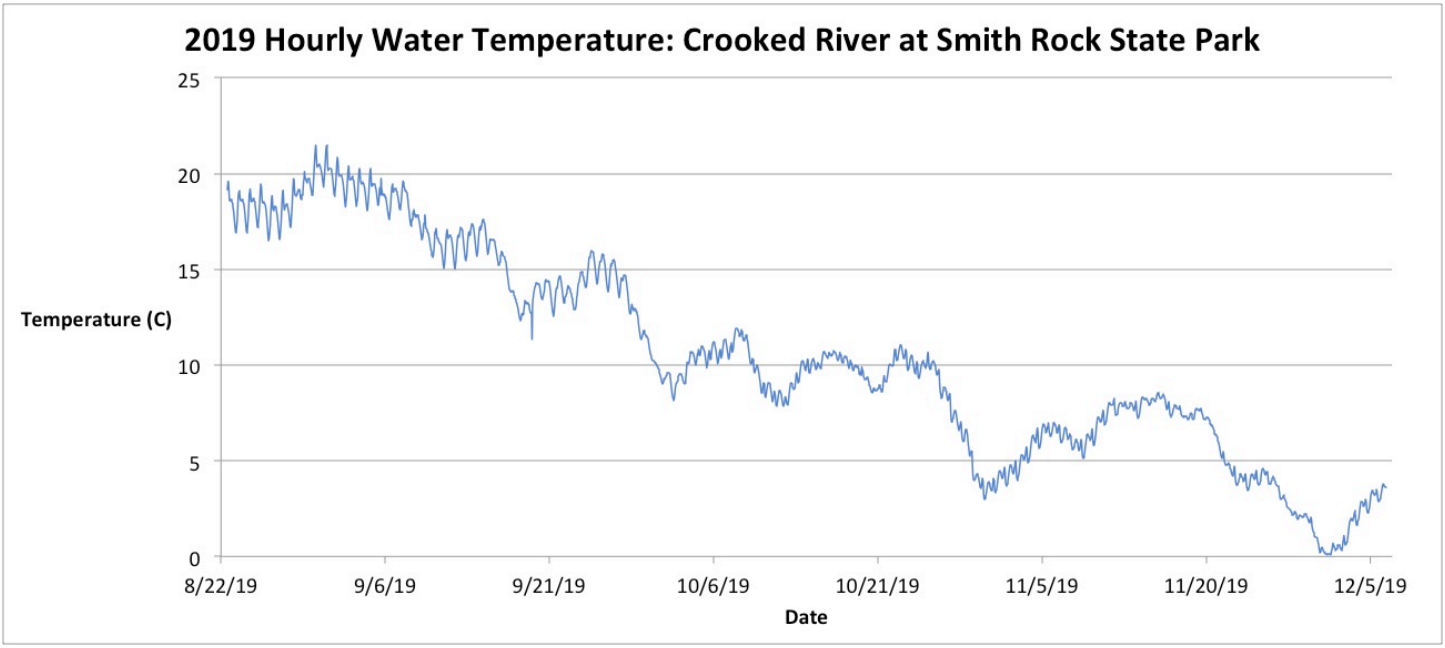

Figure 7. 2019 Crooked River hourly water temperature at Smith Rock State Park (RM 27).

7-Day Average Daily Maximum:

Oregon's stream temperature standard is based on a maximum 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) for salmon and trout rearing and migration use (see APPENDIX for maps and criteria). The 7-DADM was calculated for the four sites and graphed in Figure 8. For all four sites shown in Figure 8, the 7-DADM exceeded the basin standard from late July through early September. The Crooked River at Smith Rock State Park, RM 27, had the highest recorded 7-DADMs compared to other sites.

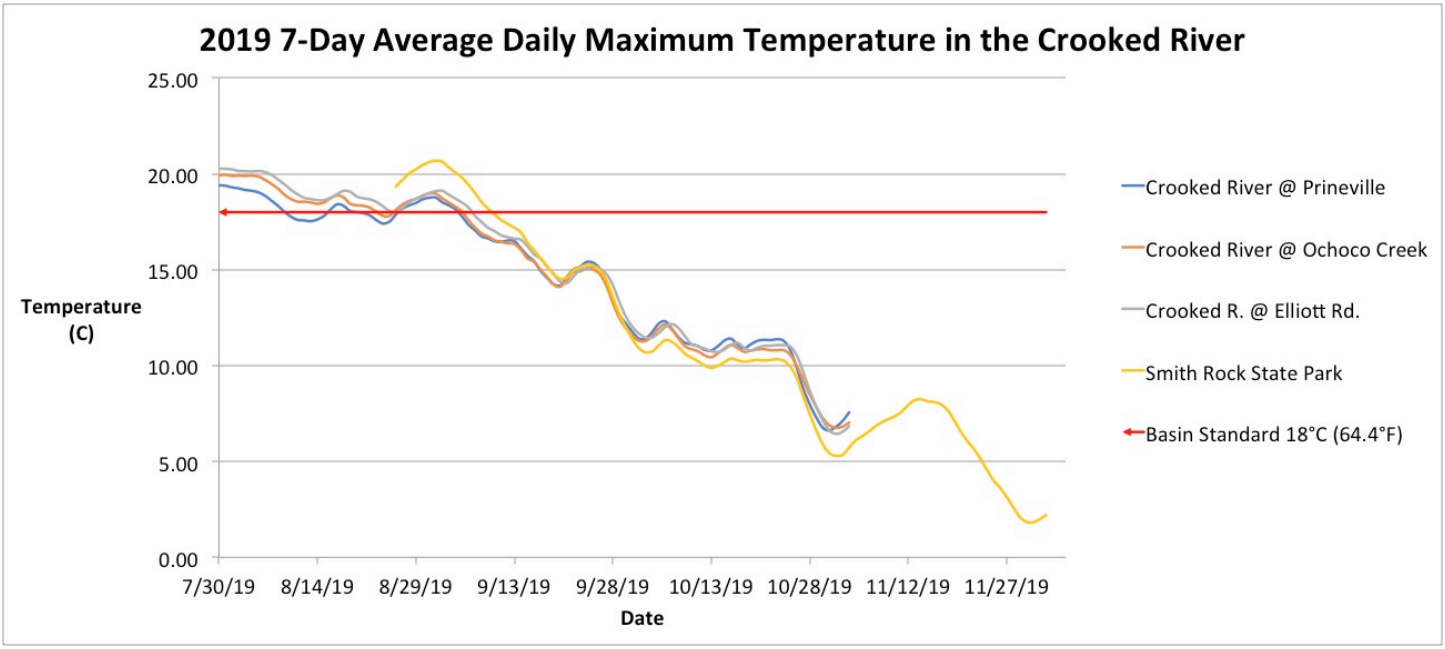

Figure 8. 2019 Crooked River 7-Day Average Daily Maximum water temperature at the monitoring sites. The state maximum water temperature standard in is 18°C (64.4°F) and is shown with a red line on the graph.

Among the three sites near Prineville, 7-DADM water temperatures were highest at RM 42 (Crooked River at Elliott Rd. Bridge). The results suggest a downstream warming trend occurred between RM 50 and RM 42 from late July until mid-September. By mid September, the 7-DADM water temperatures were within state standards at all of the monitoring sites. **Significant periods of warm water temperatures likely occurred before the DRA field monitoring started**.

pH:

As with temperature, the amplitude of the line in Figure 9 shows the difference in pH over a 24-hour period (diel range). Daily changes in pH are driven by the 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 levels typically occur 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).

Oregon's water quality standards for pH in the Deschutes Basin requires 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 a pH just above 8.5 is not lethal to aquatic life, such levels do not provide adequate protection (Robertson-Byron 2004). Figure 9 shows hourly pH measurements recorded from August 22-December 6, 2019 at RM 27 of the Crooked River (Smith Rock State Park).

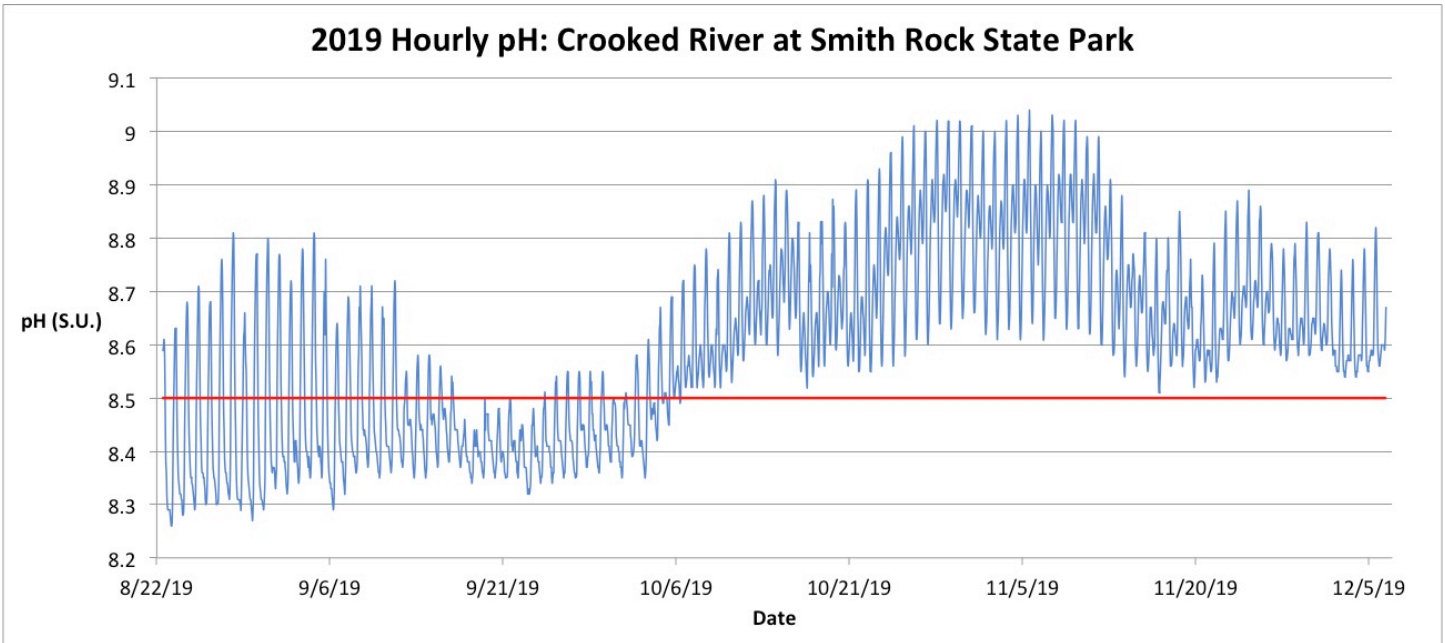

Figure 9. 2019 Crooked River hourly pH at Smith Rock State Park (RM 27). The red line shows the upper pH limit standard for the Deschutes Basin.

Overall the pH measurements were in the basic to highly basic range (alkaline) during the sampling period. The maximum recorded pH was 9.04 on November 5, 2019 at 1201 hours. The minimum recorded pH was 8.26 on August 23, 2019 at 0701 hours. The maximum diel range was 0.51 standard units on August 30, 2019. The minimum diel range was 0.09 standard units on September 17, 2019. The DRA data set contained pH measurements that exceeded the basin standard when monitoring began with the exception of the dates September 17-23 and September 30, 2019. Beginning in early October all recorded pH measurements were in the highly basic range (8.5-9.0) and were above the basin standard of 8.5 standard units. It is worth noting that due to delayed equipment installation, the recorded data set for pH is for a limited part of the summer season.

DISCUSSION

Temperature:

The results from a thermal imaging study of the lower Crooked River from Bowman Dam to Lake Billy Chinook and done August 5-8, 2005 by the Oregon DEQ characterized the summertime water temperatures in the lower Crooked River (ODEQ 2006). These results showed that during the summer, the Bowman Dam outflow is cool/cold at approximately 10°C (50°F)(summertime average range: 8.3-10.0°C, NPCC 2004). Moving downstream from RM 70 at Bowman Dam to RM 50 a rapid warming trend occurred. Irrigation diversions at RM 49.5 near the City of Prineville caused a decrease of in-stream flows, which led to further warming. Sources of cooling included Ochoco and McKay creeks (RM 44.8-44.5) and multiple springs found between RM 24.7-6 from Smith Rock State Park to Lake Billy Chinook. From RM 24.7-6 there was a general cooling trend. Maximum temperatures in the thermal imaging study were recorded near Smith Rock State Park (2005 survey maximum 23.8°C at RM 24.7).

The results of this study are consistent with those of the 2005 Oregon DEQ thermal imaging study. The limited DRA data set from the site below Bowman Dam (RM 70) showed that the water temperature was approximately 9-10°C (48-50°F) from July 27-August 8, 2019 (unpublished data). An obvious warming trend occurred during this limited observation period with water temperatures ranging from 15-20°C (59-68°F) at comparable downstream sites (RM 50, RM 44.8, RM 42). In addition, the authors of the DEQ thermal imaging study state, "Ochoco Creek (mile 44.8) was 2.5°C cooler than the Crooked River at the confluence and appeared to have a direct cooling influence on the river"(ODEQ 2006). Direct cooling was not shown in the 2019 DRA data at the RM 44.8 site compared to the RM 50 site; however, there is not enough data (i.e., sampling sites near the confluence) to verify any temperature influence from Ochoco Creek in 2019. A general warming trend was indicated in the DRA data set moving downstream from RM 50 to the furthest downstream site, RM 27, until mid September when water temperatures cooled. The general warming trend from RM 50 to RM 27, during summer months, is consistent with the results of the DEQ thermal imaging study.

Oregon's stream temperature standard is set to protect beneficial uses and to preserve the health of aquatic ecosystems (Boyd & Sturdevant 1997). The applicable temperature standard in the study area for salmon and trout rearing and migration use is a maximum temperature of 18°C (64.4°F) calculated as the 7-DADM. However, in streams that support salmon and steelhead spawning, a 13°C (55.4°F) maximum temperature standard is applied during the designated time period for salmonid spawning (APPENDIX A). A third standard is applied to some streams designated as having core cold-water habitat, but no segments of the Crooked River currently meet

these criteria.

Temperature is a primary driver of biological processes particularly in the aquatic environment. Fish and aquatic insects are cold-blooded meaning their body temperature, and thus metabolism, is 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). In addition, temperature affects a number of other water quality properties including dissolved oxygen concentrations. The 2019 DRA data set recorded temperatures that exceeded 21.1°C (70°F) at the Smith Rock State Park site (RM 27) with a survey maximum of 21.49°C (70.7°F) on August 31, 2019 at 1601 hours (Figure 7).

High water temperatures are one parameter affecting aquatic life in the study area. However, extremely cold water temperatures coupled with low 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 forms on the stream bottom) and fish mortality occurred. Such low flows are characteristic of this stream segment during the winter when irrigation managers fill Prineville Reservoir by reducing water discharge. The reduction of habitat for fish due to low winter flows and high spring discharges are the largest contributors affecting fish populations in the lower Crooked River (ODFW 2016). These hydrologic conditions are a result of flow manipulation for irrigation.

The managers of Bowman Dam have established 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, storing water for irrigation takes priority 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 10-25 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 and the area below Bowman Dam 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) will be the primary migration corridor

for anadromous salmonids. At the time of this writing, low flows and poor water quality characterize this river segment during the juvenile and adult migration months for salmonids. The success of anadromous fish reintroduction in the lower Crooked River sub-basin may depend on how successfully these problems are corrected.

pH:

As algae and aquatic plant biomass increases, the difference between the daily minimum and daily maximum pH also increases. The pH measurements collected during this study at RM 27 of the Crooked River showed large diel swings from late summer through fall (Figure 9). These results indicate that excess nutrients are contributing to high biomass production. In addition, excessive algae, fungus, and bacteria growth known as periphyton was observed at the study sites and are a common visual indicator of nutrient enrichment (EPA 2013). Figure 10 shows an example of the dense growths of 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. Photo by: Rick Hafele

Prior water quality studies have shown that the Crooked River contributes a disproportionately higher concentration of nitrates to Lake Billy Chinook when compared to the other two tributaries (DRA 2016a; Eilers & Vache 2019). In addition,

nitrates contaminate groundwater in the basin and nitrate sources are found throughout the upper and lower Crooked River sub-basins (CRWC 2008; DRA 2019b). Oregon DEQ has also listed the Crooked River as water quality limited for high elemental phosphorus levels (Table 2). Reductions in agricultural pollutants, primarily nitrogen and phosphorous, must be addressed to reduce excessive aquatic plant and algal growth in the Crooked River. Such measures will lead to reductions in excessive biomass production, and thus, reduce large diel swings in pH. In addition, such reductions in agricultural pollutants are recommended to reduce eutrophication in Lake Billy Chinook (Eilers & Vache 2019). Such conservation measures, particularly with respect to nitrogen pollution, also have potential to reduce periphyton biomass in the lower Deschutes River (Eilers & Vache 2019).

In addition to large diel swings in pH, exceedances to the basin standard for pH also occurred. Such high pH measurements, above 8.5 standard units, are characteristic in the lower Crooked River sub-basin (CRWC 2008). In general, land use (i.e., tilling of soil) and natural alkalinity of soils also contribute to elevated pH (EPA 2013). However, determining the degree to which these factors influence pH is outside of the scope of this study.

SUMMARY

Results from this study showed multiple impairments to water quality in the lower Crooked River. Exceedances of the state water quality standard, 18°C (64.4°F) maximum water temperature, for salmon and trout use were recorded. In addition, high pH measurements that exceeded the upper basin standard of 8.5 standard units were recorded throughout most of the sampling period. Large diel swings in pH were recorded and strongly indicate excessive nutrient pollution in the Crooked River.

Oregon's water quality standards are in place **to protect aquatic life.** While water quality standards are set for each parameter separately, interactions among parameters can increase the negative impact on aquatic life. For example, as water temperature increases the concentration of dissolved oxygen in water decreases, while at the same time salmonid metabolism increases, thus increasing their oxygen demand. Increased water temperatures also lead to increased incidence of parasites and diseases in salmonids (Connolly & McLean 2017; Schaaf et al. 2017).

Changes in pH affect the toxicity of other potentially toxic constituents in water. For example, the toxicity of un-ionized toxic ammonia (NH_3) increases as pH increases (Shiwanand & Tripathi 2013). Therefore, whenever water quality standards are

exceeded, the potential for negative impacts from other parameters also increases. When multiple standards are exceeded at the same time over long periods of time - days and weeks - as we have seen in this study, the negative effects on aquatic life increase substantially.

Agricultural practices (e.g., flow modification) severely limits both the quantity and quality of water in the lower Crooked River. The end result for aquatic life is often one of three fates: lesions and/or mortality due to the effects of gas bubble-disease, mortality induced by freezing (as seen in the winter of 2015/2016), or desiccation (drying out) due to the sudden lowering of in-stream flows. Other impacts caused by agriculture are also a concern including: high water temperatures, pesticide/insecticide use, turbidity and sedimentation, and bacteria (*E. coli*) among others (ODFW 1996).

The DRA is committed to improving water quality in the lower Deschutes River. Water quality improvements in the Crooked River Basin are a potential solution. Reducing the pollutants in the Crooked River has potential to decrease eutrophication in Lake Billy Chinook and excessive periphyton growth 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)

Figure 130A: Fish Use Designations Deschutes Basin, Oregon*

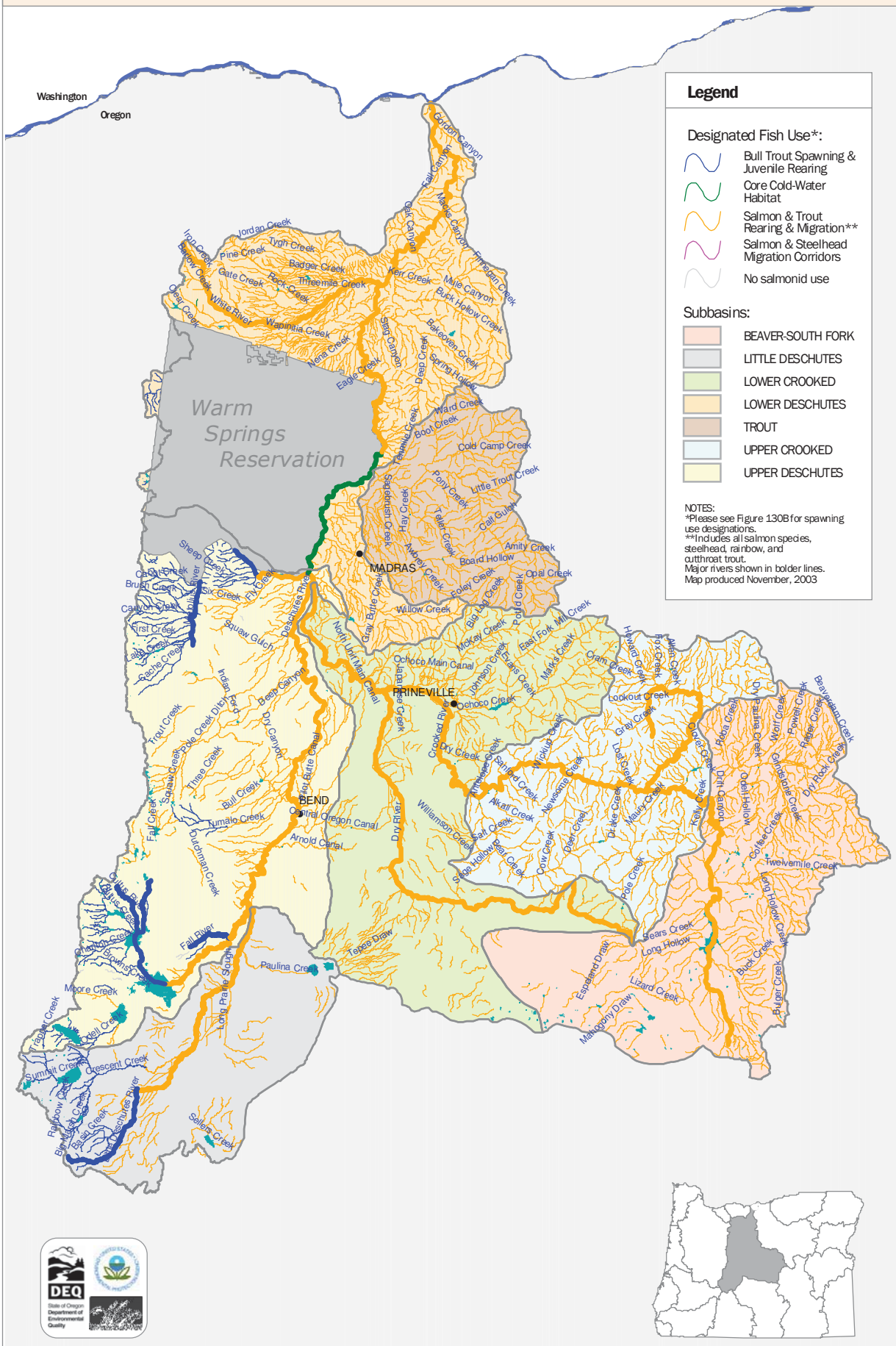
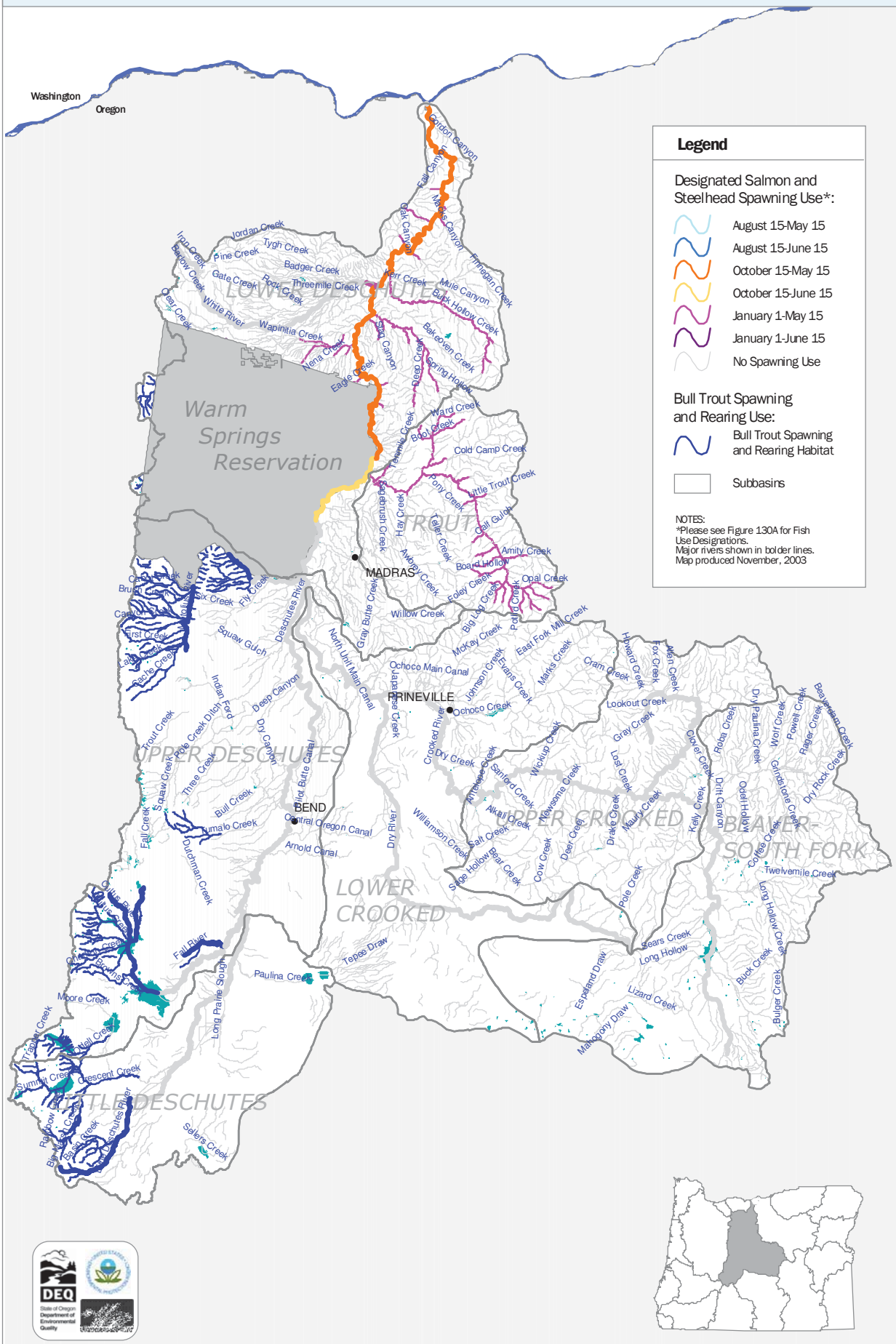


*Figure 130B: Salmon and Steelhead Spawning Use Designations**
Deschutes Basin, Oregon



APPENDIX B-AUDIT DATA

Smith Rock Audit Data	Lat/Lon	44.36764/-121.13906			
Date	8/22/19	9/19/19	10/23/19	11/21/19	12/6/19
Time	13:06	9:56	14:36	9:00	10:45
Temperature (Celcius)					
Sonde	18.76	12.86	10.73	5.12	3.61
Meter	18.8	13	10.8	5.2	3.7
pH					
Sonde	8.49	8.39	8.93	8.6	8.73
Meter	8.7	8.37	8.95	8.5	8.72
Dissolved Oxygen (mg/L)					
Sonde	1.21	1.38	0.97	1.14	1.1
Meter	11	10.08	13.46	11.53	13.73
Turbidity (NTU)					
Sonde	9	7.5	4.4	1.4	2.4
Meter	9.95	8.96	2.14	2.19	2.45
Pre/post deployment checks					
pH	pre-deployment	post-deployment			
7 s.u. buffer		7.34			
10 s.u. buffer		10.41			
Dissolved oxygen					
Air-saturated water		90.1% (DO Sat)			
Turbidity					
DI water		4.4			

Temp logger site: Bowman Dam			
Audit Precision Check		s/n: 10694487	
Date	Time	Audit	Logger
7/26/19	9:15:00 AM	9.0	9.17
11/7/19	9:39:00 AM	9.1	No Data

Notes:

Logger battery died during deployment

Temp logger site: Prineville City Limit			
Audit Precision Check		s/n: 10694492	
Date	Time	Audit	Logger
7/26/19	10:00:00 AM	15.0	15.5
11/7/19	10:10:00 AM	5.7	5.4

Temp logger site: Ochoco Creek Confluence			
Audit Precision Check		s/n: 9908631	
Date	Time	Audit	Logger
7/26/19	10:40:00 AM	16.6	16.8
11/7/19	10:30:00 AM	6.0	7.2

Temp logger site: Elliot Rd. Bridge			
Audit Precision Check		s/n: 10694495	
Date	Time	Audit	Logger
7/26/19	11:15:00 AM	18.2	18.1
11/7/19	10:41:00 AM	6.1	6.2